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Memphis, Tennessee  
February 28–March 4, 2005

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# **Proceedings of the 13<sup>th</sup> Biennial Southern Silvicultural Research Conference**

*Edited by*

**Kristina F. Connor**

**Memphis, Tennessee**

**February 28-March 4, 2005**

*Hosted by*

**Mississippi State University, Department of Forestry  
USDA Forest Service, Southern Research Station**

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## Preface

The 13<sup>th</sup> Biennial Southern Silvicultural Research Conference was held February 28–March 4, 2005, at the Hilton, Memphis, TN. This conference was the latest in a series of meetings designed to provide a forum for the exchange of research information among silviculturalists and researchers. Presentations emphasized research in wildlife ecology; pine silviculture; longleaf pine; nutritional amendments; vegetation management; site preparation; hardwoods: artificial regeneration; hardwoods: midstory competition control; growth and yield; water quality; forest health; fire; hardwoods: natural regeneration; and hardwood intermediate treatments. Field trips included visits to (1) the Ames Plantation to observe hardwood silviculture and wildlife management, and (2) the John M. Tully Wildlife Management Area to observe bottomland hardwood stand development and silviculture. The conference was attended by 335 people and had 115 oral and 59 poster presentations. James P. Shepard, Professor, Head and Graduate Student Coordinator, Department of Forestry, Mississippi State University, and Bruce Jewell, Assistant Director, USDA Forest Service, Southern Research Station, made the welcoming remarks.

Sponsors for the conference included Mississippi State University, Department of Forestry, Forest and Wildlife Research Center; National Association of Consulting Foresters of America; National Association of Professional Forestry Schools and Colleges; National Hardwood Lumber Association; Society of American Foresters; Southern Industrial Forest Research Council; and the USDA Forest Service, Southern Research Station. The steering committee for this meeting worked numerous hours to review abstracts, establish the program for oral and poster presentations, and make all necessary arrangements for the conference. Steering committee members included:

Andrew Ezell (Local Arrangements Chair) Mississippi State University, Department of Forestry, Mississippi State, MS	Brian Oswald (Moderator Selection) Steven F. Austin State University, Nacogdoches, TX
Kenneth Outcalt (Poster Session) USDA Forest Service, Southern Research Station, Athens, GA	Marty Spetich (Audio-Visual) USDA Forest Service, Southern Research Station, Hot Springs, AR
Dave Haywood (Meeting Announcements) USDA Forest Service, Southern Research Station, Pineville, LA	Norman Davis (Field Trips) Anderson-Tully, Vicksburg, MS
Eric Heitzman (Audio-Visual) University of Arkansas, Monticello, AR	Mary Anne Sword Sayer (Moderator Selection) USDA Forest Service, Southern Research Station, Pineville, LA
Brian Lockhart (Student Awards Judging Coordinator and Meeting Evaluation; Field Trips) USDA Forest Service, Southern Research Station, Stoneville, MS	Michael Blazier (Moderator Selection) Louisiana State University, Homer, LA
Don Bragg (Audio-Visual) USDA Forest Service, Southern Research Station, Monticello, AR	Callie Jo Schweitzer (Audio-Visual) USDA Forest Service, Southern Research Station, Huntsville, AL
	Andrew Londo (Audio-Visual) Mississippi State University, Department of Forestry, Mississippi State, MS

Partial funding for the conference was provided by the Southern Research Station and Mississippi State University. We gratefully acknowledge Mississippi State University's Department of Forestry for handling fiscal matters, hotel arrangements, and registration. Special thanks to all committee members for invaluable advice; to Lynne Breland for coordinating communications among the Forest Service, Mississippi State University, and the hotel; to Patricia Outcalt for creating and updating the conference Web page, to Jillian Donahoo and Gretchen Schafer for tracking abstracts and manuscripts; and to the Mississippi State University students who acted as drivers, set up poster boards, and helped with registration. The many people who contributed to the success of the field trips have our sincere thanks. We also gratefully acknowledge all those who helped judge student presentations and posters.

Special recognition is given to the moderators. They include: Nancy Herbert, Bruce Jewell, Dean Gjerstad, Tom Fox, Jimmie Yeiser, Harry Quicke, Andy Ezell, David Loftis, David Larsen, Tom Lynch, Jim Shepard, Noland Hess, Brian Oswald, David Van Lear, John Hodges, and Callie Schweitzer.

The 148 papers published in this proceedings were submitted by the authors in electronic media. Limited editing was done to ensure a consistent format. Authors are responsible for content and accuracy of their individual papers.

Kristina F. Connor  
Program Chair  
USDA Forest Service,  
Southern Research Station,  
Auburn, AL

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## **Wildlife Ecology**

*Moderator:*

**NANCY HERBERT**  
USDA Forest Service  
Southern Research Station



# INITIAL CERULEAN WARBLER RESPONSE TO EXPERIMENTAL SILVICULTURAL MANIPULATIONS, DESHA COUNTY, ARKANSAS

Paul B. Hamel, Mike Staten, and Rodney Wishard<sup>1</sup>

**Abstract**—Cerulean warbler [*Dendroica cerulea* (Wilson) Aves, Parulidae] is a neotropical migratory bird that has become a focus of management attention. Since 1992, we have studied breeding birds on a 54-ha site owned by Anderson-Tully Company, in Desha County, AR. In 2002, we conducted an unreplicated experiment there to assess the species' response to silvicultural manipulation within its habitat. We applied one of two silvicultural prescriptions to randomly selected halves of the plot. Establishment criteria were that each half-plot be the same size and have had a comparable history of warbler use. Treatments were (1) a standard Anderson-Tully Company prescription designed to establish regeneration, develop existing advance regeneration, and add growth to residual sawtimber trees; and (2) a prescription designed to add growth to residual sawtimber trees and favor development of trees similar to those used by the cerulean warbler. Our initial posttreatment survey identified three cerulean warbler territories on the subplot treated with the cerulean warbler prescription and none on the other portion.

## INTRODUCTION

Successful management of forest lands requires the translation of identified objectives into silvicultural prescriptions that can be followed by timber markers and loggers. Difficulties in making specifications clear and implementable often have led some communities of interest to doubt the silviculturists' intent or sincerity (Hamel and others 2001). More particularly, clear management prescriptions designed to support habitat objectives for nongame wildlife, including songbirds, have been lacking. Development of dependable prescriptions capable of producing habitat for late-successional species is an especially daunting task.

Cerulean warbler [*Dendroica cerulea* (Wilson) Aves, Parulidae] is a neotropical migratory bird in need of management attention. To date, however, no silvicultural prescriptions to enhance or restore its habitat have been proffered (Hamel and others 2004). Populations have declined by as much as 50 percent since 1966, as measured by the Breeding Bird Survey (Hamel 2000a). Link and Sauer (2002) reported an annual reduction of 3 percent. In the Lower Mississippi Alluvial Valley, this songbird has become a target species for landscape management, conservation, and afforestation efforts (Mueller and others 1999). Its documented population declines led to a petition filed with the U.S. Fish and Wildlife Service to list it as threatened under provisions of the Endangered Species Act of 1973, as amended (Ruley 2000). The U.S. Fish and Wildlife Service ruled that the species not be listed (Williams 2002). Although quantitative assessments of cerulean warbler habitat are available (Hamel 2000b; Hamel 2005; Kahl and others 1985), no suitable silvicultural prescription has yet been articulated, and data on fitness consequences of different habitats for this species are scarce.

Male cerulean warblers routinely spend much of their time in large sawtimber trees singing, foraging, and attempting to attract females (Hamel 2005). Female cerulean warblers choose nest sites and tend to use trees smaller in stature and more shade-tolerant than those favored by the male (Hamel

2005). Jones and others (2001) have considered other features of vertical and horizontal habitat structure that also may be of great importance in habitat selection. This report is a beginning of one effort to articulate and evaluate a prescription suitable for both economically viable timber production and ecologically viable habitat production for this important songbird.

## METHODS

### Study Site

Since 1992, we have studied the breeding population of the cerulean warbler on a 54.5-ha site (hereafter study grid) in Desha County, AR (Hamel 1998, Woodson and others 1995). The site is part of a 130-ha compartment (hereafter treatment area) on more extensive property owned and managed by Anderson-Tully Company, for production of high-quality sawtimber (fig. 1). It is located in the Mississippi Alluvial Valley, in the batture land of the Mississippi River, on sandy loam soil

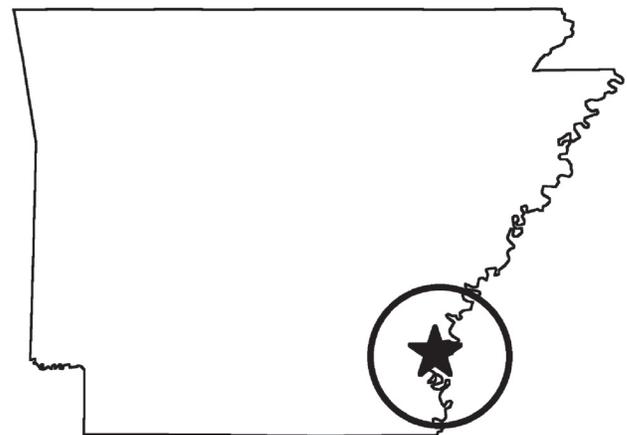


Figure 1—Locator map of cerulean warbler study site in Desha County, AR.

<sup>1</sup> Research Wildlife Biologist, USDA Forest Service, Center for Bottomland Hardwoods Research, P.O. Box 227, Stoneville, MS 38776; and Wildlife Manager and Forest Manager, respectively, Anderson-Tully Co., P.O. Box 761, Lake Village, AR 71653.

with ridge and swale topography near the riverbank. The site is typical of riverfront hardwood tracts in the Lower Mississippi Valley. Prior to our study, a harvest treatment according to standard Anderson-Tully Company prescription was conducted on the tract in 1991. In that year, coauthor Mike Staten and his colleagues located cerulean warblers on the site while searching for suitable sites for a study of distribution, habitat use, and demography of that species in the Mississippi Alluvial Valley (Hamel 1998, Hamel and others 1998).

### Pretreatment Monitoring

**Avian sampling**—From 1992 to 2001, we conducted annual spotmap surveys within the tract, sought nest locations, measured vegetation, and documented habitat use. We established a 50- by 50-m grid of points on the site using compass and tape. Initially, we marked intersections of the study grid ( $n = 230$ ) with wooden stakes and annually installed individually labeled flags thereafter.

**Vegetation sampling**—We sampled vegetation at each intersection point of the study grid. At each point, we conducted a survey of forest trees, measured canopy cover using an ocular device (forest densiometer and/or forest densitometer), determined percent ground cover, and counted saplings  $< 7.5$ -cm diameter at breast height (d.b.h.) on 0.005-ha plots. Using a 30-basal area factor English (6.9-basal area factor metric) angle gauge (prism), we identified all trees within the variable-radius plot to species and measured height in meters, d.b.h. in centimeters, and crown class. We also noted the presence or absence of lianas reaching into the crown. Further vegetation sampling was done by identifying individual trees in which cerulean warblers were located and marking those trees with uniquely numbered aluminum tags placed at ground level on the north side of the tree. We measured those trees just as we

had measured those in vegetation samples at the study grid intersections, as well as height of the bird in the tree and other associated metrics of its behavior. We identified  $> 1,000$  trees in this way, principally from 1992 to 1994.

**Preharvest timber cruise**—The preharvest cruise in 2002 consisted of 144 circular plots systematically located 2 chains (40 m) apart, on transects 10 chains (201 m) apart. This represents an approximate 5 percent cruise of the 130-ha treatment area. Diameter and commercial height of trees  $\geq 12$  inches (30 cm) d.b.h. were tallied on 0.1-acre (0.04-ha) plots. Smaller trees, 6 to 12 inches (15 to 30 cm) d.b.h., were tallied on concentric 0.05-acre (0.02-ha) subplots. Regeneration stems 1 to 5 inches (2.5 to 12 cm) were tallied on concentric 0.01-acre (0.004-ha) subplots. We estimated available timber volume from these data using proprietary software and volume tables of Anderson-Tully Company.

### Silvicultural Treatments

In 2002, the treatment area was scheduled for entry in the normal rotation of Company lands. We began an unrepeated experiment to assess the species' response to alternative silvicultural treatments. Harvesting was done by partial cutting during the nonbreeding period for cerulean warblers; it began in winter 2002 and was completed in winter 2004.

**Subplot selection**—We compiled composite spotmaps of cerulean warbler use of the study grid from 1992 to 1996. We also produced maps of the locations of uniquely marked cerulean warbler use and nest trees. We sought to divide the grid into two equal parts, reflecting equal cerulean warbler use and comparable vegetation. Use was heavier in the eastern part than in the western part of the grid but relatively equally distributed between the north and south (fig. 2). As a result,

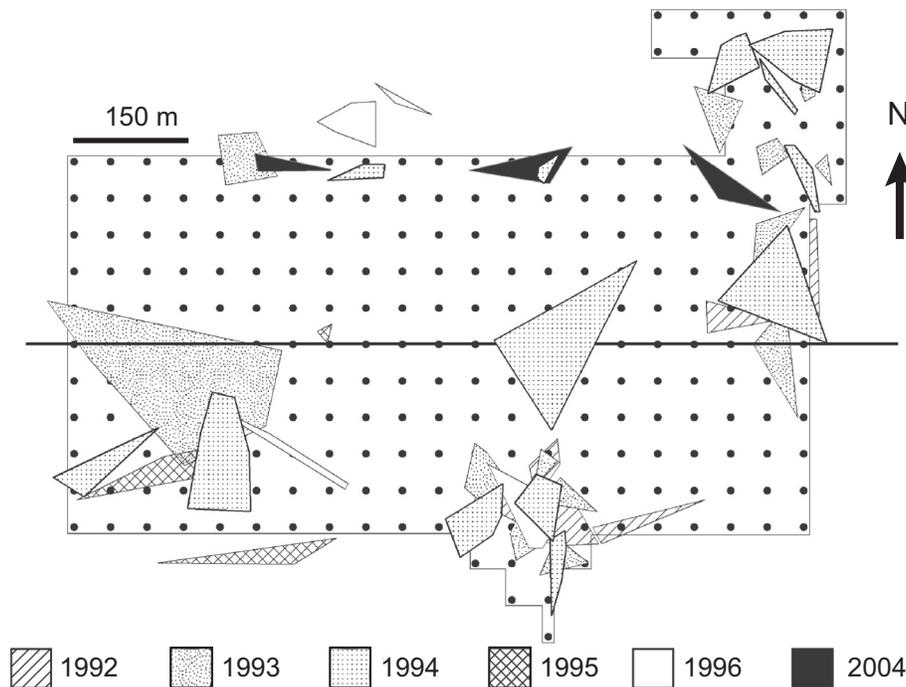


Figure 2—Distribution of cerulean warbler territories during pretreatment surveys 1992 to 1996, and posttreatment 2004, on cerulean warbler study grid, Desha County, AR. Horizontal line indicates boundary between the north and south subplots.

we subdivided the study grid into north and south subplots. By coin flip, the north subplot was selected to receive the cerulean warbler prescription.

**Standard prescription**—The Anderson-Tully Company standard prescription was applied to the southern half of the treatment area, including the southern half of the study grid. The partial-cutting prescription involved elements of improvement cutting, thinning, and regeneration cutting. It involved cutting in the overstory to reduce mortality, improve species composition and spacing, and increase growth of the residual stand. It further involved cutting in the midstory to remove poorly formed shade-tolerant species in order to release advance regeneration and encourage the establishment and growth of additional shade-intolerant regeneration of desirable species. The prescription was implemented by marking stems to be removed from the stand. Other stems, including all elm (*Ulmus americana* L.), sugarberry (*Celtis laevigata* L.), and boxelder (*Acer negundo* L.), were cut unless they were of superior form and quality.

**Cerulean warbler prescription**—Applied to the northern half of the treatment area, including the northern half of the study grid, the cerulean warbler prescription was based on the findings of Hamel (2005). It recognized the importance of tall sawtimber trees as song perch trees for the male and of large, often shade-tolerant trees for the nest. This partial-cutting prescription was a modification of the Company standard prescription, involving elements of improvement cutting, thinning, and regeneration cutting. It differed from the standard prescription in that fewer trees were removed from the shade-tolerant midstory. Researchers spent time in the stand with the foresters before timber marking in order to help them better recognize shade-tolerant midstory trees that were potential nest trees. Such trees were marked with an X and would be designated “leave trees” during the actual timber marking process.

### Postharvest Monitoring

**Harvest sampling**—We recorded sawtimber volume removed by species and tons of pulpwood removed from the entire treatment area. Diameter class distributions of unharvested *A. negundo*, *C. laevigata*, and *U. americana* stems were used to calculate the difference in residual trees of these species between the two subplots. From the calculated differences, we made an estimate of the economic value of stems not harvested during application of the cerulean warbler prescription. Future measurements will evaluate the opportunity cost to the Company of implementing the cerulean warbler treatment, in terms of differences in the release of advance regeneration and establishment of additional desirable shade-intolerant regeneration compared to the Company standard treatment.

**Vegetation sampling**—In January 2005, we randomly selected and measured a sample of 26 intersection points in each subplot on the study grid. At each of the points we selected canopy trees for inclusion in the sample using a 30-BAF English (6.9-BAF metric) angle gauge. We identified each selected tree by species, measured its d.b.h. in cm, determined crown class, and noted the presence of vines in its canopy.

**Cerulean warbler sampling**—In 2004, we conducted a spot-map census of cerulean warbler and other warbler species present on the plot, as we had in the pretreatment surveys.

We anticipate conducting annual or biennial spotmap censuses in the future.

### Data Analysis

We tested the hypothesis that no differences existed in basal area and density of trees and saplings on the two subplots before and after harvest using an analysis of variance of year nested within subplot. We tested for interaction between year and subplot using analysis of variance with year and subplot as main effects. We used analysis of variance of year, tree species, subplot, and interaction between species and subplot to assess differences in composition between subplots. For grid points sampled in both 1993 and 2005, we calculated the change in basal area for each species on each plot and used analysis of variance to test for differences between plots. Harvest data were considered an inventory and examined in tabular form. Distribution of observed cerulean warbler occurrence on the plot from 1992 to 2001 was examined visually. Trees used by the birds were summarized graphically and in tabular form. Spotmap census from the first sample post-treatment was examined visually. Statistical tests were carried out in SAS (SAS Institute 1999-2000) with statistical significance accepted at  $P = 0.05$ .

## RESULTS

### Vegetation on Treatment Subplots

Analysis of variance of tree density and basal area revealed no interaction between year and subplot for either of the parameters. Sapling density did not differ between subplots in 1993 (north –  $346 \pm 40$  saplings/ha,  $N = 137$ ; south –  $421 \pm 38$  saplings/ha,  $N = 123$ ;  $t_{258 \text{ df}} = -1.34$ ,  $P = 0.18$ ) or 2005 ( $t_{50 \text{ df}} = -0.68$ ,  $P = 0.5$ ). Analysis of tree density as a function of subplot and year nested within subplot showed a significant result ( $F_{3, 304} = 5.02$ ,  $P = 0.002$ ,  $R^2 = 0.05$ ) attributable to differences among years ( $P = 0.0007$ ) but not subplots ( $P = 0.5$ ). Tree density in the south subplot in 2005 (160 trees/ha) exceeded that in either subplot in 1993 (north – 96 trees/ha; south – 94/ha) but not that in the north in 2005 (138 trees/ha; fig. 3). Identical analysis of basal area also revealed a significant result ( $F_{3, 304} = 8.11$ ,  $P < 0.0001$ ,  $R^2 = 0.07$ ) but here attributable to differences in subplots ( $P < 0.0001$ ) but not to years nested within subplots ( $P = 0.07$ ). The north subplot had significantly greater basal area than the south in 1993 ( $25.0$  vs.  $20.3$  m<sup>2</sup>/ha,  $P = 0.01$ ) and 2005 ( $27.6$  vs.  $14.8$  m<sup>2</sup>/ha,  $P = 0.001$ ).

Estimates of basal area of three species differed between the subplots. The north subplot had higher basal area than the south for sugarberry ( $7.9$  vs.  $4.4$  m<sup>2</sup>/ha,  $F_{3, 304} = 7.51$ ,  $P < 0.0001$ ,  $R^2 = 0.07$ ) and bald cypress [*Taxodium distichum* (L.) Richard] ( $3.8$  vs.  $1.7$  m<sup>2</sup>/ha,  $F_{3, 304} = 2.8$ ,  $P = 0.04$ ,  $R^2 = 0.03$ ). Basal area of *U. americana* on the south subplot declined significantly more from 1993 to 2005 than it did on the north, where it actually increased ( $F_{1, 49} = 7.23$ ,  $P = 0.01$ ,  $R^2 = 0.13$ ; table 1).

### Cerulean Warbler Use of Space and Vegetation 1992-2002

Cerulean warbler use of north and south parts of the study grid was nearly equal during the early, pretreatment period (fig. 2). From 1992 to 1996, an average of 4.4 (range 2 to 7.5) territories were present on the north subplot, and 4.1 territories (range 2 to 7) were present on the south. After 1996, the

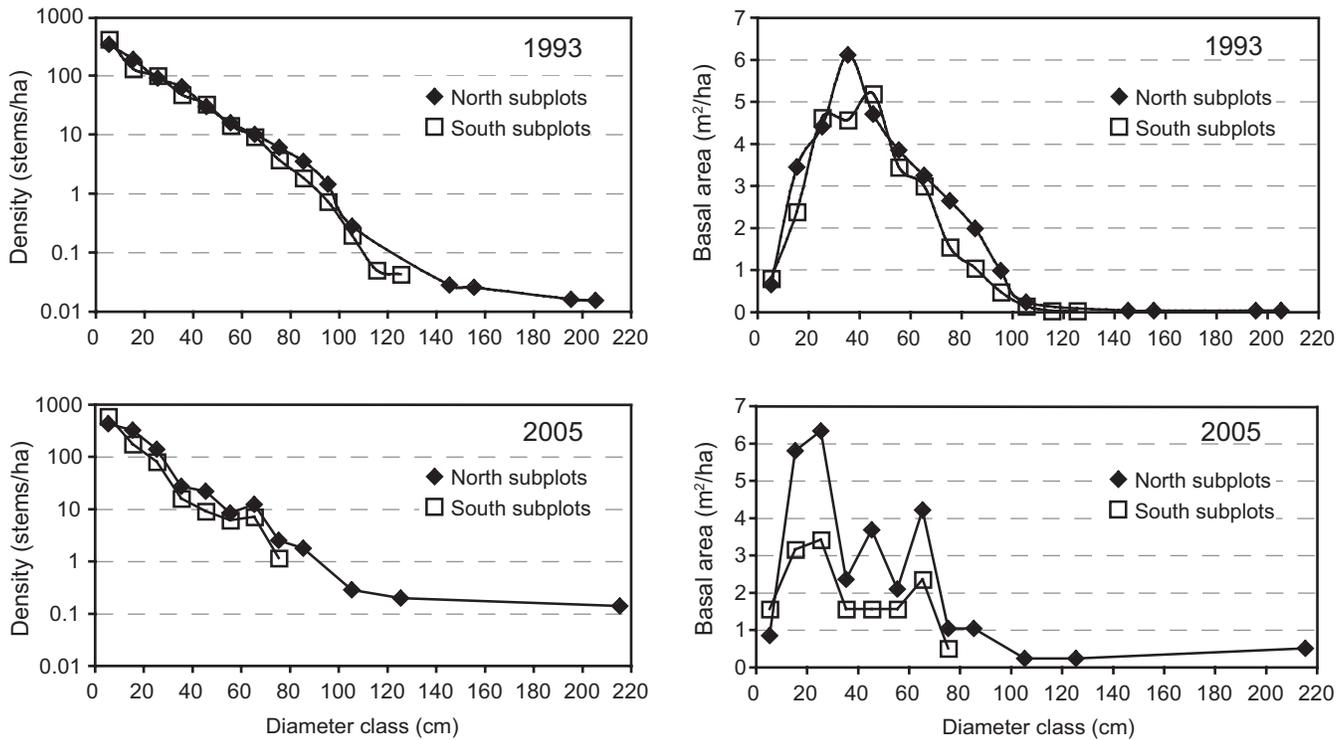


Figure 3—Diameter class distribution of basal area and stem density on north and south subplots of cerulean warbler study grid, Desha County, AR, in 1993 (pretreatment) and 2005 (posttreatment).

**Table 1—Comparison of vegetation samples in the pretreatment and posttreatment subplots, Cerulean Warbler Experimental Study Grid, Desha County, AR**

Species <sup>c</sup>	North		South	
	Sample			
	Size <sup>a</sup>	Plots (no.) <sup>b</sup>	Size <sup>a</sup>	Plots (no.) <sup>b</sup>
	137	26	123	26
<i>Acer negundo</i>	2.6 ± 0.4	2.1 ± 0.74	2.2 ± 0.43	1.59 ± 0.69
<i>A. rubrum</i> L.	0.05 ± 0.05	0 ± 0	0 ± 0	0 ± 0
<i>Carya illinoensis</i> (Wang.) K. Koch	0.6 ± 0.2	1.6 ± 0.79	0.39 ± 0.14	1.06 ± 0.5
<i>Celtis laevigata</i> <sup>d</sup>	7.3 ± 0.64	10.1 ± 1.9	4.2 ± 0.48	5 ± 1.6
<i>Cornus drummondii</i> C.A. Meyer	0 ± 0	0.53 ± 0.37	0 ± 0	0 ± 0
<i>Diospyros virginiana</i> L.	0 ± 0	0 ± 0	0 ± 0	0.26 ± 0.26
<i>Fraxinus pennsylvanica</i>	4.4 ± 0.73	4.2 ± 1.62	4.1 ± 0.71	2.1 ± 0.92
<i>Liquidambar styraciflua</i> L.	0.4 ± 0.2	0 ± 0	1.01 ± 0.27	1.3 ± 0.66
<i>Platanus occidentalis</i>	2.1 ± 0.33	0.79 ± 0.44	2.97 ± 0.46	1.85 ± 0.61
<i>Populus deltoides</i>	0.25 ± 0.17	0.26 ± 0.26	0.28 ± 0.15	0.26 ± 0.26
<i>Quercus nuttallii</i> Palmer	0.1 ± 0.07	0 ± 0	0 ± 0	0 ± 0
Dead trees	0.9 ± 0.2	0 ± 0	0.95 ± 0.24	0 ± 0
<i>Taxodium distichum</i> <sup>d</sup>	3.5 ± 0.74	5.3 ± 1.9	1.8 ± 0.49	1.06 ± 0.5
<i>Ulmus americana</i> <sup>d, e</sup>	2.2 ± 0.31	2.9 ± 0.87	2.3 ± 0.35	0.26 ± 0.26
Total basal area/ha <sup>f</sup>	32 ± 1.17	27.8 ± 2.92	26.8 ± 1.16	14.8 ± 2.08
Total tree density/ha	89 ± 5.3	138 ± 13	90 ± 6	160 ± 44
Sapling density/ha	346 ± 40	444 ± 99	420 ± 38	541 ± 102

Numbers represent basal area/ha ± S.E.

<sup>a</sup> In 1993.

<sup>b</sup> In 2005.

<sup>c</sup> Unless otherwise indicated, values in the columns do not differ at  $P = 0.05$ .

<sup>d</sup> North subplot has significantly higher basal area than South; years don't differ.

<sup>e</sup> Decline in basal area per plot from 1993 to 2005 was significantly greater in South subplot than in North subplot.

<sup>f</sup> North subplot has significantly higher basal area than South subplot in 1993 and 2005; 1993 basal area is significantly higher than 2005 as well.

birds virtually had disappeared from the plot, presumably as a result of a 1994 ice storm that severely damaged the forest canopy. The birds' use of tree species in relation to availability, summarized over the entire plot, indicated that use of the most abundant species, *C. laevigata* and *A. negundo*, was less than expected; that use of moderately abundant species, *U. americana* and green ash (*Fraxinus pennsylvanica* Marshall) was in proportion to their availability; and use of the less numerous sycamore (*Platanus occidentalis* L.) and cottonwood (*Populus deltoides* Marshall) exceeded that predicted by the number of available stems (fig. 4).

### Harvest Removals, Value of Unharvested Stems, and Opportunity Costs

Standing crop estimate of available sawtimber by subplot and combined sawtimber removals from the entire treatment area reflect differences apparent in vegetation sampling (table 2). Comparison of diameter class distribution of predominant pulpwood species (table 3) and pulpwood removals indicates an estimated value of unharvested pulpwood and sawlogs resulting from the cerulean warbler prescription (relative to the Company standard) to be approximately \$100 per acre (\$250/ha) on the 160-acre (65-ha) north subplot. Opportunity costs of lost advance regeneration cannot yet be estimated.

### Cerulean Warbler Use Posttreatment

Initial posttreatment survey of cerulean warbler response located the birds using portions of the study grid treated with the cerulean warbler prescription (fig. 2). Importantly, some 2004 use occurred in parts of the plot that had not been part of territories identified during pretreatment surveys, possibly indicating a specific response to the treatment.

### DISCUSSION

Initial results of this experiment suggest that a specific silvicultural prescription for cerulean warbler may be possible in bottomland hardwood forests. Modest differences between

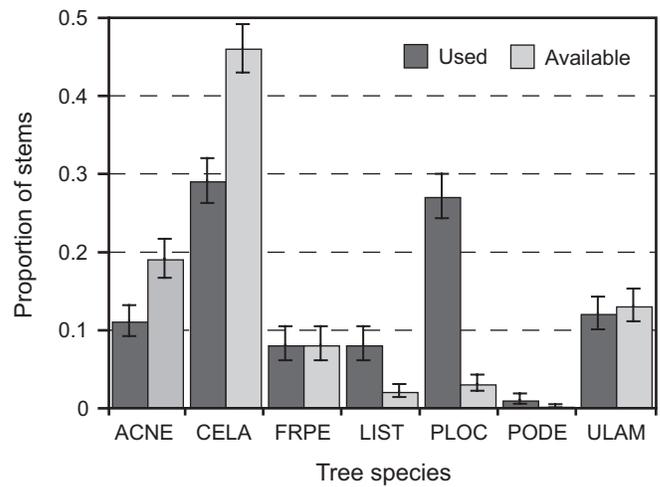


Figure 4—Availability and use by cerulean warblers of trees on cerulean warbler study grid, Desha County, AR, 1992 to 2001. Error bars indicate 95 percent confidence limits. Tree species codes are ACNE = *Acer negundo*, CELA = *Celtis laevigata*, FRPE = *Fraxinus pennsylvanica*, LIST = *Liquidambar styraciflua*, PLOC = *Platanus occidentalis*, PODE = *Populus deltoides*, and ULAM = *Ulmus americana*.

the subplots occurred where *C. laevigata* was most abundant. Within the treatment area, this species is plentiful and, in fact, it occurs in far higher abundance than is used by the birds. Differences between subplots in abundance of *T. distichum* reflect differences in extent of ridge and swale topography; because these differences occurred for a tree species for which no cerulean warbler use was registered, they are not relevant to our experiment. Difference between the subplots in abundance of *U. americana* after the harvest treatment, however, are relevant, and they reflect the specific intent of the two prescriptions. In the Company standard prescription, the commercially less valuable *U. americana* was removed.

**Table 2—Sawtimber available and removals from the subplots of the Cerulean Warbler treatment area**

Species	Preharvest cruise		
	North	South	Total removals
	160 (65) <sup>a</sup>	160 (65) <sup>a</sup>	320 (130) <sup>a</sup>
	----- board feet (m <sup>3</sup> ) -----		
<i>Carya illinoensis</i>	108,642 (256.4)	93,983 (221.8)	27,539 (65)
<i>Celtis laevigata</i>	102,647 (242.2)	74,016 (174.7)	101,753 (240.1)
<i>Fraxinus pennsylvanica</i>	294,460 (694.8)	166,725 (393.4)	185,290 (437.2)
<i>Liquidambar styraciflua</i>	3,605 (8.5)	42,279 (99.8)	14,611 (34.5)
<i>Platanus occidentalis</i>	118,895 (280.6)	277,895 (655.8)	175,519 (414.2)
<i>Populus deltoides</i>	35,673 (84.2)	63,101 (148.9)	45,187 (106.6)
<i>Quercus lyrata</i> Walter	3,087 (7.3)	0 (0)	1,431 (3.4)
<i>Q. nuttallii</i>	7,076 (16.7)	9,665 (22.8)	5,344 (12.6)
<i>Taxodium distichum</i>	216,670 (511.3)	189,362 (446.8)	71,855 (169.6)
<i>Ulmus americana</i>	45,385 (107.1)	39,320 (92.8)	21,060 (49.7)
Other species	13,000 (30.7)	10,000 (23.6)	21,544 (50.8)
<b>Total</b>	<b>949,140 ± 189,828</b> (2,240 ± 448)	<b>966,346 ± 193,269.2</b> (2,280 ± 456)	<b>671,133 ± 134,226.6</b> (1,584 ± 317)

<sup>a</sup> Area, acres (ha).

**Table 3—Pulpwood removals and costs to company of applying the cerulean warbler prescription**

Diameter at breast height	Pulpwood		Sawlogs	
inches (cm)	tons per acre (mt/ha)		board feet per acre (m <sup>3</sup> /ha)	
10 (25)	5.88	(1.082)		
14 (35)	4.03	(0.741)		
18 (45)	0.30	(0.056)	316	(0.745)
22 (55)	0.26	(0.048)	298	(0.704)
26 (65)	0.21	(0.039)	175	(0.413)
Total	10.68	(1.966)	789	(1.862)
Cost per acre (/ha)	53.42	(131.95)	51.29	(126.69)
Total cost, treatment area (dollars)	8,547.40		8,206.64	

Values in the table reflect the difference between estimated standing crop of *Acer negundo*, *Celtis laevigata*, and *Ulmus americana* in 2005 on the North and South subplots. Cost estimate reflects market values in January 2005.

In the cerulean warbler prescription, *U. americana* stems in favorable codominant and intermediate positions were left as potential nest trees. Our experimental manipulation thus created a contrast between effects of treatments that emphasize the desired difference between treatments. The experiment thus offers a test of a prediction made by Robbins and others (1992) that *U. americana* is important to cerulean warbler.

The cerulean warbler prescription appears to have fostered use by the bird in the direction of the desired future condition; this is encouraging, although it has been observed in an unreplicated study. We are cautious, also, because the species' presence does not equate with successful reproduction. Until further work is completed, we cannot distinguish the current result from one in which the birds occur in the north simply as a result of historical presence in small numbers in the northern part of the study grid but not in the southern part.

Finally, we offer a word about the difficulty of developing common terminology, measurement, and data analysis among the professions represented in the investigators of this work. Standard methods in practical forestry take measures in English units, easily produce summaries that reflect commercially important volumetric parameters, and may be developed in software that does not admit exchange of datasets with other analytical tools. Standard methods in avian behavioral ecology take measures in metric units, cannot easily produce estimates of commercial parameters but are easily communicated among analytical tools. These differences made it very difficult for us to develop a common framework for expressing preharvest conditions, as well as to create a common vocabulary for communicating instructions to the timber markers who applied the prescriptions. We hope our experience will benefit others who undertake the development of silvicultural prescriptions for songbirds and other species of special concern.

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## LITERATURE CITED

- Hamel, P.B. 1998. Landscape and habitat distribution of the cerulean warbler *Dendroica cerulea* in extensively fragmented Mississippi alluvial valley, USA. In: Adams, N.J.; Slotow, R.H., eds. Proceedings of the 22<sup>nd</sup> international ornithological congress. Ostrich. 69(3&4): 286.
- Hamel, P.B. 2000a. Cerulean warbler status assessment. St. Paul, MN: U.S. Department of the Interior, Fish and Wildlife Service. 141 p. Available online at: <<http://www.fws.gov/midwest/endangered/birds/cerw/cerw-sa.pdf>> [Date accessed: August 9, 2005].
- Hamel, P.B. 2000b. Cerulean warbler *Dendroica cerulea*. In: Poole, A.; Gill, F., eds. The birds of North America series, No. 511. Philadelphia, PA: The Birds of North America, Inc. 20 p.
- Hamel, P.B. 2005. Suggestions for a silvicultural prescription for Cerulean Warblers in the lower Mississippi Alluvial Valley. In: Ralph, C.J.; Rich, T.D., eds. Bird conservation implementation and integration in the Americas: proceedings of the third international partners in flight conference. Gen. Tech. Rep. PSW-191. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 567-575.
- Hamel, P.B.; Cooper, R.J.; Smith, W.P. 1998. The uncertain future for cerulean warblers in the Mississippi Alluvial Valley. In: Proceedings of the Delta conference. Madison, MS: U.S. Department of Agriculture, Natural Resources Conservation Service: 95-108.
- Hamel, P.B.; Dawson, D.K.; Keyser, P.D. 2004. Overview: how we can learn more about the cerulean warbler (*Dendroica cerulea*). Auk. 121(1): 7-14.

- Hamel, P.B.; Meadows, J.S.; Gardiner, E.S.; Stanturf, J.A. 2001. Chainsaws, canebrakes, and cotton fields: sober thoughts on silviculture for songbirds in bottomland forests. In: Hamel, P.B.; Foti, T.L., tech. eds. Bottomland hardwoods of the Mississippi Alluvial Valley: characteristics and management of natural function, structure, and composition. Gen. Tech. Rep. SRS-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 99-105.
- Jones, J.; DeBruyn, R.D.; Barg, J.J.; Robertson, R.J. 2001. Assessing the effects of natural disturbance on a Neotropical migrant songbird. *Ecology*. 82: 2628-2635.
- Kahl, R.B.; Baskett, T.S.; Ellis, J.A.; Burroughs, J.N. 1985. Characteristics of summer habitats of selected nongame birds in Missouri. Research Bulletin 1056. Columbia, MO: University of Missouri-Columbia Agricultural Experiment Station. 155 p.
- Link, W.A.; Sauer, J.R. 2002. A hierarchical analysis of population change with application to Cerulean Warblers. *Ecology*. 83: 2832-2840.
- Mueller, A.J.; Twedt, D.J.; Loesch, C.R. 1999. Development of management objectives for breeding birds in the Mississippi Alluvial Valley. In: Bonney, R.; Pashley, D.N.; Cooper, R.J.; Niles, L., eds. Strategies for bird conservation: the partners in flight planning process. Cornell Laboratory of Ornithology. <<http://www.birds.cornell.edu/pifcapemay/mueller.htm>> [Date accessed: August 9, 2005].
- Robbins, C.S.; Fitzpatrick, J.; Hamel, P.B. 1992. A warbler in trouble: *Dendroica cerulea*. In: Hagan, J.M., III; Johnston, D.W., eds. Ecology and conservation of Neotropical migrant landbirds. Washington, D.C.: Smithsonian Institution Press: 549-562.
- Ruley, D.A. 2000. Petition under the Endangered Species Act to list the cerulean warbler, *Dendroica cerulea*, as a threatened species. Asheville, NC: Southern Environmental Law Center. 50 p.
- SAS Institute. 1999-2000. The SAS system for Windows, proprietary release 8.1. Cary, NC: SAS Institute. [Not paged].
- Williams, B. 2002. Cerulean warbler: to list or not to list! *The Chattooga Quarterly*, Winter 2002. <<http://www.chattoogariver.org/Articles/2002W/cerulean.htm>> [Date accessed: February 24, 2005].
- Woodson, C.A.; Cooper, R.J.; Hamel, P.B. 1995. Cerulean warbler life history research in bottomland hardwood forests. *The Habitat*. 12(1): 5, 6, 12.

# EVALUATING SOME PROPOSED MATRICES FOR SCORING SUB-OPTIMAL RED-COCKADED WOODPECKER FORAGING HABITAT IN RELATION TO THE 2003 RECOVERY PLAN

Donald J. Lipscomb and Thomas M. Williams<sup>1</sup>

**Abstract**—We have used RCWFAT (an ARC-INFO program that evaluates RCW habitat) to examine the 2003 Red Cockaded Woodpecker (RCW) Recovery Plan, which will influence silvicultural activities on large tracts of southeastern forests. The new plan includes 11 specific characteristics of forest stands that constitute “Good Quality Foraging Habitat” (GQFH) and requires 120 to 200 acres of GQFH for each RCW group. To evaluate the criteria requires a minimum data set that is not met by most product-based forest inventory data. The criteria of GQFH also define ideal RCW habitat. When used as a pass-fail system, the criteria of the Recovery Plan are a poor ecosystem management tool. On the Oakmulgee Ranger District, where the RCW population is declining, only 2 of 189 clusters had sufficient GQFH. On Ft. Bragg, NC, where the RCW population is increasing, only 19 of 496 clusters had sufficient GQFH. Few foraging areas met all of the criteria, and few would meet the criteria after a single silvicultural treatment. An effort has been underway to develop a method to rank less-than-ideal habitat. We examine three alternatives considered in the pursuit of such a method. Scoring of individual stands has proven relatively consistent in all three alternatives. Due to the complexity of interaction among the 11 criteria, efforts to establish scores for entire cluster forage partitions have produced inconsistent results.

## INTRODUCTION

Management of Red-cockaded Woodpeckers (*Picoides borealis*) (RCW) has guided silvicultural treatment on a portion of the southern pine forest since the species was listed in 1970. The 2003 Recovery Plan (U.S. Fish and Wildlife Service 2003) has a goal of 13,101 active clusters on federal lands. Each cluster should have a minimum of 120 acres of foraging habitat, requiring that the federal forests be managed to maintain at least 1.6 million acres of foraging habitat at all times. The 1985 Recovery Plan (U.S. Fish and Wildlife Service 1985) and the Henry (1989) guidelines have been used to formulate management of Federal lands for the last two decades. Central to these guidelines was the requirement of 8,490 square feet of pines  $\geq 10$  inches d.b.h. within  $\frac{1}{2}$  mile of each cluster center. However, recent studies have been unable to demonstrate that the basal area of pines  $> 10$  inches d.b.h. has any relation to the success of RCW, measured either as group size or number of young fledged (Beyer and others 1996, Wigley and others 1999). The latest thinking has focused on creation of forest structure that benefits RCW foraging (James and others 2001). The 2003 Recovery Plan (p. 188 and 189) has developed new criteria for RCW foraging habitat based on forest structure.

Since 1998, we have been developing the Red-cockaded Woodpecker Forage Analysis Tool (RCWFAT) to map and evaluate RCW forage (Lipscomb and Williams 1998a, 1998b). This ARC-INFO, AML program has been routinely used to evaluate RCW foraging habitat across the Southeast (Lipscomb and Williams, in press). Prior to 2003, it evaluated potential RCW forage against the Henry (1989) guidelines to determine forage quality for each RCW cluster on a forest. The program has proven most valuable on large, densely clumped RCW populations found on DOD installations.

Following publication of the 2003 Recovery Plan, RCWFAT has been used for two aspects of management on forests

with RCW. On the Oakmulgee Ranger District (RD), AL, the RCW population has been declining, and RCWFAT was used in the preparation of an EIS for habitat restoration. In this case, RCW clusters were mapped and evaluated by the 2003 criteria. Although little of the forest met all criteria, the program was used to target stands for silvicultural treatments that would move those stands toward the desired structure. On Ft. Bragg, NC, the population is increasing, and the need was to evaluate proposed military projects. In this case, habitat is compared before and after a proposed project to assure the project does not result in a net loss of habitat value. These two forests present a significant contrast in population trends. The Oakmulgee RD population is at only 30 percent of its recovery goal and has had a steady decline in number of active clusters. At Ft. Bragg, NC, the population is nearly 80 percent of the recovery goal and has had a steady increase in active clusters (U.S. Fish and Wildlife Service 2003).

In this paper, we will review application of the 2003 Recovery Plan guidelines on these two forests. The Recovery Plan proposes foraging habitat criteria as a recovery standard. We will first examine the Recovery Plan criteria as a pass-fail system. The Recovery Plan does not present a method to evaluate stands and clusters that do not meet this standard. We will examine three draft alternatives that have been suggested during progress toward such a system to score quality of less-than-ideal habitat. The first alternative simply scores stands and partitions by producing five categories of criteria ranges that range from 1 (poor) to 5 (excellent) for each criterion of good quality foraging habitat (GQFH; table 1). This system will be designated “stand scores” for further discussion. The second alternative added a weighting factor to each criterion based on expert opinion as to the importance of the criterion. This alternative also contained a series of criteria, scores, and weights to evaluate foraging partitions of each cluster (table 2). This system will be designated as “weighted

<sup>1</sup> Research Specialist, Clemson University, Department of Forest Resources, Clemson, SC 29634; and Professor, Clemson University, Baruch Institute of Coastal Ecology and Forest Science, Georgetown, SC 29442, respectively.

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**Table 1—Systems to score stands in relation to criteria specified in 2003 recovery plan<sup>a</sup>**

Stand characteristic	Score					WS	WS2
	1	2	3	4	5		
Number 14" + pine stems	<5	5-8	9-12	13-17	18+	10	0.152
Basal area 14" + pines	<5	5-9	10-14	15-19	20+	9	0.139
Basal area 10-14" pines	>55	51-55	45-50	41-45	0-40	3	0.038
Basal area < 10" pines	>30	23-29	16-22	10-15	0-10	2	0.025
Number pines < 10"	>40	33-39	26-32	20-25	0-20	1	0.013
Basal area of pine > 10"	<20	21-26	27-32	33-39	40+	4	0.051
Percent vegetative ground cover	<10	10-19	20-29	30-39	40+	6	0.101
Hardwood midstory:	T-D	M-M	M-S	L-M	L-S		
Tall = T (>15'), Dense = D	M-D	T-S	L-D				
Medium = M (7-15')	T-M					7	0.114
Low = L (<7') Sparse = S (hardwood pulpwood BA)	>30	22-30	16-22	10-16	<10		
Percent canopy hardwoods							
longleaf stands	>30	23-29	16-22	10-15	<10	5	0.063
loblolly/shortleaf stands	>50	43-49	36-42	30-35	<30		
Stand age	30	31-39	40-49	50-59	60+	9	0.139
Fire return interval (year)	7+	6	5	3-4	<3		0.089
Season of burn			NGS		GS		0.076

<sup>a</sup> Stand score—uses 10 stand characteristic criteria. For each criterion meeting the values specified for GQFH, a score of 5 was assigned. Smaller scores were assigned to values of the stand characteristic further from the criterion. If all 10 criteria were measured, a score from 10 to 50 would be assigned to the stand (a stand that qualified as GQFH would score a 50 in this system). Weighted score (WS)—The importance of each criterion was determined by committee agreement, and a weighting factor was assigned from 1 to 10. Each weighting factor was multiplied by the stand score for each criterion and summed to produce the weighted stand score. In this system stands could score from 56 to 280 if all criteria were evaluated. Weighted stand score 2 (WS2)—the weighted system was re-evaluated and changed by adding two burning criteria. The weights were reduced to fractional values with the same ranking of importance but not exactly proportional to the previous weights. In this system, scores ranged from 1 to 5 if all 12 criteria were used.

scores" for further discussion. The third alternative was developed later as a revision of stand weights (table 1) and revised criteria and weights to evaluate partitions (table 3). This revision will be designated "weighted scores 2" for further discussion.

We will examine these in relation to their value for evaluating silvicultural alternatives for forests with RCW populations. If we

assume habitat differences are responsible for the population growth at Ft. Bragg, NC, and the decline on the Oakmulgee, a scoring system should differentiate habitat conditions on the two forests. The system should also allow differentiation of stand and cluster habitat quality. Finally, scores should be usable to prioritize silvicultural treatments by their value for improving foraging habitat.

**Table 2—Partiton scoring and partition score for weighted score system<sup>a</sup>**

Forage partition characteristic	Score					Weighting factor
	1	2	3	4	5	
Total acres GQFH <sup>b</sup> in partition	<75	75-89	90-104	105-120	120+	6
Total acres pine in partition	<120	120-146	147-173	174-199	200+	1
Total acres GQFH within ¼ mile	<40	40-60	61-90	91-119	120+	5
Last prescribed burn (years)	>6	6	5	4	1-3	4
Season of last burn			NGS		GS	2
# of contiguous foraging acres	<75	75-89	90-104	105-119	120+	
If in sandhills	<75	75-116	116-157	158-199	200+	3

<sup>a</sup> The partition is defined as all area within ½ mile of the cluster center minus any area that is closer to an adjacent cluster. This system evaluates burning as a partition characteristic and defines GQFH as any stand that has a weighted score of at least 175 from table 1. Foraging acres are any stand with a weighted score of at least 56 from table 1. The partition score is calculated as the sum of the criteria scores. The weighted partition score is the sum of the products of criteria scores and weighting factors. Any partition with a weighted score over 74 was considered adequate forage in the weighted system.

<sup>b</sup> GQFH — Sum of acres in stands that scored over 175, used for weighted partition score only.

**Table 3—Partition scores for weighted scoring system 2<sup>a</sup>**

Forage partition characteristic <sup>b</sup>	SI <sup>c</sup>	Score					Weighting factor
		1	2	3	4	5	
Total acres GQFH in partition		<75	75-89	90-104	105-120	120+	0.4
Total acres pine (30 years or older) in partition	L	<100	100-150	150-200	200-250	250+	0.1
	M	<100	100-125	125-150	150-175	175+	
Total acres GQFH <sup>a</sup> within ¼ mile	H	<90	90-105	105-120	120-135	135+	0.3
		<40	40-60	61-90	91-119	120+	
Number of contiguous foraging acres in partition	L	<100	100-150	150-200	200-250	250+	0.2
	M	<100	100-125	125-150	150-175	175+	
	H	<90	90-105	105-120	120-135	135+	

<sup>a</sup>In this system, GQFH is only those stands that score a 5 from table 1. The weighted score is also calculated as the sum of the criteria scores and weighting factors which varies from 0.1 to 0.4.

<sup>b</sup>GQFH=Sum of acres in stands that scored 5 (in table 1 with this method), used for weighted partition score only.

<sup>c</sup>SI =Site index age 50,L ≤ 50, M=50-75, H=75+.

## METHODS

The 2003 Recovery Plan does not change the geometric designation of RCW foraging habitat. Potential foraging habitat is circumscribed by a ½-mile-radius circle around the cluster center, with overlap of circles (when cluster centers are closer than 1 mile apart) partitioned by a bisector of the overlapping arcs. This corresponds to the original geometric definition of foraging habitat in RCWFAT (Lipscomb and Williams 1995). There is a new criterion that involves evaluation of habitat within ¼ mile of the cluster. A new routine was added to create a similar habitat map using a ¼-mile-radius circle instead. For each cluster of cavity trees, RCWFAT now produces two unique areas, a polygon determined by a ½-mile-radius circle and bisectors of any overlapping circles from adjacent clusters and a similar polygon formed by a ¼-mile-radius circle and bisectors of overlapping circles. These two areas will be referred to as the ½- and ¼-mile foraging partitions for the remainder of the paper. In the final step in the geometric section of RCWFAT, these foraging partitions are overlaid on a stand map (with required data in the attribute table) to populate a stand table with data needed to evaluate forage quality within that partition.

The four different evaluation techniques reported in this paper were produced by reprogramming the original report module of RCWFAT (Lipscomb and Williams 1998a). Each system required differing modifications as described below.

### Recovery Plan Criteria as a Pass-Fail System

The 2003 Recovery Plan lists criteria of GQFH. These can be listed as 11 minimum stand values and 4 minimum partition values.

Stand requirements (from stand data):

1. Pine type
2. BA (basal area) of pines ≥ 14 inches d.b.h. is > 20 square feet per acre
3. 18 or more pine stems per acre ≥ 14 inches d.b.h. and over age 59
4. BA of pines ≥ 10 inches d.b.h. and < 14 inches d.b.h. is between 0 and 40 square feet per acre
5. BA of pines < 10 inches d.b.h. is < 10 square feet acre

6. Stems of pines < 10 inches d.b.h. is < 20 stems per acre
7. BA of all pines ≥ 10 inches d.b.h. is ≥ 40 square feet per acre
8. Native plants ≥ 40 percent of ground cover and dense enough to carry a growing-season burn once every 5 years
9. Stand age ≥ 30 years
10. No hardwood midstory or sparse and < 7 feet tall
11. Canopy hardwoods ≤ 10 percent in longleaf and ≤ 30 percent in other pine types

Partition requirements (from partition summaries of stand data) are: (1) for site index ≥ 60, 120 acres of GQFH within ½ mile of cluster; (1a) for site index of < 60, 200 to 300 acres of GQFH within ½ mile; (2) half of the above acres of GQFH within ¼ mile; (3) the above GQFH can be separated by no more than 200 feet of non-foraging areas; and (4) 200 acres of pine type within ½ mile.

The first step in evaluation was production of a stand data table that had variables corresponding to each of the 11 stand criteria listed. Ft. Bragg, NC, had stand data from which criteria 2 to 7 could be measured directly; the data from the Oakmulgee RD did not include diameter distributions. These were derived from the listed data (total basal area and average tree diameter in sawtimber and pulpwood size classes) and data on the whole forest diameter distribution (Lipscomb and Williams 2004). Neither forest had data that could be used to evaluate native ground cover, and this criteria was not tested in any of the following systems. Neither forest had data on midstory hardwoods as listed in the guidelines but did have hardwood pulpwood basal area. We assumed that hardwood pulpwood over 10 square feet per acre did not meet the requirement. Finally, we calculated overstory hardwood percent from percent hardwood sawtimber basal area.

The reporting section of RCWFAT was modified to evaluate each stand in relation to the 11 criteria. Type and age were used as screens, and all non-pine stands and pine stands < 30 years old were removed from further analysis. A series of tests were applied to each criterion to produce a logical yes/no as to whether that criterion met the guidelines. For

all stands where the results were all “yes”, the stand was assigned a “yes” in a new attribute item. New attributes were also added for six reasons why the stand failed: (1) “lacks large pine” — criteria 2,3; (2) “10-14 inch pine basal area”, criterion 4; (3) “pine understory,” criteria 5,6; (4) “lacks total basal area”, criterion 7; (5) “hardwood midstory” criterion 10; and (6) “hardwood overstory”, criterion 11. Following the stand analysis, each cluster was then evaluated against the four cluster criteria to determine the status of the entire cluster.

### **Alternative One — Simple Score**

The simplest scoring system utilizes the first 6 columns and 10 criteria in table 1. A stand score is determined as the sum of the scores of each criterion. A stand that had minimal value in all criteria would score 10 in this system, and one meeting the guidelines would score 50. Since these criteria are similar to the Recovery plan criterion, it required a minimal reprogramming of the pass/fail system. The section that evaluated pass/fail and reason was replaced with a section that assigned a value for each criterion based on the criterion value and summed these for the stand. In our evaluation, scoring for stand age was not included and ground cover was not available, so our maximum score was 40 instead of 50.

In addition to scoring stands, this system also scored partitions. Six criteria were used for scoring partitions (table 2). A contiguous forage area was calculated and was used on each partition to select those stands scoring 40 and contiguous to the center to determine GQFH within ½ mile. These stands were then clipped with the ¼-mile forage polygon to get GQFH within ¼ mile. Total pine acres were defined as acres in all pine type stands in the ½-mile partition. Total contiguous pine foraging was also calculated from the contiguous polygon-partition intersection. There were two new partition criteria added: burn return interval and season of burning. These were added as criteria to the partition evaluation. This proved quite problematic for automated evaluation since burn boundaries did not correspond to partition boundaries, and a single partition could have several different burn histories. The Oakmulgee data did not include any burn information so we simply assigned all partitions with a 4 year, non-growing season burn. At Ft. Bragg, NC, burning is done on large rectangles, and we had to assign a dominant burn year and season to each stand in a partition.

### **Alternative Two — Weighted Scoring**

The next alternative suggested added weighting factors to each of the stand and partition criteria (table 1- column 7, table 2 - last column). These weighting factors were determined by group consensus on the importance of each criterion by a group of knowledgeable scientists and managers. In addition to weighting factors, the definition of GQFH to be used in partition evaluation was changed to include stands that scored over 175 of the maximum 280 points in the stand scoring system. This system required a substantial reprogramming of the reporting function. During that reprogramming, age was programmed into a variable criterion like all the others. Stands were again screened for type and age over 30. In this case, each pine type stand was evaluated for each of the remaining nine criteria and assigned a score based on the criteria value. Each score was then multiplied by the appropriate weighting factor, and the products were summed to produce a stand score. For a complete analysis, the maximum score was 280. Since we did not have ground cover data, the maximum was 250.

Partition scoring (table 2) also required a new program to select all stands with scores over 175 rather than 250 (equivalent of 40 in the simple score system). Calculation of total pine acres and contiguous acres were not changed. We did not use the larger contiguous acreages required for the sandhills in order to run both data sets with the same program.

### **Alternative Three — Weighted Score 2**

During 2004, the above weighted scoring system was further refined (table 1- last column, table 3). This refinement provided substantial changes to both the mechanics of calculation and the definition of criteria. Again the changes required a substantial reprogramming of the reporting module. The largest changes were moving burning from a partition evaluation to a stand evaluation. The weighting values were changed from 1-10 to 0-1, and the 2 burning categories added to make 12 criteria scored. Burning information is not generally stored as part of the stand inventory but as maps of burn units. We only had this information for Ft. Bragg, NC, so the evaluation of the Oakmulgee only includes the nine criteria used in the weighted system. On Ft. Bragg, NC, burning is done on large rectangles, so we were required to overlay the burn maps on the stand boundaries to create a new map of stand polygons with unique burn history. This overlay resulted in a stand map with over 18,000 stand polygons. Each stand polygon was evaluated for 11 criteria for Ft. Bragg, NC. A score of 3.67 on the Oakmulgee corresponded to meeting all 9 criteria, while a score of 4.495 on Ft. Bragg, NC, corresponded to meeting all 11 criteria.

Partition scoring reverted to only four criteria. Only stands that scored five on all criteria were considered GQFH for this system. “Total pine acres” was also changed to only include pine stands over 30 rather than all pine type in the partition. Both total pine and contiguous pine now have three separate criteria ranges depending on the site index. For our analysis, we chose to use only the medium site index range, since we did not have site index data on the Oakmulgee and testing for site index would have required an additional level of programming. Since site index was recorded on the stand level, a method to determine the dominant site index for each partition prior to evaluation would also be needed for partition evaluation.

The Oakmulgee and Ft. Bragg, NC, data were each evaluated by all four systems of stand and partition evaluation. The comparisons are not completely exact pairings due to the variation of the original data. Since the two weighted systems were developed in the NC Sandhills, they are much more likely to include data as it was collected on Ft. Bragg, NC. The Oakmulgee data was collected from the standard USFS inventory system, which we adapted to evaluate the recovery plan criteria (Lipscomb and Williams 2004).

## **RESULTS**

The pass/fail system simply evaluated each stand to determine if it met the guidelines as specified on pages 188 and 189 of the Recovery Plan. We did not have ground cover data for either forest and could not evaluate stands in relation to this criterion. For this reason, the number of stands represented as meeting the guidelines is a maximum, and it is likely that the total number meeting the guidelines would decrease if ground cover data were available. Only 6,793 acres (13.9 percent) on the Oakmulgee and only 20,102 acres (18.8 percent)

on Ft. Bragg, NC, met all criteria of GQFH. Of the 86.7 percent of the stands on Oakmulgee and 81.2 percent on Ft. Bragg, NC, that failed to meet the guidelines, there was more than one reason for failure (fig. 1). If we sum the area represented by all 6 reasons, it totals 191 percent of Ft. Bragg, NC, and 193 percent of the Oakmulgee, indicating that most stands fail for at least two reasons on both forest. The number of partitions passing is even smaller than the number of stands at 2.3 percent and 3.4 percent. Over 80 percent of the partitions on both forests lack GQFH in both the 1/2- and 1/4-mile ranges (fig. 2). Also, over 40 percent of the Oakmulgee partitions and nearly 60 percent of the partitions on Ft. Bragg, NC, have fewer than 200 acres in pine stands.

All three scoring alternatives are summarized in figures 3 and 4. Examining the stand scores (fig. 3), the two forests are similar with the exception of the larger portion of Oakmulgee (43 percent) in stands that do not provide forage. Ft. Bragg, NC, has only 29 percent in stands that do not provide forage. Since non-forage is based on stand type and age, all three scoring systems identify the same non-forage areas. The scored stands are listed in 5 categories that represent 20 percent increments of the possible range of scores for that system. All three scoring systems agree fairly well and identified differences in stand properties. Since over 50 percent of the failing stands in both forests had too many stems or too much basal area of small pines, the low weighting of these factors tended

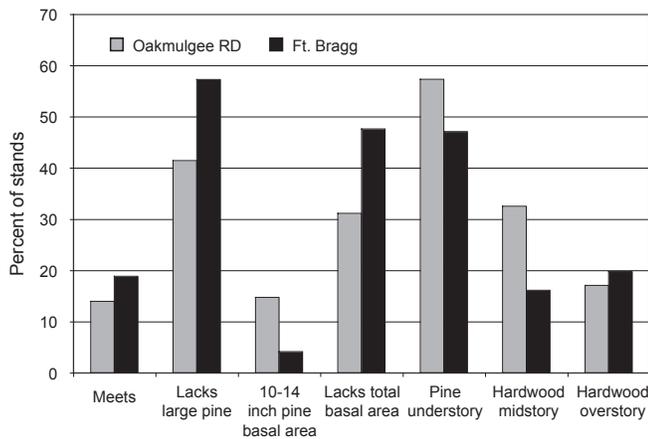


Figure 1—Distributions of stands that meet the Recovery Plan guidelines and those that fail to meet for 1 of 6 reasons developed by combination of the 11 criteria. A stand may fail for more than one reason, and the sum of all failing stands exceeds 100 percent.

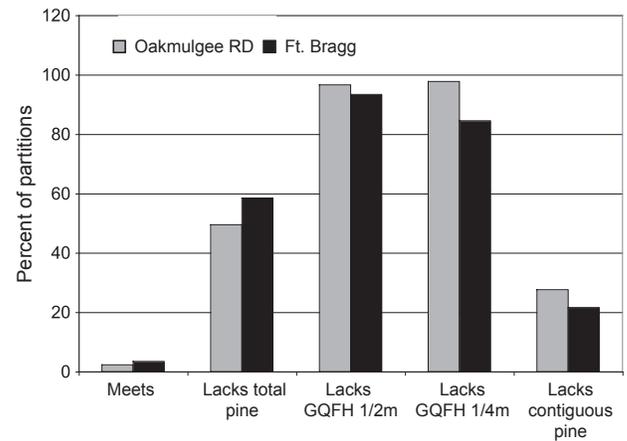


Figure 2—Distribution of foraging partitions that meet the Recovery Plan guidelines and those that fail to meet one of four criteria. A partition may fail more than one criteria, and the sum of failing partitions will exceed 100 percent.

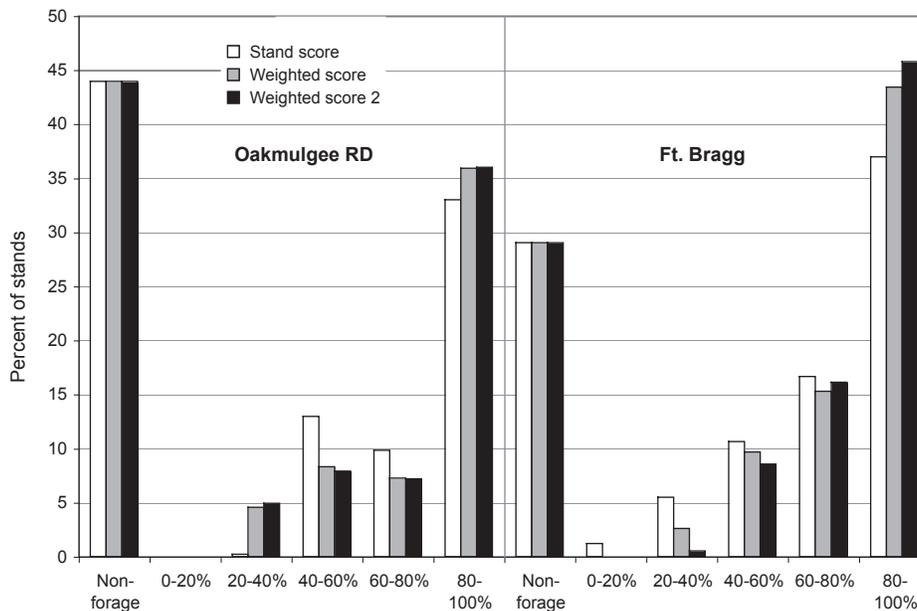


Figure 3—Distribution of stand scores evaluated by all three alternative scoring methods. Non-forage are all stands that are not pine or pine < 30 years old. For each method, scores of foraging stands were separated into five ranges such that each bracket represented 20 percent of the range from lowest to highest possible score for that method.

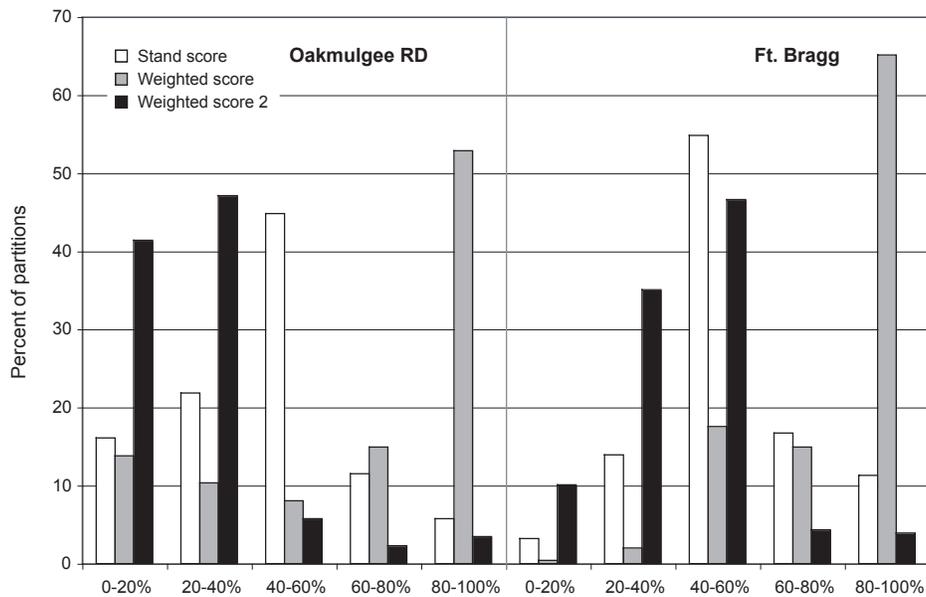


Figure 4—Distribution of partition scores evaluated by all three alternative scoring methods. For each method, scores of partitions were separated into five ranges such that each bracket represented 20 percent of the range from lowest to highest possible score for that method.

to increase the scores in the two weighted systems. With the exception of the burning criteria, both weighting systems had similar priorities, and on the Oakmulgee (where we assigned medium burn criteria) these systems are quite close. Even with the burn criteria included on Ft. Bragg, NC, there was only a 5 percent difference in the overall stand evaluations. All systems ranked individual stands nearly identically (table 4).

The similarity of the stands' scores is not found in the three alternatives when partitions are evaluated (fig. 4). Partition scores vary considerably between systems. The weighted system shows 52 percent of the partitions on the Oakmulgee and 65 percent on Ft. Bragg, NC, to be in the upper 20 percent of the range, when only 2 and 3 percent, respectively, actually met the guidelines. On Ft. Bragg, NC, much of the area had received a growing season burn in the last 3 years. With the weights in table 2, it is obvious two burn parameters are weighted as heavily as the amount of GQFH in the whole partition. The altered definition of GQFH in this system also increases the overall scores as seen on the Oakmulgee, where burning was assumed to non-growing season and 4 year return. The weighting system 2 results are even more difficult to interpret. On both forests, this system produces the highest stand scores, with more stands in the highest ranges. Yet, it produces the lowest partition scores of any system. The distribution on the Oakmulgee is most difficult. Less than 5 percent of the stands are in the lowest 40 percent of the stand score

range, yet over 85 percent of the partitions are in the lower 40 percent of the range.

## CONCLUSIONS

It has been possible to modify the RCWFAT program to include the criteria in the revised habitat guidelines of the Recovery Plan. The program has successfully examined 87 clusters on the Oakmulgee RD and 496 clusters on Ft. Bragg, NC. On both data sets, we used hardwood pulpwood basal area as a surrogate for the density-height criteria of hardwood mid-story. Also, neither dataset contained information that could be used to evaluate native ground covers, and the U.S. Forest Service inventory data on the Oakmulgee did not contain diameter distributions for individual stands. The data requirements of the criteria in the Recovery Plan are not met by traditional product-based inventory information. Data manipulation required to execute the program now requires custom programming for individual data sets. RCWFAT has allowed analysis of large data sets and can be used to indicate the implications of alternative methods to evaluate foraging habitat. This ability to examine many RCW clusters allows insight that was not available during deliberations of those developing RCW guidelines.

The Recovery Guidelines present a very exacting definition of GQFH. Less than 5 percent of the cluster foraging partitions meet all of the requirements of this exacting definition. This is

**Table 4—Regression equations of the stand scores by three scoring systems. For each regression the first listed system is used as the x variable. WFR is the weighting factor ratio the score expected for a score of one in the x system**

	Oakmulgee equation	r <sup>2</sup>	Ft. Bragg equation	r <sup>2</sup>	WFR
Stand score vs weighted	y = 6.266x - 1.683	0.993	y = 6.09x - 2.807	0.998	6.22
Weighted vs weighted 2	y = 0.0147x - 0.003	0.999	y = 0.0178x + .0401	0.993	0.0177
Stand score vs weighted 2	y = 0.919x - 0.026	0.991	y = 0.1086x - .0206	0.989	0.1008

true for both a declining and an increasing population with very little difference in the percentage that met the guidelines in either forest. The stringent definition results in a rejection of most stands. In fact, most stands fail to meet two or more criteria. Simply examining the number of stands or partitions meeting the guidelines will provide little guidance to the forest manager. Without some method to score the quality of less-than-ideal habitat, it will also be difficult to demonstrate progress in habitat management over short time periods. It may take several decades to show substantial progress in the percentage of passing stands or partitions.

Three alternatives have been suggested during efforts to develop a system to evaluate less-than-optimal forage. These alternatives were devised without the ability to examine the implications of choices on large areas. When individual stands or partial stand polygons were examined, all alternatives produced similar results. The data in table 4 indicates that the slopes of the regressions were almost identical to the average weighting factors between the systems. The usable message in this is that any of these systems can be used to rate how close a particular stand is to meeting the guidelines. Therefore, any of them can be used to set priority for silvicultural action. Also, if the changes in the criteria values resulting from silvicultural plans can be quantified, a new stand score can be calculated to rank these plans for quality of RCW foraging.

The three suggested alternatives also included techniques to score cluster forage partitions. Applying these alternatives to a large number of clusters produced highly inconsistent results. The choice of technique had more influence on the results than any factor in the data. Using identical stand scores, the techniques showed variation of three to five fold in the number of partitions in any evaluation from poor to good. These differences were much larger than any differences between the forests. None of these alternatives could be used to confidently assign priority to clusters for silvicultural treatment. It would seem that simply overlaying the partition outlines on a map of stand scores would allow better qualitative assessment of cluster forage than any of these quantitative alternatives.

We have found that there is a reliable method to rank stands that do not meet all the criteria of GQFH in the 2002 Recovery Plan. Any of the three alternatives described here will produce a ranked list of stands from very good to poor. Combined with a simple listing of which criteria are responsible for the low score, this ranking can form the foundation of a silvicultural plan to improve RCW foraging habitat. However, alternatives

to establish a quantitative method to evaluate forage within partitions have resulted in highly inconsistent results. For now, the silviculturalist will be able to evaluate the plans in relation to habitat quality of individual stands but not implications to quality of forage for groups of birds.

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## LITERATURE CITED

- Beyer, D.E.; Costa, R.; Hooper, R.G.; Hess, C.A. 1996. Habitat quality and reproduction of red-cockaded woodpecker groups in Florida. *Journal of Wildlife Management*. 60: 826-835.
- Henry, V.G. 1989. Guidelines for preparation of biological assessments and evaluations for the red-cockaded woodpecker. Atlanta, GA: U.S. Fish and Wildlife Service, Southeast Region. 95 p.
- James, F.C.; Hess, C.A.; Kicklighter, B.C.; Thum, R.A. 2001. Ecosystem management and the niche gestalt of the red-cockaded woodpecker in longleaf pine forests. *Ecological Applications*. 11: 854-870.
- Lipscomb, D.J.; Williams, T.M. 1995. Use of geographic information systems for determination of Red-cockaded Woodpecker management areas. In: Kulhavy, D.L.; Hooper, R.G.; Costa, R., eds. *Red Cockaded Woodpecker symposium III: species recovery, ecology and management*. Nacogdoches, TX: Steven F. Austin State University, Center for Applied Studies in Forestry: 137-145.
- Lipscomb, D.J.; Williams, T.M. 1998a. RCWFAT: an Arc/INFO AML program to assist in evaluating RCW foraging habitat. In: *SOFOR GIS '98: second southern forestry GIS conference*. Athens, GA: University of Georgia: 43-56.
- Lipscomb, D.J.; Williams, T.M. 1998b. Spatial changes in RCW management constraint areas over a ten year period on Hobcaw Barony. In: *SOFOR GIS '98: second southern forestry GIS conference*. Athens, GA: University of Georgia: 57-68.
- Lipscomb, D.J.; Williams, T.M. 2004. Examining RCW management changes in the 2003 recovery plan using habitat mapping. In: *Proceedings of the southern forest GIS conference 2004*. [CD-ROM]. Athens GA: Southern Regional Extension Forestry.
- Lipscomb, D.J.; Williams, T.M. [In press]. Development of a geographic information system based model of Red Cockaded Woodpecker habitat. In: Costa, R.A., ed. *Red-cockaded Woodpecker symposium IV*. U.S. Fish and Wildlife Service.
- Wigley, T.B.; Sweeney, S.W.; Sweeney, J.R. 1999. Habitat attributes and reproduction of red-cockaded woodpeckers in intensively managed forests. *Wildlife Society Bulletin*. 27: 801-809.
- U.S. Fish and Wildlife Service (USFWS). 1985. *Red-cockaded woodpecker recovery plan*. Atlanta, GA: U.S. Fish and Wildlife Service, Southeast Region. 460 p.
- U.S. Fish and Wildlife Service. 2003. *Recovery plan for the red-cockaded woodpecker (Picoides borealis): second revision*. Atlanta, GA: U.S. Fish and Wildlife Service. 296 p.

# RESPONSE OF AVIAN BARK FORAGERS AND CAVITY NESTERS TO REGENERATION TREATMENTS IN THE OAK-HICKORY FOREST OF NORTHERN ALABAMA

Yong Wang, Callie Jo Schweitzer, and Adrian A. Lesak<sup>1</sup>

**Abstract**—We examined bark-foraging and cavity-nesting birds' use of upland hardwood habitat altered through a shelter-wood regeneration experiment on the mid-Cumberland Plateau of northern Alabama. The five regeneration treatments were 0, 25, 50, 75, and 100 percent basal area retention. The 75 percent retention treatment was accomplished by stem-injecting herbicide into mostly midstory canopy trees; the other removal treatments were implemented through chain saw felling and grapple skidding. Density and species composition of bark-foraging and cavity-nesting birds were monitored during the breeding season of 2002 and 2003. Signs of bark-foraging and excavation activities were examined for permanently-marked trees in vegetation sampling plots in spring and fall of 2003 and spring, 2004. A total of 11 species were detected; 9 of them established breeding territories on the study plots. Tufted Titmice were the most abundant species ( $1.35 \pm 0.12$  territories per plot per year), followed by White-breasted Nuthatch ( $0.67 \pm 0.08$  territories per plot per year) and Downy Woodpecker ( $0.58 \pm 0.11$  territories per plot per year). Species richness, abundance, and diversity indices of bark-foraging and cavity-nesting birds varied by the regeneration treatments: Clearcut had the lowest values. Interestingly, no difference was detected among the other four treatments. The amount of snags (measured as total d.b.h.) differed among the treatments: Plots that received the 75 percent retention (herbicide) treatment had the highest value. The signs of bark foraging and excavation activities (number of pecks and excavations) were positively correlated with the availability of dead trees.

## INTRODUCTION

Cavity-nesting and bark-foraging avian species are common in the world's forests. They depend on forest resources for survival and reproduction. Conversely, they provide important ecological services to forest ecosystems through pest control, decomposition of standing dead trees, and as components of forest food webs. Because of their life history traits, interactions with other species, and disproportionate influence over the structure and function of forest bird community, cavity-nesting and bark-foraging species are considered as keystone species in forest ecosystems (Bendnarz and others 2004, Farris and others 2004). They affect biotic and abiotic factors influencing resource creation, use, and exchange for many species of microorganisms, plants, insects, amphibians, reptiles, and mammals.

Cavity-nesting avian species in forest ecosystems are composed of primary cavity excavators and secondary cavity nesters (Conner 1978). The former includes most woodpeckers that excavate their own nest and roost cavities; the latter, such as bluebirds, use existing cavities either formed naturally or abandoned by primary excavators. The factors, including various forest management practices, that affect snag resources have a direct effect on primary cavity excavators who will in turn affect secondary cavity nesters (Conner 1978, Martin and others 2004). Studies have shown that snag availability on forest lands affects species richness and abundance of cavity nesting birds. For example, Balda (1975) found that the amount of snags was positively related with the abundance, diversity, and species richness of cavity-nesting birds. Forest management practices such as clearcutting, timber stand improvement, short harvest rotations, and removing snags to reduce fire and safety hazards result in

elimination of cavity-nest sites from the forest (Runde and Capen 1987). Other forest management practices, such as herbicide application for forest stand improvement, can create snags desirable for foraging and nesting of cavity-nesting birds (Conner and others 1981, McComb and others 1986, McComb and Rumsey 1983, Wagner and others 2004). There is little information about how different levels of removal of basal area affects cavity-nesting and bark-foraging bird communities and how herbicide treatment of select midstory trees affects snag resources and use by these birds.

The objective of this study is to examine the response of cavity-nesting and bark-foraging songbirds to a gradient of forest stand manipulation, including canopy tree removal and midstory herbicide treatments. We are interested in testing the hypotheses that (1) territory density, species richness, and diversity of cavity-nesting and bark-foraging birds differ among these treatments; and (2) bark foraging and excavation activities are positively related with snag availability.

## METHODS

### Study Site

The study sites were located at Miller Mountain ( $34^{\circ} 58' 30''$  N,  $86^{\circ} 12' 30''$  W) and Jack Gap ( $34^{\circ} 56' 30''$  N,  $86^{\circ} 04' 00''$  W), Jackson County, AL, in the Mid-Cumberland Plateau of the southern Appalachian Mountains (Smalley 1982).

The physiography of this region is characterized by narrow, flat plateaus dissected with numerous deep valleys. Study site elevation ranged from 260 to 520 m. Upland hardwood is the dominant forested land cover type in the northern half of Jackson County, with many large continuous tracts throughout. The forests of the sites and much of the surrounding

<sup>1</sup> Associate Professor, Center for Forestry and Ecology, Alabama Agricultural and Mechanical University, Normal, AL 35762; Research Forester, USDA Forest Service, Southern Research Station, Ecology and Management of Southern Appalachian Hardwood Forests, Normal, AL 35762; and former Graduate Student, Center for Forestry and Ecology, Alabama Agricultural and Mechanical University, Normal, AL 35762, respectively.

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area were composed of mature (80- to 100-year-old) oak-hickory (*Quercus* spp. and *Carya* spp.), with yellow-poplar (*Liriodendron tulipifera* L.), sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), and American beech (*Fagus grandifolia* Ehrh.) as associates (Hartsell and Vissage 2001).

### Research Design and Vegetation Sampling

The research was a randomized complete block design with three replicates. The treatments included 5 overstory retention treatments: 0 (clearcut), 25 percent, 50 percent, 75 percent, and control. Each treatment plot was approximately 4 ha (10 acres). The clearcut, 25, and 50 percent retention treatments were accomplished by conventional chainsaw felling and skidding (December 2001 to March 2002). For the 75 percent retention, an herbicide (Arsenal®, active ingredient: imazapyr) was applied mainly to the small-diameter midstory trees to reduce competition and increase light intensity for oak regeneration, without creating large overstory gaps (November 2001). Five 0.01-ha circular subplots in each treatment plot were used for vegetation measurements. Diameter at breast height (d.b.h.) of all live trees and snags  $\geq 3.8$  cm in diameter was measured in spring, 2003.

### Bird Survey

We established three bird survey transects spaced evenly across the width and parallel with the slope in each treatment plot (Lesak and others 2003). Along each transect, marked reference points were placed at 25-m intervals to facilitate bird-territory mapping. To adequately sample the entire treatment unit during spot-mapping, the distance between transects was  $\leq 50$  m.

Territory spot-mapping was used to determine each avian cavity-nesting and bark-foraging species' territorial density (Ralph and others 1993). Each of the 15 treatment plots received 10 spot-mapping visits between late April and July, 2002, and again in 2003. One block of five plots was visited each morning. One rotation of visits through all of the blocks was completed before moving on to the next visit. The order of visits to the 3 blocks was randomized for each of the 10 rotations leaving 5 days between visits to the same block. Bird surveys began between 05:00 a.m. and 05:30 a.m., depending on light conditions that varied with sunrise time and cloud cover. All surveys were completed by approximately 10:30 a.m. Each treatment plot received 1 hour of surveying per visit. All surveys were performed by one individual (A. Lesak). Bird species, behaviors, and positions were recorded during the surveys. Detections from 10 visits were used for territory interpretation in each year following the rules established by International Bird Census Committee (1970). Birds were classified as primary cavity-excavator, secondary cavity-nester, and bark-forager based on Conner (1978) and our own observations.

We quantified excavation and bark foraging activities by examining signs of excavations and peck marks on each tree and snag in the vegetation sampling subplots in April and November, 2003, and March, 2004. Each tree was observed in 3-m increments from the ground with the aid of binoculars.

### Statistical Analysis

Live tree and snag data from five subplots in each treatment plot were summarized for estimating the total basal area/ha

of live trees and snags of each treatment plot. Excavation activities were also summarized across subplots of each treatment plot. Two-way factorial analysis of variance (ANOVA) was used to test the treatment and year effects while controlling the block effect. Tukey HSD test was used for mean separations. Regression analysis was performed between total snag basal area and excavation activities by birds. All analyses were performed with SAS version 9.1 (SAS 2004) and SPSS version 11.0 (SPSS 2001). We reported means and standard errors. Statistical tests were declared significant when the probability of Type I error was smaller than  $\alpha = 0.05$ .

## RESULTS AND DISCUSSION

The pretreatment data suggested that the average total basal area was not different among the treatments (Schweitzer 2003). After the treatment, the mean total basal area was  $25.4 \pm 4.9$  m<sup>2</sup>/ha for live trees and was  $2.8 \pm 1.0$  m<sup>2</sup>/ha for snags. Both average total basal area of live trees and snags differed among the 5 treatments ( $F_{4,6} = 43.3$ ,  $P < 0.0001$  and  $F_{4,6} = 9999.0$ ,  $P < 0.0001$ , respectively) (table 1). Control and 75 percent retention treatments had the highest total live tree basal area, clearcut had the lowest, and 25 percent and 50 percent retention treatments were in-between. The herbicide treatment plots (75 percent retention) had the highest amount of snags compared to the other 4 treatments. Although the mean total basal area of snags differed among control, 25 percent, 50 percent, and clearcut, the difference was relatively small and ranged between 0.48 m<sup>2</sup>/ha (control) and 1.46 m<sup>2</sup>/ha (clearcut). The pattern of total live tree and snag basal area among the treatment plots is consistent with our expectation and is the direct consequence of the treatments we introduced. The treatments created four distinct habitat types: open-scrub, open forest, closed canopy forest with a standing midstory, and closed canopy forest with an intact midstory (Lesak and others 2003).

During the breeding seasons of 2002 and 2003, nine species classified as cavity-nesters or bark-foragers established territories at the study sites (table 2). Tufted Titmice had the highest density followed by White-breasted Nuthatch and Downy Woodpecker. Two species, Pileated Woodpecker and Red-headed Woodpecker, were observed during the study, but the detections were too few to infer the territories. The average territory density differed among the 5 tree basal area retention treatments ( $F_{4,18} = 10.02$ ,  $P < 0.001$ ) and was not different between the 2 years ( $F_{1,18} = 0.80$ ,  $P < 0.38$ ). Two-way factorial ANOVA suggested that the average territory density did not interact between treatment and year ( $F_{4,18} = 1.51$ ,  $P < 0.24$ ). In other words, the pattern was consistent between the 2 years. In both years, the territory density was significantly lower in the clearcut treatment plots than in the other four treatment plots. The average territory density did not differ among the treatment plots receiving between 25 percent and 100 percent basal retention. This is contrary to our expectation that increasing snag resources in herbicide-treatment plots would have increased the number of territories. Species richness, Shannon diversity, and evenness indices of cavity-nesting and bark-foraging birds showed patterns similar to territory density in both years.

Excavation activity differed among the treatment types. The herbicide-treated plots had more peck marks and excavations than the other four treatments. There was also a significant

linear relationship between total snag basal area and the number of pecks ( $r = 0.73$ ,  $P < 0.01$ ) and excavations ( $r = 0.62$ ,  $P < 0.01$ ) among the treatment plots.

Our results demonstrated that forest management practices, specifically basal area reduction by harvesting upper canopy trees and herbicide treatment of midstory trees, affected habitat resource (the availability of snags) of cavity-nesting and bark-foraging birds. This is consistent with other studies that showed forest management practices may have direct and indirect impacts on the wildlife species (e.g. Conner 1978, Conner and others 1994, McComb and Rumsey 1983, Runde and Capen 1987). Although snag availability was different among clearcut, 25 percent, and 50 percent retention, and control plots, the difference was small (all below 1.5 m<sup>2</sup>/ha). Territory density, species richness, and diversity of this group of bird species were much lower in clearcut treatment. We speculate that the reduction of species richness and abundance in clearcut treatments would have been an indirect effect due to habitat and environmental condition changes in these plots. Clearcutting changed specific forest structure, altering sites used by birds for functions such as perching, protection, and food resources. For example, reduction in basal area reduces the canopy cover that provides protection from predators. In clearcuts, air moisture was low, and air temperature was higher (Felix and others 2003), which could directly affect physiological function of wildlife, including birds.

Herbicide treatment did result in more snags and more use, as indicated by signs of excavations and pecks. Conner and others (1981) suggested that substrate sources for cavity-nesting birds could be created by applying herbicides. McComb and others (1986) found that density of primary cavity-nesting birds was positively related with snag density. However, in our study, we found that territory density, species richness, and diversity on herbicide treatment plots were not different from treatment plots that had 25 and 50 percent retention and control treatments. This could be due to several reasons. Our herbicide treatment was applied mainly to small-diameter midstory trees to reduce competition and increase light intensity for oak regeneration without creating large overstory gaps; these trees may be too small for building nests. Conner (1978) found that each species of woodpeckers required a specific size range of snags for nesting. However, Land and others (1989) found cavity occurrence was not related to snag d.b.h. Woodpeckers prefer snags or trees that are infected by fungi that lead to rotting heartwood for nest sites (Conner 1978, Jackson and Jackson 2004, Runde and Capen 1987); woodpeckers usually use well-decayed tops and bases of snags for nest excavation (Conner and others 1994). We did not examine the fungi infection of snags but suspect that the time between our herbicide treatment and this study was not sufficiently long for herbicide-killed trees to develop heart rot. Cain (1996) found that wildlife cavities per snag increased with time since herbicide introduced mortality. Moorman and others (1999) also found that stage of snag decay and number of cavities/snag increased with year since snag recruitment. Similar to the 25 percent and 50 percent retention and control plots, the number of breeding territories of cavity-nesting and bark-foraging bird species in herbicide treatment plots in this study could have been limited by the availability of the larger-diameter snags occurring naturally in these forest stands. Although herbicide kills trees, the quality of these snags is different from that of naturally occurring snags

at our study sites. It appears that snags created by herbicide treatment provided foraging habitat to bird species in this study, which resulted in the positive relationship between the availability of snags and excavation activities.

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## LITERATURE CITED

- American Ornithologists' Union. 1998. Check-list of North American birds. Seventh edition. Washington, DC: American Ornithologists' Union. 829 p.
- Balda, R.P. 1975. Vegetation structure and breeding bird diversity. In: Proceedings of the symposium on management of forest and range habitats for nongame birds. Gen. Tech. Rep. WO-1. Washington, DC: U.S. Department of Agriculture, Forest Service: 59-80.
- Bendnarz, J.; Ripper, D.; Radley, P.M. 2004. Emerging concepts and research directions in the study of cavity-nesting birds: keystone ecological processes. *Condor*. 106: 1-4.
- Cain, M.D. 1996. Hardwood snag fragmentation in a pine-oak forest of southeastern Arkansas. *American Midland Naturalist*. 136: 72-83.
- Conner, R.N. 1978. Snag management for cavity nesting birds. In: Conner, R.N. 1978. Snag management for cavity nesting birds. In. DeGraaf, R.M., tech. coord. Proceedings of the workshop management of southern forests for non-game birds. Gen. Tech. Rep. SE-14. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 120-128.
- Conner, R.N.; Dickson, J.G.; Locke, B.A. 1981. Herbicide-killed trees infected by fungi: potential cavity sites for woodpeckers. *Wildlife Society Bulletin*. 9: 308-310.
- Conner, R.N.; Jones, S.D.; Jones, G.D. 1994. Snag condition and woodpecker foraging ecology in a bottomland hardwood forest. *Wilson Bulletin*. 106: 242-257.
- Farris, K.L.; Huss, M.J.; Zack S. 2004. The role of foraging woodpeckers in the decomposition of ponderosa pine snags. *Condor*. 106: 50-59.
- Felix, Z.I.; Wang, Y.; Schweitzer, C.J. 2003. Relationships between herpetofaunal community structure and varying levels of overstory tree retention in northern Alabama: first-year results. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 7-10.
- Hartsell, A.J.; Vissage, J.S. 2001. Forest statistics for north Alabama, 2000. *Resour. Bull. SRS-64*. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 50 p.
- International Bird Census Committee. 1970. An international standard for a mapping method in bird census work recommended by the International Bird Census Committee. *Audubon Field Notes*. 24: 722-726.
- Jackson, J.A.; Jackson, B.J.S. 2004. Ecological relationships between fungi and woodpecker cavity sites. *Condor*. 106: 37-49.
- Land, D.; Marion, W.R.; O'Meara, T.E. 1989. Snag availability and cavity nesting birds in slash pine plantations. *Journal of Wildlife Management*. 53: 1165-1171.

- Lesak, A.A.; Wang, Y.; Schweitzer, C.J. 2003. Songbird community variation among five levels of overstory retention in northern Alabama. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 18-24.
- Martin, K.; Aitken, K.E.H.; Wiebe, K.L. 2004. Nest sites and nest webs for cavity-nesting communities in interior British Columbia, Canada: nest characteristics and niche partitioning. *Condor*. 106: 5-19.
- McComb, W.C.; Bonney, S.A.; Sheffield, R.M.; Cost, N.D. 1986. Snag resources in Florida- are they sufficient for average populations of primary cavity-nesters? *Wildlife Society Bulletin*. 14: 40-48.
- McComb, W.; Rumsey, R.L. 1983. Characteristics and cavity-nesting bird use of picloram-created snags in the central Appalachians. *Southern Journal of Applied Forestry*. 7: 34-37.
- Moorman, C.E.; Russell, K.R.; Sabin, G.R.; Guynn, D.C., Jr. 1999. Snag dynamics and cavity occurrence in the South Carolina Piedmont. *Forest Ecology and Management*. 118: 37-48.
- Ralph, C.J.; Geupel, G.R.; Pyle, P. [and others]. 1993. Handbook of field methods for monitoring landbirds. Gen. Tech. Rep. PSW-144. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 41 p.
- Runde, D.E.; Capen, D.E. 1987. Characteristics of northern hardwood trees used by cavity-nesting birds. *Journal of Wildlife Management*. 51: 217-223.
- SAS Inc. 2004. Basic getting started guide for SAS 9.1.3. Cary, NC: SAS Institute. 12 p.
- Schweitzer, C.J. 2003. First-year response of an upland hardwood forest to five levels of overstory tree retention. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 287-291.
- Smalley, G.W. 1982. Classification and evaluation of forest sites on the Mid Cumberland Plateau. Gen. Tech. Rep. SO-38. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 58 p.
- SPSS Inc. 2001. SPSS Base 11.0 user's guide. Chicago, IL: SPSS Inc. 574 p.
- Wagner, R.G.; Newton, M.; Cole, E.C. [and others]. 2004. The role of herbicides for enhancing forest productivity and conserving land for biodiversity in North America. *Wildlife Society Bulletin*. 32: 1028-1041.

# DRY CREEK LONG-TERM WATERSHED STUDY: THE EFFECTS OF HARVESTING IN STREAMSIDE MANAGEMENT ZONES AND ADJACENT UPLANDS OF RIPARIAN CORRIDORS ON AVIAN COMMUNITIES IN THE COASTAL PLAIN OF GEORGIA

Merideth P. Grooms, J. Drew Lanham, and T. Bently Wigley<sup>1</sup>

**Abstract**—We evaluated the effects of Best Management Practices (BMPs) harvesting on avian communities associated with headwater streams in the Georgia Coastal Plain. Two watersheds served as references, with no timber harvesting, and two treatment watersheds were clearcut with retention of Streamside Management Zones (SMZs) according to Georgia BMPs for forestry. Bird communities were surveyed in each watershed before and after harvest by variable-distance transect surveys. The bird community surveyed in each watershed was divided into foraging, nesting, and disturbance guilds. A Partners In Flight (PIF) composite score-based index was used to calculate the conservation value (CV) of those communities. Among variables measured, disturbance guilds showed the most apparent response to harvesting. This response, considered in the context of the CV index response, indicated that there was some changeover from high priority disturbance-sensitive species to moderate/high priority disturbance-tolerant species resulting from harvesting. We recommend the use of PIF scores and associated CV indexes along with other bird community variables in investigations of the value of SMZs for songbirds.

## INTRODUCTION

Streamside Management Zones (SMZs), as recommended by Best Management Practices (BMPs) guidelines in the Southeastern United States, are designed primarily to protect water quality during forestry activities and have been shown to do so effectively (Ward and Jackson 2004, Wynn and others 2000). Land managers are becoming increasingly interested in the protection SMZs afford wildlife that occupy riparian environments. Many recent studies in the Eastern United States focus on the relationship between riparian buffer strips and bird communities (Conner and others 2004, Hodges and Krementz 1996, Kilgo and others 1998, Meiklejohn and Hughes 1999). These studies' major interest has been on width requirements for forest interior species. Several researchers have concluded that riparian corridors >100 m are necessary to conserve avian communities associated with interior bottomland forest (Croonquist and Brooks 1993, Keller and others 1993, Kilgo and others 1998, Spackman and Hughes 1995). However, retaining riparian corridors >100 m may be impractical for some forest landowners, particularly on small headwater streams. Thus, there is a need for better information about how bird communities respond to minimum-width SMZs as recommended in forestry BMPs.

Researchers who have studied effects of riparian buffer width on bird communities have primarily used summary statistics and guilds to make inferences about bird communities. However, these analytical methods do not take into account the regional conservation needs of species in the study area. A recent tool for assessing the conservation value of habitat is Partners in Flight's (PIF) species prioritization scores for North American landbirds (Hunter and others 1993). These scores, which range in magnitude from 7 to 35, are based on a species' vulnerability and need for conservation action, including distribution, relative abundance, threats of decline or extirpation, population trend, and area importance. The scoring

process and context of conservation application are described by Carter and others (2000). Since the introduction of the PIF scoring system, its most common application has been the sum of all the scoring components, known as the composite score. The composite score has been included in tables of species abundance and frequency to indicate species of highest concern and has also been used as a weighting factor in a conservation value index which, along with traditional summary statistics and information about species composition, creates a more complete picture of a site's value for birds (Nuttle and others 2003).

The bird conservation value concept can be applied to many management issues, including the question of how well minimum SMZs recommendations conserve bird communities associated with headwater streams. The minimum SMZs recommendations for forestry BMPs developed for Georgia are to leave 12 m of SMZs on each side of perennial streams for 0 to 20 percent slopes and 21 m for 21 to 40 percent slopes (Georgia Forestry Commission 1999). The Dry Creek Long-Term Watershed Study was designed to contribute to an assessment of the effectiveness of these recommendations for protecting water quality and hydrology, riparian environments, and associated biotic communities, including birds. This project, as part of the long-term study, evaluates the value of SMZs for conserving bird communities associated with headwater streams in the Georgia Coastal Plain using a combination of traditional summary statistics, guild-based evaluations, and a PIF composite score-based conservation value index.

## STUDY AREA

The ongoing Dry Creek Long-Term Watershed Study is located on International Paper Company's Southlands Forest, which is approximately 16 km south of Bainbridge, GA (latitude 30.8 N, longitude 84.6 W), in the Coastal Plain physiographic

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<sup>1</sup> Graduate Research Assistant and Associate Professor, respectively, Department of Forestry and Natural Resources, Clemson University, Clemson, SC 29634; and Manager of Sustainable Forestry and Eastern Wildlife Program, National Council for Air and Stream Improvement, Inc., Clemson, SC 29634-0317.

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Figure 1—Location of study area, with inset illustrating the four watersheds examined in the study.

province (fig. 1). The four watersheds (labeled from north to south as A, B, C, and D) in the study area range in size from 26.1 ha (Watershed A) to 46.6 ha (Watershed D). They are oriented in a roughly east-to-west direction and lie on the sharply sloping boundary between the Dougherty Plain and Tifton Upland Districts, known as the Pelham Escarpment. The Pelham Escarpment forms the southeastern border of the larger Apalachicola-Chattahoochee-Flint (ACF) River basin. As part of this basin, these headwater streams drain into the Dry Creek and on into the Flint River (Couch and others 1996). Ambient temperatures average a maximum of 26.2 °C and a minimum of 12.5 °C. Average annual precipitation is 138.7 cm (Southeast Regional Climate Center 2005). Prior to the study, overstory vegetation was dominated by *Liriodendron tulipifera* L., *Nyssa biflora* Walt., *Pinus glabra* Walt., and *Pinus taeda* L.

## PROCEDURES

### Overall Study Design

Two of the four watersheds (A and D) served as references with no timber harvesting, and two treatment watersheds (B and C) were clearcut-harvested and site-prepared according to Georgia BMPs for forestry during the months of September to November, 2003 (fig. 2). SMZs were 12 to 21 m wide on both stream sides.

### Bird Community Sampling

During 2003 and 2004, breeding bird communities within each watershed were surveyed using a single variable-distance transect running parallel to the stream within SMZs. In 2003, each transect was surveyed 6 times from June 2 to July 1, and in 2004 (the breeding season following harvest), each transect was surveyed 10 times from June 2 to July 3. Transects ranged from 300 to 675 m in length, depending on the length of SMZs available for sampling, and each transect was divided into 25-m segments. Bird communities were surveyed by walking each transect at a slow, steady rate and recording the distance perpendicular to the transect from which each bird was heard or seen. All watersheds were surveyed between 0600 and 0900 EST, and each survey was taken by the same observer. To decrease time bias, sampling was alternately initiated at the upstream or downstream end of a transect.

### Data Analysis

Because length of transect varied by watershed, overall abundance and species richness of bird species were standardized

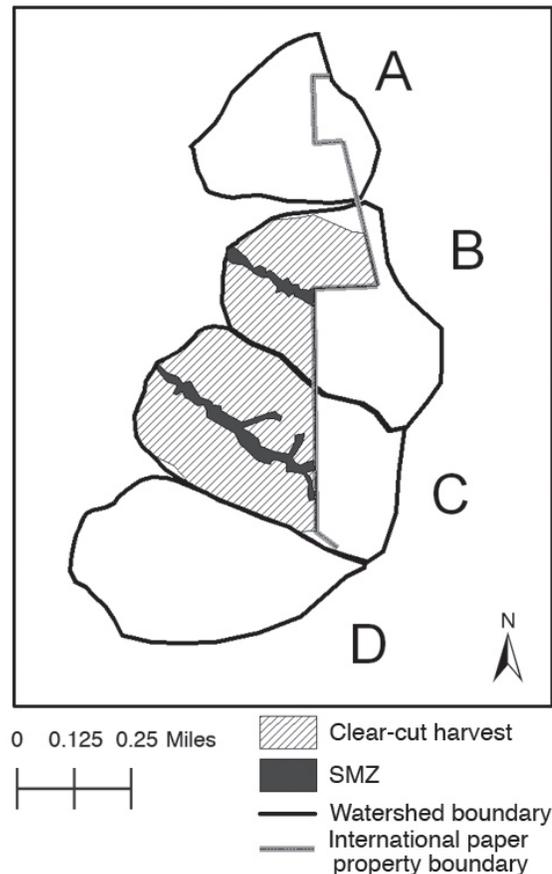


Figure 2—Treatments initiated in the fall of 2003. Watersheds A and D served as references and were not harvested.

by unit area. Each bird species recorded was assigned to a foraging, nesting (Hamel 1992), and disturbance guild (Canterbury and others 2000). Disturbance guilds included disturbance-sensitive species (e.g. Hooded Warbler), disturbance-tolerant species (e.g., Indigo Bunting), and disturbance-neutral species (e.g., Carolina Wren) (Table 1). Relative abundance was used to make comparisons among guilds. Avian conservation value (CV) [equation (1)] was calculated for each sample in each watershed by summing the relative abundance of each species weighted by its PIF composite score after Nuttle (1997).

**Table 1—List of all species recorded in the watersheds studied. Guild associations and PIF composite score are indicated for each species.**

Species	Foraging guild <sup>a</sup>	Nesting guild <sup>a</sup>	Disturbance guild <sup>b</sup>	Southeastern Coastal Plain (BCR)
Wild Turkey <i>Meleagris gallopavo</i>	Ground	Ground/shrub	Neutral	17
Green Heron <i>Butorides virescens</i>	Other	Ground/shrub	Neutral	18
Red-shouldered Hawk <i>Buteo lineatus</i>	Other	Canopy	Neutral	17
Broad-winged Hawk <i>Buteo platypterus</i>	Other	Canopy	Neutral	20
American Woodcock <i>Scolopax minor</i>	Ground	Ground/shrub	Neutral	21
Northern Bobwhite	Ground	Ground/shrub	Neutral	21
Mourning Dove <i>Zenaida macroura</i>	Ground	Ground/shrub	Neutral	13
Yellow-billed Cuckoo <i>Coccyzus americanus</i>	Foliage	Canopy	Neutral	21
Barred Owl <i>Strix varia</i>	Other	Canopy	Sensitive	15
Ruby-throated Hummingbird <i>Archilochus colubris</i>	Other	Canopy	Neutral	18
Red-headed Woodpecker <i>Melanerpes erythrocephalus</i>	Bark	Cavity	Tolerant	20
Red-bellied Woodpecker <i>Melanerpes carolinus</i>	Bark	Cavity	Sensitive	18
Downy Woodpecker <i>Picoides pubescens</i>	Bark	Cavity	Neutral	17
Hairy Woodpecker <i>Picoides villosus</i>	Bark	Cavity	Sensitive	18
Northern Flicker <i>Colaptes auratus</i>	Bark	Cavity	Neutral	18
Pileated Woodpecker <i>Dryocopus pileatus</i>	Bark	Cavity	Sensitive	17
Acadian Flycatcher <i>Empidonax virescens</i>	Hawker	Canopy	Sensitive	21
Great Crested Flycatcher <i>Myiarchus crinitus</i>	Hawker	Cavity	Neutral	19
Eastern Kingbird <i>Tyrannus tyrannus</i>	Hawker	Canopy	Tolerant	20
White-eyed Vireo <i>Vireo griseus</i>	Foliage	Ground/shrub	Tolerant	21
Yellow-throated Vireo <i>Vireo flavifrons</i>	Foliage	Canopy	Neutral	22
Red-eyed Vireo <i>Vireo olivaceus</i>	Foliage	Canopy	Sensitive	15
Blue Jay <i>Cyanocitta cristata</i>	Foliage	Canopy	Neutral	17
American Crow <i>Corvus brachyrhynchos</i>	Ground	Canopy	Neutral	12
Fish Crow <i>Corvus ossifragus</i>	Ground	Canopy	Neutral	18
Carolina Chickadee <i>Poecile carolinensis</i>	Foliage	Cavity	Neutral	21
Tufted Titmouse <i>Baeolophus bicolor</i>	Foliage	Cavity	Neutral	16
Carolina Wren <i>Thryothorus ludovicianus</i>	Ground	Ground/shrub	Neutral	17
Blue-gray Gnatcatcher <i>Poliophtila caerulea</i>	Foliage	Canopy	Neutral	17
Wood Thrush <i>Hylocichla mustelina</i>	Ground	Ground/shrub	Sensitive	24
Brown Thrasher <i>Toxostoma rufum</i>	Ground	Ground/shrub	Neutral	19
Northern Parula <i>Parula americana</i>	Foliage	Canopy	Sensitive	22
Swainson's Warbler <i>Limnothlypis swainsonii</i>	Ground	Ground/shrub	Sensitive	27
Louisiana Waterthrush <i>Seiurus motacilla</i>	Ground	Ground/shrub	Sensitive	21
Kentucky Warbler <i>Oporornis formosus</i>	Ground	Ground/shrub	Sensitive	23
Hooded Warbler <i>Wilsonia citrina</i>	Foliage	Ground/shrub	Sensitive	21
Yellow-breasted Chat <i>Icteria virens</i>	Foliage	Ground/shrub	Tolerant	19
Summer Tanager <i>Piranga rubra</i>	Foliage	Canopy	Neutral	19
Eastern Towhee <i>Pipilo erythrophthalmus</i>	Ground	Ground/shrub	Tolerant	20
Northern Cardinal <i>Cardinalis cardinalis</i>	Foliage	Ground/shrub	Neutral	14
Blue Grosbeak <i>Guiraca caerulea</i>	Foliage	Ground/shrub	Tolerant	18
Indigo Bunting <i>Passerina cyanea</i>	Foliage	Ground/shrub	Tolerant	17
Brown-headed Cowbird <i>Molothrus ater</i>	Ground	Other	Tolerant	11

<sup>a</sup> From Hamel (1992).

<sup>b</sup> From Canterbury and others (2000).

$$CV = \sum_{i=1}^n RA_i * PIF \quad (1)$$

for species  $i=1$  to  $n$

where:

$CV$  = conservation value,

$RA_i$  = relative abundance of the  $i^{\text{th}}$  species, and

$PIF$  = PIF composite concern score of the  $i^{\text{th}}$  species.

A general linear model was constructed which included the effects of years, treatments, and replications. Analysis of variance (ANOVA) was used to analyze the model and determine differences in abundance and species richness between treatments and between years. All calculations were performed using SAS, and all comparisons were made with  $\alpha=0.05$ .

## RESULTS AND DISCUSSION

When examining bird communities within each watershed, we found no significant differences between pre- and post-harvest species richness/ha. Abundance/ha did not change significantly in each watershed after harvest, except in Watershed B (Treatment), where it was significantly lower following harvest ( $p=.0021$ ).

Relative abundance of foraging and nesting guilds showed few clear trends in response to harvest. We detected no significant differences between pre- and post-harvest relative abundance of ground or foliage foragers within each watershed. Bark foragers (e.g., woodpeckers) increased post-harvest in Watershed B (Treatment;  $p=.0278$ ), likely as a result of an open pine stand left on a portion of one slope on the downstream end of Watershed B. Hawks (e.g., flycatchers) increased post-harvest in Watershed A (Reference;  $p=.0366$ ) but decreased in Watershed B (Treatment;  $p=.0138$ ) following harvest. There was no statistical difference in the relative abundance of cavity nesters in each watershed before and after harvest. Ground/shrub nesters increased after harvest in Watershed A (Treatment;  $p=.0433$ ) and Watershed C (Treatment;  $p=.0403$ ), and canopy nesters decreased in Watershed C (Reference;  $p=.0029$ ).

Disturbance guilds exhibited a clearer response than foraging and nesting guilds. Not surprisingly, relative abundance of disturbance-sensitive species in reference watersheds (A and D) did not change significantly after harvest but significantly decreased in both treatment watersheds (B and C;  $p \leq .0008$ ; fig. 3a). In contrast, relative abundance of disturbance-tolerant species significantly ( $p \leq .010$ ) increased in both treatment watersheds while remaining the same or decreasing ( $p=.0385$ ) in both reference watersheds (fig. 3b). Disturbance-neutral species were no more abundant post-harvest than pre-harvest in all watersheds but B (Treatment;  $p=.0108$ ; fig 3c).

The CV of bird communities within each of the four watersheds was not significantly different before harvest, with the exception of Watershed B, which had the lowest CV of all four watersheds. After harvest, CV remained high in reference watersheds while decreasing in Watershed C to about the level of Watershed B, which stayed about the same post-harvest (fig. 4a). Although the decrease of CV in Watershed C following harvest was significant ( $p=.0021$ ), the magnitude of the decrease was such (1.3 units or 6.6 percent) that CV remained relatively high (fig 4b).

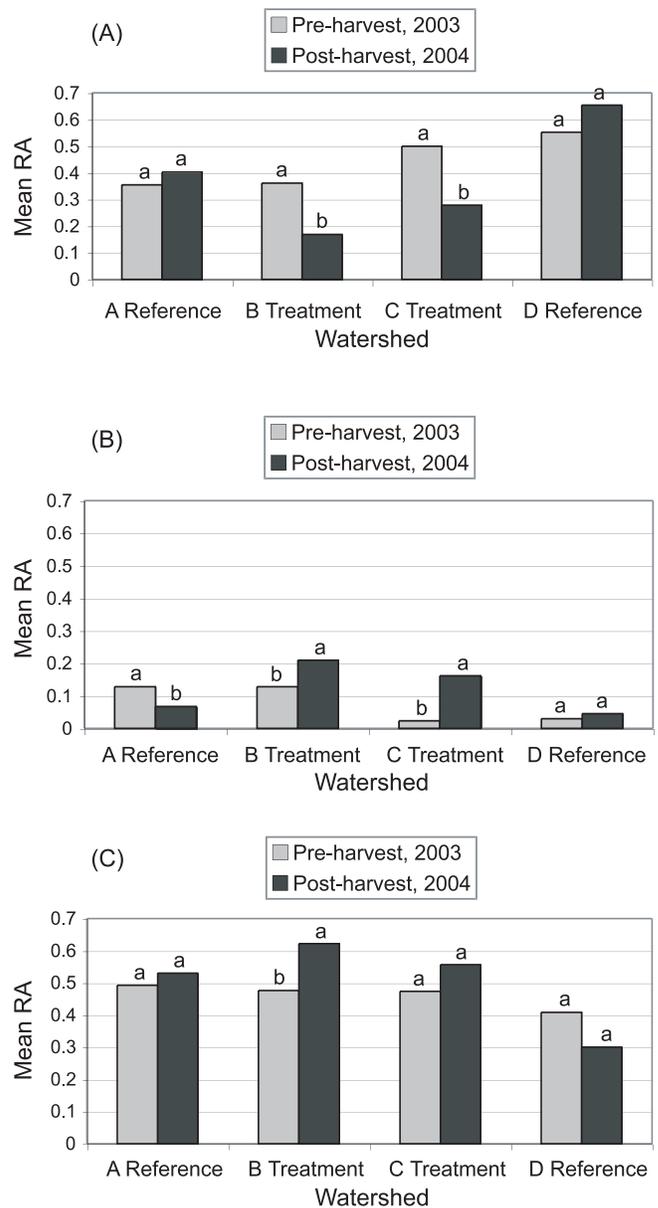


Figure 3—Mean relative abundance of disturbance-sensitive (A), disturbance-tolerant (B), and disturbance-neutral species (C) in watersheds before and after harvest.

In harvested watersheds, the change in species composition (i.e., disturbance-sensitive versus disturbance-tolerant) and the retention of relatively high CV index scores suggests that there was a changeover from relatively high-priority disturbance-sensitive species to moderate/high-priority disturbance-tolerant species. In Watershed B, Acadian Flycatcher and Hooded Warbler, two relatively high-priority ( $PIF=21$ ) disturbance-sensitive species, both significantly ( $p < .0032$ ) declined in relative abundance following harvest. Three disturbance-tolerant species, Eastern Kingbird ( $PIF=20$ ), Blue Grosbeak ( $PIF=18$ ), and Indigo Bunting ( $PIF=17$ ), increased in response to harvest ( $p < .0006$ ). Watershed C showed a significant ( $p < .0169$ ) decrease in relative abundance of 4 high-priority ( $PIF > 20$ ) species (Yellow-throated Vireo, Northern Parula, Louisiana Waterthrush, and Hooded Warbler), which likely made a large contribution to the decrease in CV. However,

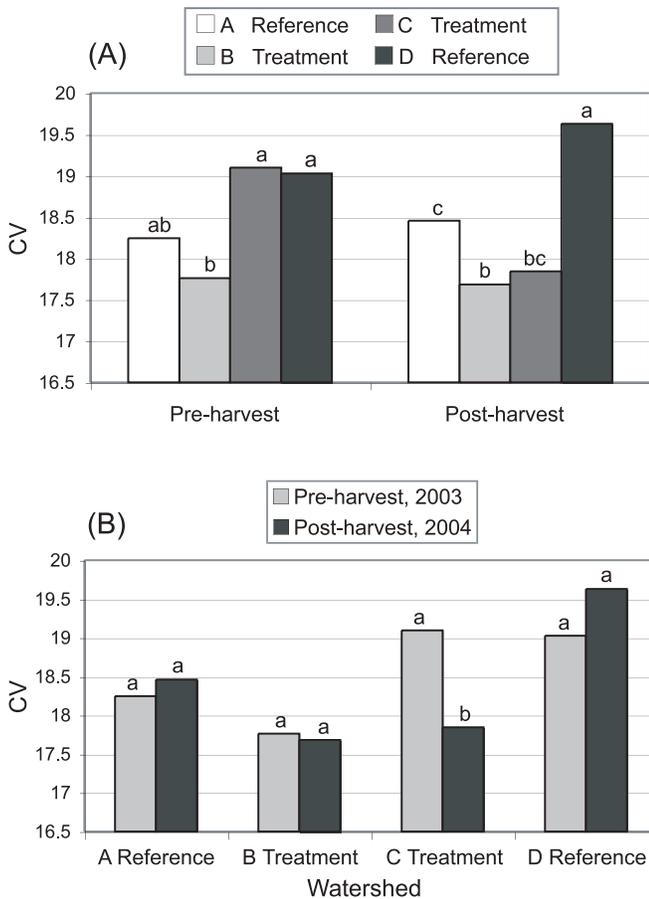


Figure 4—Conservation Value (CV) comparison among watersheds both before and after harvest (A) and between years within each watershed (B).

this decrease was probably mitigated to some extent by the significant ( $p < .0472$ ) increase in relative abundance of a relatively high-priority early-successional species (Eastern Towhee, PIF=20) and the sustained relative abundance of Acadian Flycatcher (PIF=21), which before harvest made up roughly 10 percent of bird abundance in Watershed C.

## CONCLUSIONS

Although abundance, species richness, and relative abundance of foraging and nesting guilds showed few readily apparent patterns related to disturbance, the use of disturbance guilds and PIF score-based indexes suggests that implementation of minimum Georgia SMZs recommendations in this study resulted in some changeover from high priority disturbance-sensitive species to moderate/high priority disturbance-tolerant species. PIF scores are being increasingly applied to management decisions by highlighting conservation needs of bird communities, and when interpreted in the context of other variables (such as disturbance guilds), they can be a meaningful way to make pre- and post-disturbance comparisons of a bird community's conservation value. We recommend that future research on SMZs and bird communities use PIF scores and associated conservation value concept along with other bird community variables to help guide forest wildlife management decisions.

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## LITERATURE CITED

- Canterbury, G.E.; Martin, T.E.; Petit, D.R. [and others]. 2000. Bird communities and habitat as ecological indicators of forest condition in regional monitoring. *Conservation Biology*. 14(2): 544-558.
- Carter, M.F.; Hunter, W.C.; Pashley, D.N.; Rosenberg, K.V. 2000. Setting conservation priorities for landbirds in the United States: the Partners In Flight approach. *Auk*. 117(2): 541-548.
- Conner, R.N.; Dickson, J.G.; Williamson, J.H.; Ortego, B. 2004. Width of forest streamside zones and breeding bird abundance in eastern Texas. *Southeastern Naturalist*. 3(4): 669-682.
- Couch, C.A.; Hopkins, E.H.; Hardy, P.S. 1996. Influences of environmental settings on aquatic ecosystems in the Apalachicola-Chattahoochee-Flint River Basin. U.S. Geological Survey Water Resources Investigations Report. 95-4278. 58 p.
- Croonquist, M.J.; Brooks, R.P. 1993. Effects of habitat disturbance on bird communities in riparian corridors. *Journal of Soil and Water Conservation*. 48(1): 65-70.
- Georgia Forestry Commission. 1999. Georgia's Best Management Practices for forestry. 68 p.
- Hamel, P.B. 1992. The land manager's guide to the birds of the South. Chapel Hill, NC: The Nature Conservancy, Southeastern Region. 437 p.
- Hodges, M.F., Jr.; Krementz, D.G. 1996. Neotropical migratory breeding bird communities in riparian forests of different widths along the Altamaha River, Georgia. *Wilson Bulletin*. 108(3): 496-506.
- Hunter, W.C.; Carter, M.F.; Pashley, D.N.; Barker, K. 1993. Partners in Flight species prioritization scheme. In: Finch, D.M.; Stangel, P.W., eds. Status and management of neotropical migratory birds. Gen. Tech. Rep. RM-229. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 109-119.
- Keller, C.M.E.; Robbins, C.S.; Hatfield, J.S. 1993. Avian communities of riparian forests of different widths in Maryland and Delaware. *Wetlands*. 13(2): 137-144.
- Kilgo, J.C.; Sargent, R.A.; Chapman, B.R.; Miller, K.V. 1998. Effect of stand width and adjacent habitat on breeding bird communities in bottomland hardwoods. *Journal of Wildlife Management*. 62(1): 72-83.
- Meiklejohn, B.A.; Hughes, J.W. 1999. Bird communities in riparian buffer strips of industrial forests. *The American Midland Naturalist*. 141(1): 172-184.
- Nuttle, T.J. 1997. Response of breeding bird communities to afforestation of hardwood bottomland sites in Mississippi. Mississippi State, MS: Mississippi State University, Department of Wildlife and Fisheries. 68 p. M.S. thesis.
- Nuttle, T.; Leidolf, A.; Burger, L.W., Jr., 2003. Assessing conservation value of bird communities with Partners in Flight-based ranks. *Auk*. 120(1): 541-549.
- Southeast Regional Climate Center. 2005. Bainbridge, Georgia, climate information. <http://climate.engr.uga.edu/bainbridge/index.html>. [Date accessed: May 9, 2005].
- Spackman, S.C.; Hughes, J.W. 1995. Assessment of minimum stream corridor width for biological conservation: species richness and distribution along mid-order streams in Vermont, USA. *Biological Conservation*. 71: 325-332.
- Ward, J.M.; Jackson, C.R. 2004. Sediment trapping within forestry streamside management zones: Georgia Piedmont, USA. *Journal of the American Water Resources Association*. 40(6): 1421-1431.
- Wynn, T.M.; Mostaguimi, S.; Frazee, J.W. [and others]. 2000. Effects of forest harvesting Best Management Practices on surface water quality in the Virginia Coastal Plain. *Transaction of the American Society of Agricultural Engineers*. 43(4): 927-936.

# IMPLICATIONS OF LARGE OAK SEEDLINGS ON PROBLEMATIC DEER HERBIVORY

Christopher M. Oswalt, Wayne K. Clatterbuck, Allan E. Houston, and Scott E. Schlarbaum<sup>1</sup>

**Abstract**—Seedling herbivory by whitetail deer [*Odocoileus virginianus* (Boddaert)] can be a significant problem where artificial regeneration is attempted. We examined the relationship between deer herbivory and morphological traits of northern red oak (*Quercus rubra* L.) seedlings for two growing seasons for both browsed and non-browsed seedlings. Logistic regression analyses indicate that seedling height in each dormant season was related to terminal shoot removal (TSR) through herbivory in each of the subsequent growing seasons, 2002 and 2003 ( $P < 0.0001$  and  $P < 0.0001$ , respectively). Browse line was defined as the maximum height deer attempted to browse on seedling shoots and was identified as 148 cm for the 2002 growing season. Seedlings with observed TSR in both 2002 and 2003 were 36 cm ( $P < 0.001$ ) smaller than seedlings with observed TSR in only one or no growing seasons. The results indicate that deer browse is inversely related to seedling size. Larger seedlings would be more likely to surpass the browse line much faster, if not at the time of planting. The cost of producing taller seedlings may be higher per capita, but higher seedling survival and the reduced need for high-density plantings may help offset the higher cost per seedling.

## INTRODUCTION

Challenges to successful regeneration of oak (*Quercus* spp.) have been discussed in a wide array of scientific literature. However, natural regeneration of oak can be problematic in many stands, particularly on highly productive sites, where aggressive pioneer species colonize following disturbance, (e.g., harvest). Large wildfires following complete overstory removal (Abrams 1992, Lorimer 2001), the loss of American chestnut [*Castanea dentata* (Marsh.) Borkh.], Native-American's and colonial use of fire (Delcourt and Delcourt 1998, Hough 1878), and regional stand development patterns (Clatterbuck and Hodges 1988, Oliver 1981) all appear to have contributed to the dominance of oak throughout the eastern deciduous forest. However, many of the conditions favorable to the regeneration of oak are no longer present (Loftis and McGee 1993). Moreover, favorable conditions for oak regeneration are unlikely to be regained.

Difficulty in naturally regenerating oak can be viewed as a result of social and economic constraints imposed on an existing biological solution. Loftis (1983, 1990) demonstrated that oak regeneration can be developed on highly productive sites using a shelterwood approach. However, economic and temporal constraints render this approach unacceptable to many non-industrial private forestland (NIPF) owners. Many NIPF owners rely on short-term economic considerations to dictate forestland management decisions, particularly harvest timing. This tendency does not usually allow for pre-harvest planning and/or intermediate operations necessary to ensure a viable advance oak reproduction population. One alternative could be artificial regeneration, which, over the past 10 years has received a great deal of attention and in which numerous challenges have been identified.

Obstacles to widespread use of artificial oak regeneration include competitive influences of faster-growing species, production of quality seedling stock, and of particular importance,

the influence of whitetail deer herbivory. The whitetail deer population has increased significantly through the 20<sup>th</sup> century, and deer are now the most abundant wild ungulate on the North American continent (Russell and others 2001). Concomitantly, deer browsing has profoundly impacted both the composition and structure of many plant communities, including the depression of natural (Rooney and Waller 2003) and artificial (Buckley and others 1998) oak regeneration. In addition, deer herbivory can result in increased seedling mortality (Buckley and others 1998) and has significant impacts on height growth (Oswalt and others 2004). The aggregate effect is the reduced competitive capacity of planted oak seedlings.

Management options for reducing the impact of deer herbivory on planted seedlings are limited. The primary techniques used to protect planted seedlings from deer herbivory include the use of tree shelters (Dubois and others 2000), deer repellents (Romagosa and Robison 2003), and fenced exclosures (Opperman and Merenlender 2000). While the use of larger tree shelters (> 4 feet) has generally been successful, their cost can be prohibitive for many NIPF owners. Fencing can also be cost-prohibitive and is often more expensive than tree shelters. Repellents vary in effectiveness (Romagosa and Robison 2003) and may retard growth and development. Planting large and vigorous seedlings, i.e., high-quality seedlings, is one alternative to eliminate or reduce deer herbivory. Inherent in the idea of a tree shelter is the assumption that a seedling will reach a height in which the probability of adverse impacts is significantly lessened. Planting taller seedlings may benefit from the same relationship.

This study examines the impacts of deer herbivory on height growth of planted high-quality northern red oak (*Q. rubra* L.) seedlings. Specifically, we investigate the hypothesis that the impact of deer herbivory on smaller seedlings is more substantial than on taller seedlings. In addition, we quantify the associated impacts of variable levels of deer herbivory on

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<sup>1</sup> Graduate Research Assistant and Associate Professor, respectively, The University of Tennessee, Department of Forestry, Wildlife and Fisheries, 274 Ellington Plant Sciences Building, Knoxville, TN 37996-4563; Director, The Ames Plantation, Grand Junction, TN 38039; and James R. Cox Professor of Forest Genetics, Department of Forestry, Wildlife and Fisheries, The University of Tennessee, 274 Ellington Plant Sciences Building, Knoxville, TN 37996-4563.

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seedling height growth and explore the possibilities of planting taller seedling stock to reduce problematic deer browse.

## STUDY SITE

The study was conducted on the Ames Plantation in southwest Tennessee, along an intermittent stream in the headwaters region of the North Fork of the Wolf River (NFWR) (35°09' N, 89°13' W). The site encompasses approximately 100 acres of mixed bottomland and riparian hardwood forest dominated by various oak species and is part of the Southeastern Mixed Forest Province (Bailey 1995). Two distinct landforms were identified within the immediate study site: a minor bottom near the confluence of the stream with the NFWR and ancestral terraces of the minor stream.

The headwaters region of the NFWR is located within the Mississippi Embayment of the Gulf Coastal Plain. The geology is dominated by the highly erodible Wilcox and Claiborne formations of Tertiary age exposed by the erosion of Quaternary and Tertiary fluvial deposits and the overlying Pleistocene loess deposits common in western Tennessee (Fenneman 1938, Safford 1869). The principal soil groups are Grenada-Loring-Memphis on the terraces and Falaya-Waverly-Collins within the minor bottom (U.S. Department of Agriculture 1964).

## MATERIAL AND METHODS

In the fall of 2001, three experimental blocks were identified based on landform and position. Significant differences in average stand basal area ( $P < 0.05$ ) were found among the blocks. Twelve 2-acre treatment units were designated within the experimental blocks; four units were located within the minor bottom (Bottom block), and eight units were located within the terrace sites upstream from the minor bottom (four each within the East and West blocks). Species composition at the time of establishment was dominated by oak spp. on the ancestral terraces and by cherrybark oak (*Q. falcata* var. *pagodifolia* Ell.), yellow-poplar (*Liriodendron tulipifera* L.), and sweetgum (*Liquidambar styraciflua* L.) in the Bottom block.

Four overstory treatments (table 1), including a control (no cut), with 3 replications were randomly assigned to the 12 units using a randomized complete block design. Harvesting for all treatments was completed in the winter of 2001-2002.

Seedlings originating from two genetic families (families 321 and 234) in a seedling seed orchard on the Ames Plantation (Schlarbaum and others 1998) were chosen for planting following harvest. The seedlings were grown at the Georgia Forestry Commission's Flint River Nursery under fertilization and irrigation protocols developed by Kormanik and others

(1994a). The seedlings were lifted in February, 2002, and were evaluated using procedures developed by Kormanik and others (1994a, 1994b), as modified by Clark and others (2000). Height, root collar diameter (rcd), and the number of first-order lateral roots (folr) *sensu* (Ruehle and Kormanik 1986) were recorded, and seedlings were visually classified into one of three categories (cull, good, premium). Thirty seedlings from the good and premium classes in each family were planted by shovel (20 by 20 feet) in March, 2002, within each of the 12 units for a total of 720 seedlings.

Survival, height growth, and browse pressure data were obtained in January, 2003, and January, 2004, for all seedlings after they entered dormancy. A "browse pressure classification" was used (Buckley 2001) to investigate the effects of deer herbivory on planted seedlings. Browse pressure was classified into one of four categories: no browse, terminal browse, lateral browse and complete browse. No browse was defined as no visible signs of herbivory, lateral browse was defined as herbivory limited to lateral shoots only, terminal browse was herbivory limited to only the terminal shoot, and complete browse was defined as observed herbivory on both lateral and terminal shoots. In addition, a binary variable called "terminal shoot removal" (TSR) was created by combining the complete browse and the terminal browse categories. This variable allowed consolidation of seedlings where terminal shoots were browsed.

Mean 2-year seedling height growth and survival by TSR category were analyzed for differences between growing seasons using mixed effects ANOVA models and post-ANOVA mean separation using Fisher's Least Significance Difference Procedure (SAS Institute Inc. 1989). An error level of  $\alpha = 0.05$  indicated significant differences. Logistic regression and chi-square analyses were used to explore the possible relationship between seedling height before bud break and the probability of TSR and to determine the limiting height for browse.

## RESULTS

Mean initial rcd, initial shoot height, and number of folr for premium seedlings ( $n = 216$ ) were 12.55 mm, 124.30 cm, and 21, respectively. Mean initial rcd, initial shoot height, and number of folr for good seedlings ( $n = 504$ ) were 10.23 mm, 103.85 cm, and 16, respectively.

Seedlings experienced browse pressure during both growing seasons. Seedlings exhibited signs of TSR following the 2002 growing season only ( $n = 104$ , 18 percent of surviving seedlings), the 2003 growing season only ( $n = 58$ , 10 percent), and

**Table 1—Overstory treatment descriptions for the oak regeneration study on Ames Plantation, Fayette County, TN, December 2001**

Treatment	Description
Commercial clearcut	Removal of all stems > 6 inches diameter breast height.
Two age	Residual stand basal area of 15-20 square feet per acre was targeted. Residual stems were chosen based on spacing criteria and the desire to leave stems of desirable species with an opportunity to increase in value. Desirable species included oaks, hickories ( <i>Carya</i> spp.), and yellow-poplar.
High grade	Removal of all stems > 14 inches diameter breast height.
No cut (control)	Designed to act as the study control. No removals.

both growing seasons ( $n = 76$ , 12 percent), irrespective of overstory treatment. However, many seedlings did escape TSR in both 2002 and 2003 ( $n = 355$ , 60 percent). Mortality, primarily in the control units, accounted for 127 seedlings. Herbivory by whitetail deer had no significant influence on seedling survival following two growing seasons but did influence 2-year height growth ( $P < 0.0001$ ) through TSR. Mean 2-year height growth was greatest for seedlings that did not exhibit signs of TSR and least for seedlings that exhibited signs of TSR following both growing seasons (table 2). Seedlings that experienced TSR in both 2002 and 2003 were on average 36 cm shorter than seedlings exhibiting no signs of TSR. Chi-square analysis identified 148 cm as the limiting height for TSR ( $P < 0.0001$ ). TSR did not occur on any seedling  $> 148$  cm initial planting height (5 percent of population) during the 2002-growing season. Following the 2003 growing season, 47 percent of the seedlings had surpassed the 148 cm “browse-line”. Consequently, logistic regression analysis of pooled seedling data (pooled across treatment) suggested that dormant season seedling height influenced TSR in both 2002 and 2003 ( $P < 0.0001$  and  $P < 0.0001$ , respectively).

## DISCUSSION AND CONCLUSIONS

While TSR was not extensive (15 percent of total planted in 2002, 8 percent in 2003, and 11 percent for both growing seasons), it did show that deer herbivory had a significant impact on 2-year seedling height growth, particularly on seedlings that were browsed in both years. Seedlings with observed TSR in both 2002 and 2003 were on average 36 cm smaller than seedlings that maintained an unbrowsed terminal shoot. The study demonstrated that planting taller seedlings reduces deer herbivory of the terminal shoot without the associated expense of tree shelters (Clatterbuck 1999), repellents, or exclosures. The cost of seedlings, however, is greater due to using only a portion of the seedlings purchased. In this study, roughly 45 percent of the available seedlings were selected for planting. This selection regime almost doubles the price per seedling. The increased cost can be somewhat mitigated, however, by a reduction in planting density due to relatively higher survival and greater growth. Concomitantly, taller seedlings not only provide some protection from deer herbivory but also appear to have higher rates of growth (Oswalt and others 2003). As a result, the benefits of planting taller seedlings appear to be multi-dimensional.

**Table 2—Season of occurrence, number (N), mean height growth after two growing seasons and associated standard error of northern red oak (*Quercus rubra* L.) seedlings with observed terminal shoot removal (TSR) pooled across treatments within the oak regeneration study on Ames Plantation, Fayette County, TN**

Season	N	Mean	S.E.
2002 Only	104	34.21 <sup>a</sup>	2.68
2003 Only	58	10.10 <sup>b</sup>	2.78
2002 & 2003	75	4.67 <sup>b</sup>	2.13
No TSR	355	40.72 <sup>c</sup>	1.71

Different lettering indicates differences ( $P < 0.05$ ).

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## LITERATURE CITED

- Abrams, M.D. 1992. Fire and the development of oak forests. *BioScience*. 42: 346-353.
- Bailey, R.G. 1995. Descriptions of the ecoregions of the United States. Misc. Pub. 1391. Washington, DC: U.S. Department of Agriculture, Forest Service. 108 p.
- Buckley, D.S. 2001. Field performance of high-quality and standard northern red oak seedlings in Tennessee. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 323-327.
- Buckley, D.S.; Sharik, T.L.; Isebrands, J.G. 1998. Regeneration of northern red oak: positive and negative effects of competitor removal. *Ecology*. 79: 65-78.
- Clark, S.L.; Schlarbaum, S.E.; Kormanik, P.P. 2000. Visual grading and quality of 1-0 northern red oak seedlings. *Southern Journal of Applied Forestry*. 21: 93-97.
- Clatterbuck, W.K. 1999. Effects of tree shelters on growth of hardwood seedlings after seven growing seasons. In: Haywood, J.D., ed. Proceedings of the 10<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 43-46.
- Clatterbuck, W.K.; Hodges, J.D. 1988. Development of cherrybark oak and sweet gum in mixed, even-aged bottomland stands in central Mississippi. *Canadian Journal of Forest Research*. 18: 12-18.
- Delcourt, P.A.; Delcourt, H.R. 1998. The influence of prehistoric human-set fires on oak-chestnut forests in the southern Appalachians. *Castanea*. 63: 337-345.
- Dubois, M.R.; Chappelka, A.H.; Robbins, E. [and others]. 2000. Tree shelters and weed control: effects on protection, survival and growth of cherrybark oak seedlings planted on a cutover site. *New Forests*. 20: 105-118.
- Fenneman, N.N. 1938. *Physiography of the Eastern United States*. New York: McGraw-Hill Book Company. 691 p.
- Hough, F.B. 1878. Report on forestry. Washington, DC: Washington Government Printing Office. 650 p.
- Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. 1994a. Irrigating and fertilizing to grow better nursery seedlings. In: Proceedings of the northeastern and international forest and conservation nursery associations. Gen. Tech. Rep. RM-243. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Rangeland Experiment Station: 115-121.
- Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. 1994b. Toward a single nursery protocol for oak seedlings. In: Proceedings of the 22<sup>nd</sup> southern forest tree improvement conference: 89-98.
- Loftis, D.L. 1983. Regenerating southern Appalachian mixed hardwood stands with the shelterwood method. *Southern Journal of Applied Forestry*. 7: 212-217.
- Loftis, D.L. 1990. A shelterwood method for regenerating red oak in the southern Appalachians. *Forest Science*. 36: 917-929.
- Loftis, D.L.; McGee, C.E., eds. 1993. Oak regeneration: serious problems, practical recommendations. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 319 p.
- Lorimer, C.G. 2001. Historical and ecological roles of disturbance in eastern North American forests: 9,000 years of change. *Wildlife Society Bulletin*. 29: 425-439.
- Oliver, C.D. 1981. Forest development in North America following major disturbances. *Forest Ecology and Management*. 3: 153-168.
- Opperman, J.J.; Merenlender, A.M. 2000. Deer herbivory as an ecological constraint to restoration of degraded riparian corridors. *Restoration Ecology*. 8: 41-47.

- Oswalt, C.M.; Clatterbuck, W.K.; Oswalt, S.N. [and others]. 2004. First-year effects of *Microstegium vimineum* and early growing season herbivory on planted high-quality oak (*Quercus* spp.) seedlings in Tennessee. In: Yaussy, D.A.; Hix, D.M.; Long, R.P.; Goebel, P.C., eds. Proceedings of the 14<sup>th</sup> central hardwood forest conference. Gen. Tech. Rep. NE-316. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 1-9.
- Oswalt, C.M.; Clatterbuck, W.K.; Schlarbaum, S.E.; Houston, A. 2003. Growth and development of high-quality northern red oak seedlings and the effects of competing herbaceous production within four over-story treatments - first year results. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 559-564.
- Romagosa, M.A.; Robison, D.J. 2003. Biological constraints on the growth of hardwood regeneration in upland Piedmont forests. *Forest Ecology and Management*. 175: 545-561.
- Rooney, T.P.; Waller, D.M. 2003. Direct and indirect effects of white-tailed deer in forest ecosystems. *Forest Ecology and Management*. 181: 165-176.
- Ruehle, J.L.; Kormanik, P.P. 1986. Lateral root morphology: a potential indicator of seedling quality in northern red oak. Res. Note SE-344. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 6 p.
- Russell, F.L.; Zippin, D.B.; Fowler, N.L. 2001. Effects of white-tailed deer (*Odocoileus virginianus*) on plants, plant populations and communities: a review. *The American Midland Naturalist*. 146: 1-26.
- Safford, J.M. 1869. *Geology of Tennessee*. Nashville, TN: Tennessee State Printing Office. 550 p.
- SAS Institute Inc. 1989. *SAS/STAT user's guide*. Version 6. Fourth edition. Cary, NC: SAS Institute Inc. 846 p.
- Schlarbaum, S.E.; Barber, L.R.; Cox, R.A. [and others]. 1998. Research and development activities in northern red oak seedling seed orchard. In: Steiner, K., ed. Proceedings of the second IUFRO genetics of *Quercus* meeting: diversity and adaptation in oak species. State College, PA: Pennsylvania State University: 185-192.
- U.S. Department of Agriculture 1964. *Soil survey of Fayette County, Tennessee*. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 165 p.

# RESPONSE OF TIMBER GROWTH AND AVIAN COMMUNITIES TO QUALITY VEGETATION MANAGEMENT IN MID-ROTATION CRP PINE PLANTATIONS

Brandon G. Sladek, Ian A. Munn, L. Wes Burger, and Scott D. Roberts<sup>1</sup>

**Abstract**—Provisions of the 2002 Farm Bill gave Conservation Reserve Program (CRP) participants greater flexibility to implement mid-contract management activities that encourage wildlife habitat improvement and timber production. Quality Vegetation Management (QVM) is one such technique that utilizes the selective herbicide Imazapyr and prescribed burning. Timber growth (d.b.h., total/merchantable heights, and cubic foot volume per acre) and summer avian community responses (relative abundance, species richness, and total conservation value) to the QVM treatment are being evaluated in mid-rotation CRP loblolly pine plantations in two physiographic regions of Mississippi. By 2-years post-treatment, significant increases in the relative abundance of six early successional bird species were detected on treated sites. Although not significant, mean pine growth increment increases were slightly greater on treated plots than on control plots.

## INTRODUCTION

Since the late 1950s, several federal programs (e.g., Conservation Reserve phase of the Soil Bank, Forestry Incentives Program) have promoted forest management on private lands (Allen and others 1996). Although the majority (34 million acres) of land enrolled in the Conservation Reserve Program (CRP) is distributed throughout the Midwestern and Great Plains states, the program has had a tremendous impact on land-use changes in the Southeast as well (Burger 2000). Through February, 2005, 3,271,838 acres had been enrolled in the CRP across 12 Southeastern States (Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia) (USDA 2005). In the Midwest, the predominant conservation practice is grass establishment, whereas tree planting has been the most commonly used practice in the Southeast, representing 1,868,893 acres, or 57 percent, of the total enrolled acres as of February 2005 (USDA 2005). Pine plantings, either newly established plantations or existing plantations, represent 48 percent of these acres (USDA 2005).

From plantation establishment until stand maturity, competing vegetation will in some way affect the growth of desired crop trees. Some competition can be beneficial; it helps maintain good tree form and small branches. However, substantial competition, usually from other plant species, will negatively affect pine growth through competition for important resources (Schultz 1997). Numerous studies have shown a significant growth response to competition control in young pine plantations (Bacon and Zedaker 1987, Creighton and others 1987, Knowe and others 1985), and others have demonstrated that significant increases in growth can still be achieved with competition removal at mid-rotation (Fortson and others 1996, Oppenheimer and others 1989).

Early successional and disturbance-dependent habitats are in decline in the Southeast as many of the land-use changes (urbanization, modernized farming, introduction of exotic and monoculture communities) within these forested systems have resulted in the loss of many early-successional habitats

(Burger 2000). With loss of early-successional and pine-grassland habitats, many bird species dependent on these communities are declining in the Southeast. The enrollment of agricultural lands into the CRP in the Southeast has the potential to provide critical early-successional habitat for many regionally-declining grassland and shrub-successional bird species. Despite success across the Great Plains and Midwest, wildlife habitat value and population response of these regionally-declining bird species to the CRP in the Southeast have not been as positive, largely because of the relatively short window of early-successional habitat in planted pines and lack of mid-rotation management.

Under the 2002 Farm Bill, mid-contract management practices, including thinning, prescribed fire, disking, herbicide, and interseeding of legumes, are permitted on CRP; and effective February, 2004, such practices are encouraged through the availability of cost-share (USDA 2003a, 2003b). Quality Vegetation Management (QVM) is one such habitat improvement technique that utilizes the selective herbicide Arsenal<sup>®</sup> and controlled burning to improve wildlife habitat and timber production. The application of Arsenal during the late growing season controls most lower to midstory hardwood encroachment with minimal long-term effects on forbs and grasses (Hurst 1989). In a study on the effects of using Arsenal for pine release, Hurst (1989) found that it was effective for controlling midstory hardwoods, but important wildlife plants such as blackberry, dewberry, greenbrier, and other various legumes quickly recovered following initial setback. Winter burning is beneficial for wildlife foods by stimulating prolific sprouting from understory plants and permitting more light to aid herbaceous growth (Chen and others 1975, Dills 1970).

QVM studies have been conducted in mature (45- to 50-years-old) naturally-regenerated pine stands (Edwards and others 2004, Jones and others 2003) and mid-rotation commercial pine plantations (Hood 2001, Thompson 2002, Woodall 2005) in east-central Mississippi. In both instances, preliminary results indicate that QVM can improve wildlife habitat quality; however, research is lacking on the effects of QVM on wildlife habitat and timber production in CRP pine plantations.

<sup>1</sup> Graduate Research Assistant and Professor, respectively, Mississippi State University, Department of Forestry, Mississippi State, MS 39762; Professor, Mississippi State University, Department of Wildlife and Fisheries, Mississippi State, MS 39762; and Associate Professor, Mississippi State University, Department of Forestry, Mississippi State, MS 39762.

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## METHODS

### Study Area and Treatments

This study was conducted in two physiographic regions (Upper Coastal Plain, Lower Coastal Plain) of Mississippi. There were six study sites (blocks) in each of the two regions. They were located in Kemper (4 sites) and Neshoba (2 sites) counties in northern Mississippi and Lincoln (3 sites) and Covington (3 sites) counties in southern Mississippi. The 12 study sites were chosen based on age (15- to 18-years-old), and enrollment in a cost-share program. All sites had been thinned prior to the start of the study. Each of the 12 study sites consists of approximately 45 acres of privately-owned mid-rotation pine plantation enrolled in the Conservation Reserve Program. Pre-treatment stand conditions [mean, minimum, maximum diameter at breast height (d.b.h., 4.5 feet), mean total height, and volume per acre] are given in table 1. The dominant understory species across study sites in northern Mississippi is sweetgum (*Liquidambar styraciflua* L.), whereas Chinese privet (*Ligustrum sinense* Lour.) is the predominant understory species across study sites in southern Mississippi. There were two treatments at each study site (block), a control and an Arsenal application combined with a winter burn (QVM), which were assigned at random to 20-acre plots within each study site. On the QVM-treated plots, a mixture of Imazapyr, 0.5 pounds active ingredient and a surfactant in 20 gallons of solution per acre, was applied during October to December, 2002, followed by a prescribed burn during January to March, 2003.

### Timber Volume and Growth

At 11 of the 12 study sites, 9 permanent 0.05-acre sub-plots [control (n)=108, QVM (n)=108] were established per 20-acre treatment plot on a 3 x 3 grid with a spacing of 4 x 5 chains. Due to space limitations at one study site, only 6 0.05-acre sub-plots were established within each 20-acre treatment plot. All trees [pine and merchantable hardwoods (>4.99 inches at d.b.h.)] in each sub-plot were marked for identification purposes with an aluminum tag placed at breast height. Variables of interest [d.b.h., total height (H), and total merchantable height (MH=height to a 3-inch top)] were recorded pre-treatment (February to March 2003) and twice following application of the QVM treatment (post-treatment) during the 2003-2004 and 2004-2005 dormant seasons. D.b.h., total height, and total merchantable height measurements were used to calculate total and merchantable cubic foot stem volume for each stem, using the equations from Merrifield and Foil (1967). Plot-level mean total and merchantable volumes were averaged and expressed on a per acre basis. Annual growth was calculated as the difference in plot means between years.

**Table 1—Pretreatment stand conditions (number of sites; mean, minimum, maximum d.b.h. (inches); mean height (feet); volume per acre (cubic feet) by treatment in mid-rotation CRP loblolly pine plantations in Mississippi**

	n	Mean d.b.h.	(Min-Max)	Mean height	Volume/acre
Control	6	9.2	(2.0-16.6)	56	2,099
QVM	6	9.2	(1.7-22.9)	56	1,974

### Avian Community Sampling

The avian community was sampled once in June, twice in July and once in August, 2003, and once in May, and twice in both June and July, 2004. Ten-minute standardized point counts were conducted from the three permanently-marked sampling stations within each treatment plot, [control (n)=36, QVM (n)=36]. All surveys were conducted between 5:30 a.m. and 10:30 a.m. and only when Breeding Bird Survey weather conditions were satisfied (Robbins and others 1986). All birds seen or heard during the 10-minute point count were recorded by appropriate time (0 to 3 minutes, 4 to 5 minutes, 6 to 10 minutes) and distance (<82 feet, 82 to 164 feet, >164 feet flyover) combination. Point count data was used to estimate relative abundance and species richness. Total conservation value is an index to the habitat-specific relative conservation value of the avian community; it is estimated by weighting relative abundance measures by Partners in Flight species conservation priority scores and summing across all species that occurred in a stand, forest, or habitat type of interest (Nuttall and others 2003).

## RESULTS AND DISCUSSION

### Timber Growth

Similar studies evaluating growth responses from mid-rotation competition control (Quicke 2002, Shiver 1994) have demonstrated that these practices can be successful in producing significant gains in timber growth, but these gains usually begin appearing 3 to 4 years post-treatment or later. By 2 years post-treatment, we found no significant differences in mean growth increments (d.b.h.,  $P=0.15$ ; total height,  $P=0.25$ ; cubic foot volume per stem,  $P=0.06$ ), between treated and control plots (table 2). Although not significant, mean growth increment increases on treated plots were slightly greater than on control plots. Due to a variety of circumstances over the past 3 years, which has resulted in the loss of three stands from the study, 2-year results are from the nine remaining stands. As seen in similar studies (Oppenheimer and others 1989, Pienaar and others 1983), growth response continues to increase with time since treatment, and we expect that the small increases in growth seen to this point will become significant by year 4 post-treatment or later.

### Avian Community Metrics

Avian community indices of interest [species richness (sprich), total abundance (abundance), and total conservation value (TCV)] did not differ during either year 1 [sprich 2003 ( $F_{1,11}=0.41$ ,  $P=0.53$ ); abundance 2003 ( $F_{1,11}=0.00$ ,  $P=0.97$ ); TCV 2003 ( $F_{1,11}=0.07$ ,  $P=0.80$ )] or year 2 post-treatment [sprich 2004 ( $F_{1,9}=1.40$ ,  $P=0.27$ ); abundance 2004 ( $F_{1,9}=1.17$ ,  $P=0.31$ ); TCV 2004 ( $F_{1,9}=2.17$ ,  $P=0.17$ )] (table 3). An initial reduction in all three community indices was expected since

**Table 2—Mean diameter (inches), total height (feet), and volume (cubic feet) growth increment on control and QVM plots 2 years post-treatment (nine sites)**

Treatment	Diameter	Height	Volume
Control	0.79	5.68	3.2
QVM	0.85	6.04	3.4

**Table 3—Mean total abundance, mean species richness, mean conservation priority score, and standard error by year and by treatment in mid-rotation CRP loblolly pine plantations in Mississippi. Standard errors are in parentheses**

Community indices	2003		2004	
	Control	QVM	Control	QVM
Mean total abundance	7.86 (0.49)	7.85 (0.49)	8.08 (0.37)	7.73 (0.37)
Mean species richness	4.95 (0.25)	4.83 (0.25)	5.88 (0.23)	5.68 (0.23)
Mean conservation priority score	144.93 (9.14)	143.04 (9.14)	150.98 (8.00)	139.86 (8.00)

the QVM treatment was anticipated to create a shift in the breeding bird community from one dominated by forest interior and edge species to one dominated by early successional, pine-grassland, and shrub-successional species. During this shift in bird communities, these three parameters will decrease slightly until the desired suite of avian species responds to the vegetative shift back to an early successional vegetative community. Although by year 2 no significant increases in any of the three avian community indices were seen, a significant increase in the relative abundance of several target species was observed (table 4).

## CONCLUSIONS

The results presented here give 2-year post-treatment responses of timber growth and avian communities to the QVM treatment, and, although still early for this type of study, are promising. A similar study evaluating growth responses from mid-rotation competition control (Pienaar and others 1983) has demonstrated that these practices can be successful in producing significant gains in timber growth. Usually these gains begin appearing 3 to 4 years post-treatment or later and increase as time-since-treatment increases. Given more time to monitor timber growth responses to the QVM treatment, we expect to see similar results. Seeing significant increases in the relative abundance of several target avian species is encouraging. A similar study (Woodall 2005) reports that by year 4, the total abundance, species richness, and total conservation value were significantly higher in QVM-treated plots than in untreated (control) plots. Ongoing monitoring of bird communities on these sites will substantiate whether these patterns observed in commercial pine plantations also exist on CRP plantations.

**Table 4—Significant increases ( $\alpha = 0.05$ ) in the relative abundance of the following avian species was observed on treated plots**

Common name	Scientific name
Common yellowthroat	<i>Geothlypis trichas</i>
Downy woodpecker	<i>Picoides pubescens</i>
Eastern wood-pewee	<i>Contopus virens</i>
Indigo bunting	<i>Passerina cyanea</i>
Pine warbler	<i>Dendroica pinus</i>
Summer tanager	<i>Piranga rubra</i>

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## LITERATURE CITED

- Allen, A.W.; Bernal, Y.K.; Moulton, R.J. 1996. Pine plantations and wildlife in the Southeastern United States: an assessment of impacts and opportunities. Information and Technical Report 3. Washington, DC: U.S. Department of Interior. 32 p.
- Bacon, C.G.; Zedaker, S.M. 1987. Third-year growth response of loblolly pine to eight levels of competition control. Southern Journal of Applied Forestry. 11(2): 91-95.
- Burger, L.W. 2000. Wildlife responses to the conservation reserve program in the Southeast. In: Hohman, W.L., ed. A comprehensive review of farm bill contributions to wildlife conservation 1995-2000. Tech. Rep. [Place of publication unknown]: U.S. Department of Agriculture/Natural Resource Conservation Service/Wildlife Habitat Management Institute: 55-74.
- Chen, M.; Hodgkins, E.J.; Watson, W.J. 1975. Prescribed burning for improving pine production and wildlife habitat in the hilly Coastal Plain of Alabama. Bulletin 473. Auburn, AL: Auburn University, Alabama Agriculture Experiment Station. 19 p.
- Creighton, J.L.; Zutter, B.R.; Glover, G.R.; Gjerstad, D.H. 1987. Planted pine growth and survival responses to herbaceous vegetation control, treatment duration, and herbicide application technique. Southern Journal of Applied Forestry. 11(4): 223-227.
- Dills, G.G. 1970. Effects of prescribed burning on deer browse. Journal of Wildlife Management. 34: 540-545.
- Edwards, S.; Demarais, S.; Watkins, B.; Strickland, B.K. 2004. White-tailed deer forage production in managed and unmanaged pine stands and summer food plots in Mississippi. Wildlife Society Bulletin. 32(3): 739-745.
- Fortson, J.C.; Shiver, B.D.; Shackelford, L. 1996. Removal of competing vegetation from established loblolly pine plantations increases growth on Piedmont and upper Coastal Plain sites. Southern Journal of Applied Forestry. 20(4): 188-193.
- Hood, S.A. 2001. Response of small mammals and herpetile communities to prescribed burning and herbicide application in thinned, mid-rotation loblolly pine plantations in Mississippi. Mississippi State, MS: Mississippi State University. 87 p. M.S. thesis.
- Hurst, G.A. 1989. Forestry chemicals and wildlife habitat. Forest Farmer. 48(4): 10-11.
- Jones, J.; Burger, W.; Watkins, B. 2003. Bird and plant communities in a loblolly pine forest managed with prescribed fire and herbicide. Forest Landowner. May/June: 29-31.
- Knowe, S.A.; Nelson, L.R.; Gjerstad, D.H. [and others]. 1985. Four-year growth and development of planted loblolly pine on sites with competition control. Southern Journal of Applied Forestry. 9(1): 11-15.
- Merrifield, R.B.; Foil, R.R. 1967. Volume equations for southern pine pulpwood. Hill Farm Facts, Forestry Publication No. 7. Homer, LA: North Louisiana Hill Farm Experiment Station. 4 p.
- Nuttle, T.; Leidolf, A.; Burger, L.W. 2003. Assessing the conservation value of bird communities with Partners in Flight-based ranks. Auk. 120: 541-549.

- Oppenheimer, M.J.; Shiver, B.D.; Rheney, J.W. 1989. Ten-year growth response of mid-rotation slash pine plantations to control of competing vegetation. *Canadian Journal of Forest Research*. 19: 329-334.
- Pienaar, L.V.; Rheney, J.W.; Shiver, B.D. 1983. Response to control of competing vegetation in site-prepared slash pine plantations. *Southern Journal of Applied Forestry*. 7(1): 38-45.
- Quicke, H. 2002. Fourth-year response following operational scale mid-rotation release with Arsenal herbicide applicators concentrate: The 1994 Waverly Hall Study. Research Report 99-02. [Place of publication unknown]: American Cyanamid Forestry. 4 p.
- Robbins, C.S.; Bystrak, D.; Geissler, P.H. 1986. The breeding bird survey: its first fifteen years, 1965-1979. Resource Pub. 157. Washington, DC: U.S. Department of Interior, Fish and Wildlife Service. 205 p.
- Schultz, R.P. 1997. Loblolly pine: the ecology and culture of loblolly pine (*Pinus taeda* L.). Agric. Handb. 713. Washington, DC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 493 p.
- Shiver, B.D. 1994. Response and economics of mid-rotation competition control in southern pine plantations. In: Weed Science Education: the cost of ignorance". The 47th annual meeting of the southern weed science society. Proceedings of the Southern Weed Science Society: 85-92.
- Thompson, J.L.R. 2002. Response of plant and avian communities to prescribed burning and selective herbicide treatments in thinned, mid-rotation loblolly pine plantations in Mississippi. Mississippi State, MS: Mississippi State University. 162 p. M.S. thesis.
- USDA. 2003a. U.S. Department of Agriculture, Natural Resources Conservation Service, National Bulletin 300-3-3. [http://policy.nrcs.usda.gov/scripts/lpsiis.dll/NB/NB\\_300\\_3\\_3.htm](http://policy.nrcs.usda.gov/scripts/lpsiis.dll/NB/NB_300_3_3.htm) [Date accessed: unknown].
- USDA. 2003b. Highlights of expected conservation reserve program (CRP) changes for 2003 and beyond. U.S. Department of Agriculture, Natural Resources Conservation Service, National Bulletin 300-3-4. [http://policy.nrcs.usda.gov/scripts/lpsiis.dll/NB/NB\\_300\\_3\\_4.htm](http://policy.nrcs.usda.gov/scripts/lpsiis.dll/NB/NB_300_3_4.htm) [Date accessed: unknown].
- USDA. 2005. Conservation reserve program, monthly summary, February 2005. U.S. Department of Agriculture, Farm Services Agency. <http://www.fsa.usda.gov/dafp/cepd/stats/Feb2005.pdf> [Date accessed: March 31, 2005].
- Woodall, L.T. 2005. Response of plant and avian communities to prescribed burning and selective herbicide treatments in thinned, mid-rotation loblolly pine plantations in Mississippi. Mississippi State, MS: Mississippi State University. 117 p. M.S. thesis.



## **Pine Silviculture**

*Moderator:*

**BRUCE JEWELL**  
USDA Forest Service  
Southern Research Station



# STACKING THE LOG DECK, OR SOME FALLACIES ABOUT NATURAL PINE MANAGEMENT

Don C. Bragg, James M. Guldin, and Michael G. Shelton<sup>1</sup>

**Abstract**—The increasing use of intensive plantation management in the South has led to inferences that natural pine stands are unacceptably inferior in terms of fiber production, rotation length, wood quality, and regeneration. In this paper, we have compiled information from studies of different silvicultural practices in southern pine stands of natural origin to provide a more meaningful comparison with plantations. Research has shown that aggressive precommercial and commercial thinning regimes in stands of natural origin and the careful retention of high-quality residual stems dramatically closes the productivity gap. In addition, natural-origin pine stands often provide other products and compositional, structural, and esthetic values that exceed those of plantations. Although plantations have become an increasingly important element of silviculture, most southern pine forests will remain in stands of natural origin and must be managed appropriately to help ensure future timber supplies and environmental integrity.

## INTRODUCTION

Since the 1960s, plantation management has become the standard practice for most industrial timberland owners in the Southern United States. This is especially true for loblolly (*Pinus taeda* L.), slash (*P. elliottii* Englem.), and other southern pines. Recently, there has been considerable effort to maximize the productivity of pine plantations (Rogers and Munn 2003, Rousseau and others 2005, Siry 2002). Genetic improvement, site preparation, competition control, and manipulation of stand density are some of the principal treatments for greater growth and yield. Careful implementation of these techniques has produced some spectacular results (e.g., Allen and others 2005, Borders and Bailey 2001, Miller and others 2003). However, this effort comes at a high price: Borders and Bailey (2001) placed the cost of their most productive experimental treatment at \$600 per acre. In addition, intensive plantation management has significant environmental and social consequences that are not traditionally incorporated in the economic evaluation of this practice.

From an industrial perspective, pine plantations have distinct advantages over stands of natural origin (Allen and others 2005, Siry 2002). Well-managed plantations can produce more fiber in less time than naturally seeded pine stands and are often more easily treated to control density and non-pine competition. However, few outside of forest industry or investment management organizations can invest \$200 to \$400 (or more) per acre for plantation establishment at the start of a rotation, especially when pulpwood and fiber markets are limited.

Naturally regenerated stands offer a viable alternative to many landowners. Unfortunately, positive descriptions of southern pine stands of natural origin are rare in the silvicultural literature, and several recent papers have portrayed these forests unfavorably. To counter this impression, we have compiled research on the potential of well-managed natural pine stands to provide a basis for more realistic comparisons with pine plantations. In addition, we suggest a

different philosophy for considering whether to manage forest stands using planted stock or natural regeneration.

## METHODS

We critically reviewed statements made about aspects of naturally regenerated pine stands. In particular, we focused on three papers (Allen and others 2005, Stanturf and others 2003, Yin and Sedjo 2001) that made claims for the economic advantages of plantations over stands of natural origin. These papers suggest that natural pine stands have unacceptably low productivity. Additionally, we discuss published reports of South-wide studies that deal with factors such as rotation length, wood quality, and regeneration consistency of natural pine stands on sites of varying quality.

## RESULTS AND DISCUSSION

### Low Fiber Production

Yin and Sedjo (2001) compared the economic viability of silvicultural options in the Georgia Piedmont. As their control, they chose natural-origin stands of mixed pine and hardwoods originally described in Shiver and Brister (1996) and Martin and Brister (1999). Yin and Sedjo (2001) compared these stands to pine plantations on cutover and old field sites. By age 35, natural-origin stands were decidedly less productive than the plantations. Yin and Sedjo (2001) reported average pine diameters of 8.7 inches for the natural stands and 9.4 to 10.2 inches for the plantations. In addition, natural-origin stands yielded only 30 to 67 percent of the sawtimber and pulpwood produced by plantations (table 3 in Yin and Sedjo). However, there were several critical flaws in these comparisons.

First, only the pine component of the natural stands was included in the growth-and-yield data. Thus, yield of the natural pine-hardwood stand was based on only 300 trees per acre (no hardwood data were reported), whereas the planted stands averaged slightly > 500 stems per acre. It would have been more appropriate to compare the productivity of the plantations with that of better stocked natural pine

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<sup>1</sup> Research Forester, USDA Forest Service, Southern Research Station, Monticello, AR 71656; Research Ecologist, USDA Forest Service, Southern Research Station, Hot Springs, AR 71902; and Research Forester, USDA Forest Service, Southern Research Station, Monticello, AR 71656, respectively.

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stands thinned to 500 trees per acre (with competition control) at a very young age, since the plantations had been planted to approximately 600 trees per acre and received periodic postestablishment herbicide applications. Furthermore, Martin and Brister (1999, p. 180) acknowledged that shortleaf pine (*P. echinata* Mill.) was “treated as loblolly pine” in their study. This was not a trivial assumption, as shortleaf constituted an average of 5.4 percent (range: 0 to 37.6 percent) of the pines in these natural stands. Since shortleaf pine has long been recognized as slower growing and less productive than loblolly pine under most conditions (Mattoon 1915, Walker and Wiant 1966), its incorporation will also negatively bias the results of Yin and Sedjo (2001).

Second, the natural-origin stands used by Yin and Sedjo (2001) had a large component of hardwoods, which further diminished the productivity of the pines. Martin and Brister (1999) reported that 71 percent of their natural-origin plots had at least 10 percent of their basal area in hardwoods, and that hardwood basal area exceeded 40 percent or more of the total in some plots. Yin and Sedjo (2001) did not report on the average hardwood stocking in these natural pine stands when they analyzed them, but presumably a significant amount remained. Both Shiver and Brister (1996) and Martin and Brister (1999) predicted sharp declines in pine sawtimber volume as hardwood basal area increased (see also Miller and others 2003). Martin and Brister (1999) forecast that a stand with minimal hardwood basal area at age 25 (0.01 percent of the total) would produce approximately 3,500 cubic feet of pine sawtimber at age 35, but that a stand with 20 percent of its basal area in hardwoods at age 25 would yield only 2,300 cubic feet of pine sawtimber 10 years later. Given that Yin and Sedjo assumed for their economic analysis that pine sawtimber was worth \$94 per cord, and using their conversion (95 cubic feet = 1 cord), this particular scenario suggests that the hardwoods reduced pine sawtimber production by 12.6 cords, or \$1,184, per acre.

Stanturf and others (2003) provided another unfavorable picture of natural stand productivity. They estimated that a natural-origin southern pine stand initiated in the 1920s produced 1 ton per acre per year, but did not explain how this number was determined. According to Miscellaneous Publication 50 (U.S. Department of Agriculture Forest Service 1929), a fully stocked natural loblolly pine stand on even the poorest site listed ( $SI_{50} = 60$  feet) is capable of producing between 63 and 76 cubic feet (peeled) per acre per year over the first 6 decades of the stand. Assuming 1 cubic foot of loblolly pine weighs 53 pounds when green (Panshin and de Zeeuw 1970), this implies an annual production of between 1.5 and 2.0 tons per acre. On a better site ( $SI_{50} = 90$ ), the annual production of fiber for a 35-year-old stand increases to 3.5 tons per acre. Other sources report even higher volume production from natural-origin stands. In a thinning study of a naturally regenerated loblolly pine-dominated stand arising after the clearing of the virgin forest, Burton (1980) reported periodic annual increments of 143 to 165 cubic feet per acre for these stands at age 45, or 3.8 to 4.4 tons per acre. Mean annual increments of young, thinned pine stands on a good site in southern Arkansas ranged from 139 to 153 cubic feet (3.7 to 4.1 tons) per acre (Cain and Shelton 2003). Even though these values still represent only about half of the 8 tons per acre per year claimed for the “fifth forest” of Stanturf and others (2003), they are much higher

than the estimate of 1 ton per acre per year for natural stands.

Allen and others (2005) emphasized the productive capacity of intensively managed young (8- to 26-year-old) southern pine plantations, assigning them a potential of 12 to 15 tons per acre per year, compared to 1.8 to 2.8 tons per acre per year for natural stands of similar age. Once again, this understates the currently known productivity of well-managed stands of natural origin.

In terms of sheer merchantable volume, there is little doubt that naturally regenerated stands are less productive than plantations. If a forest landowner is determined to quickly maximize fiber yield, and capital is available to cover establishment costs in the first decade, plantations represent a good investment decision. However, if landowners have limited resources or no desire to invest in expensive stand re-establishment based on an intensive plantation model, many productive low-cost natural silvicultural alternatives are available to them (e.g., Baker and others 1996, Cain and Shelton 2001).

### Rotation Length

Shorter rotations are one of the primary benefits of plantation management. In part, this is an argument of utilization, since comparing the rotation length of pulpwood or chips vs. large sawtimber is an unreasonable contrast. Assuming the same product goals, plantations generally have an advantage over stands of natural origin because of the degree of stocking control permitted by planting. In other words, it is much easier for an individual tree to quickly reach sawtimber size if stand density is 600 trees per acre at establishment, rather than allowing 10,000 or more stems to self-thin.

Avoiding this extended period of intense competition in natural stands would allow the young crop trees to more rapidly reach merchantable size. Cain (1996) and Cain and Shelton (2003) provided an example of the value of well-timed early thinnings of natural-origin pine stands. In this study on a good site in southern Arkansas, different thinning and competition control techniques were applied to regulate the density of naturally regenerated loblolly and shortleaf pine. Stands were precommercially thinned when 6 years old by mowing swaths to reduce initial densities, and some stands also received later commercial thinnings and prescribed burns. By the time they reached 20 years of age, the most intensively treated stands (precommercial thinning + commercial thinning + prescribed burning) produced pines that averaged 8.9 inches diameter at breast height (d.b.h.), compared to 7.4 inches for the unmanaged control. Most of these crop trees had reached minimum sawtimber size (9.6 inches d.b.h.) by age 25 (Cain and Shelton 2003) and would probably average at least 14 inches d.b.h. by age 35. This growth performance is only somewhat lower than that for well-managed plantations from the area (e.g., Wiley and Zeide 1992).

### Wood Quality Issues

It is unlikely that future southern pine wood quality will ever approach that of the virgin forest, regardless of how much tree improvement can be done. Logs cut from old-growth are typically slow-grown, low in taper, and knot-free for many decades, whereas most contemporary well-managed forests

are maintained to maximize production and are cut at relatively young ages (Davis 1931, Guldin and Fitzpatrick 1991). These factors combine to produce small-diameter logs with a high proportion of juvenile wood and abundant knots, both of which result in wood with less favorable mechanical properties and decreased lumber value (Bendtsen 1978, Patterson and others 2000). Note that low-density stands of any origin can quickly produce knot-free wood with a considerable investment in pruning.

Product-based economic analysis has repeatedly shown that natural, uneven-aged stands of loblolly and shortleaf pine produce higher quality logs. For instance, Groom and others (2002) reported that the percentage of premium veneer was greater in naturally regenerated stands than in plantations. In a comparison of log quality in southern Arkansas, Guldin and Fitzpatrick (1991) reported significantly better log quality from natural uneven-aged stands than from plantations, primarily because logs of a given size in natural stands were older, had grown in denser stands when young, and thus had fewer knots. There is value in log quality related to ring count (witness the supplement in value given to dense grades of lumber by the Southern Pine Inspection Bureau), a property sacrificed when the rapidity of growth drives stand management.

### Regeneration Consistency

Since the time Gifford Pinchot first worked the mountains of North Carolina, foresters have been concerned about regenerating stands by natural methods, since relying on natural pine regeneration holds certain risks. Plantation culture has reduced the uncertainty associated with stand replacement but has by no means eliminated it. The challenges associated with natural propagation can be minimized by understanding the factors (and their interactions) affecting regeneration processes and applying appropriate silvicultural practices. For example, seed production and seedbed conditions affect the initial establishment of regeneration, while competition from retained trees and understory vegetation impact subsequent development by influencing the availability of light, water, and nutrients.

Much has been published about the art and science of regenerating natural pine stands (e.g., see Shelton and Cain 2000). Indications are that seed production—the factor under the least amount of silvicultural control—is adequate for successful natural regeneration within most of the core ranges of the southern pines, especially for loblolly-shortleaf pine stands in the west gulf region. The other major factors affecting natural regeneration—seedbed condition, light regime, and competing non-pine vegetation—are more responsive to manipulation. In addition, procedures exist to forecast the adequacy of upcoming seed crops so that an adequate seedfall can be timed to coincide with a receptive seedbed and low levels of competing vegetation (Shelton and Wittwer 2004). Regrettably, there is little Southwide quantitative information about the success of natural pine regeneration when the proper silvicultural procedures have been applied. However, one basic tenet is apparent: Successful natural pine regeneration requires more skill and patience than plantation culture.

The use of improved planting stock provides a degree of control over heritable tree properties. Natural populations of

pine can have a wide range of genetic characteristics, some of which are favorable and others that are not. For instance, loblolly pine attributes such as specific gravity, the transition between juvenile and mature wood production, and fusiform resistance are at least partially a function of genetics and thus may be “improved” upon (Choong and others 1986, Loo and others 1984, Skoller and others 1983). However, the advantage of controlling genetics to improve pine growth or disease resistance may come at the expense of lower genetic diversity and increased vulnerability to other damaging agents (Schultz 1997).

### Other Benefits of Natural Stands

Because stands of natural origin require less intensive effort (and therefore lower expenditures) to establish and maintain, the economic viability of managing for larger logs is less burdensome to the landowner. It is therefore possible to grow bigger trees at a slower rate, producing higher quality sawtimber and veneer that can bring extra revenues. Premium prices for prime logs can significantly impact which management actions are best for a given stand, although finding buyers willing to reward pine log quality is becoming increasingly difficult (Huang and Kronrad 2004).

Well-managed natural-origin stands have other noncommodity benefits not supplied by the pine plantations that often replace them. Almost by definition, natural-origin pine stands have more genetic diversity, greater overstory richness, and more structural complexity than plantations. Rarely are intensively managed southern pine plantations allowed to grow beyond 35 to 40 years old (some are cut at less than half this age), making them poor habitat substitutes for mature natural-origin forests and the species dependent upon them. As an example, young loblolly pine plantations are inadequate nesting habitat for the red-cockaded woodpecker (RCW) (*Picoides borealis* Vieillot), but at least two active RCW colonies can be found in the Good Forty Demonstration Area of the Crossett Experimental Forest, managed using single-tree selection for the past 70 years. In addition, even-aged natural-origin pine stands are often allowed to reach older ages and larger sizes, which have greater esthetic appeal to many people than young, tightly spaced plantations (Hull and Buhyoff 1986, Rudis and others 1988).

Furthermore, when considering the total land base, debates about which method is best from the rather narrow perspective of growth, yield, and financial return are myopic. For example, are there any circumstances for which a forest industry landowner who devoutly practices plantation silviculture would, or should, consider the use of natural regeneration? Clearly there are, and those opportunities lie in the large percentage of commercial timberlands found in streamside management zones, roadside buffers, or other locations in which special considerations apply (see also Rousseau and others 2005). When examined carefully, one finds that these areas are often the most productive sites in forested landscapes. And yet, the prevailing harvest strategy is often just high-grading. A better tactic would be to practice natural stand management in sensitive portions of an ownership.

One of the best arguments for intensifying plantation management is that the same volume of wood fiber can be produced on fewer acres, thereby allowing larger areas of natural forests to be retained in a less intensively managed state

(Allen and others 2005, Rousseau and others 2005). This is a logical argument for capturing the full potential of a given piece of ground through a well-regulated treatment regime. However, from a broader perspective, this assertion is only true if the regional volume production is fixed and the rest of the land base is allowed to adjust accordingly. In other words, if all landowners (or even just a large portion of them) convert their holdings to intensive plantations, and no areas revert to lesser management, then the preservative benefits of intensive plantations for forests of natural origin will not be realized.

## CONCLUSIONS

Several recent publications have compared growth and yield from unmanaged even-aged loblolly pine stands with that from more intensively managed plantations. Not surprisingly, these natural stands (often regarded as a “control”) produce noticeably less fiber and sawtimber-sized material at an older age than the better regulated plantations, and this negatively affects economic evaluations. Natural stand management rarely applies the entire suite of silvicultural treatments used on intensively managed pine plantations, and therefore fiber yields will never match those from plantations. However, more aggressive precommercial and commercial thinning regimes, the careful retention of high-quality residual stems, fertilization, and other interventions have the potential to noticeably improve natural stand growth and yield performance (Cain 1999, Ruark and others 1991).

Arguments over which silvicultural system (natural vs. plantation) is most appropriate need to be based on legitimate comparisons of well-managed systems and not on neglected natural stands vs. intensively cultured plantations. With the acreage of southern pine plantations predicted to increase 33 to 100 percent over the next few decades and significant decreases expected for natural pine forests (Prestemon and Abt 2002, South and Buckner 2003), decisions to convert from one silvicultural system to another based even partially on productivity must avoid biased evaluations if southern pine-dominated forestlands are to maintain their full range of economic, ecological, and social values.

Both Siry (2002) and Rousseau and others (2005) note that many aspects of intensive management are harder to implement and more expensive on smaller parcels of land, and that increasing landscape fragmentation in the South has contributed to the reduction of management options. The multitudes of small tracts held by many owners with highly variable resource goals provide a myriad of opportunities for natural stand management. Finally, we are concerned that philosophical approaches to forestry that claim the superiority of plantations over natural stands may discourage foresters from considering silvicultural and ownership situations, even in an intensively managed land base, for which natural stand management is better than the current practice.

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## LITERATURE CITED

- Allen, H.L.; Fox, T.R.; Campbell, R.G. 2005. What is ahead for intensive pine plantation silviculture in the South? *Southern Journal of Applied Forestry*. 29: 62-69.
- Baker, J.B.; Cain, M.D.; Guldin, J.M. [and others]. 1996. Uneven-aged silviculture for the loblolly and shortleaf pine forest cover types. Gen. Tech. Rep. SO-118. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 65 p.
- Bendtsen, B.A. 1978. Properties of wood from improved and intensively managed trees. *Forest Products Journal*. 28: 61-72.
- Borders, B.E.; Bailey, R.L. 2001. Loblolly pine—pushing the limits of growth. *Southern Journal of Applied Forestry*. 25: 69-74.
- Burton, J.D. 1980. Growth and yield in managed natural stands of loblolly and shortleaf pine in the West Gulf Coastal Plain. Res. Pap. SO-159. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 23 p.
- Cain, M.D. 1996. Growth expectations from alternative thinning regimes and prescribed burning in naturally regenerated loblolly-shortleaf pine stands through age 20. *Forest Ecology and Management*. 81: 227-241.
- Cain, M.D. 1999. Woody and herbaceous competition effects on stand dynamics and growth of 13-year-old natural, precommercially thinned loblolly and shortleaf pines. *Canadian Journal of Forest Research*. 29: 947-959.
- Cain, M.D.; Shelton, M.G. 2001. Natural loblolly and shortleaf pine productivity through 53 years of management under four reproduction cutting methods. *Southern Journal of Applied Forestry*. 25: 7-16.
- Cain, M.D.; Shelton, M.G. 2003. Effects of alternative thinning regimes and prescribed burning in natural, even-aged loblolly-shortleaf pine stands: 25 year results. *Southern Journal of Applied Forestry*. 27: 18-29.
- Choong, E.T.; Zabala, N.Q.; Thielges, B.A.; Fogg, P.J. 1986. Variations in growth and certain wood properties of loblolly pine seed sources in Louisiana. Research Report 9. Baton Rouge, LA: Louisiana Agricultural Experiment Station. 16 p.
- Davis, E.M. 1931. The defects and some other characteristics of virgin-growth and of second-growth commercial shortleaf pine lumber. *Journal of Forestry*. 29: 54-63.
- Groom, L.; Newbold, R.; Guldin, J.M. 2002. Effects of silviculture on the yield and quality of veneers. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 170-175.
- Guldin, J.M.; Fitzpatrick, M.W. 1991. Comparison of log quality from even-aged and uneven-aged loblolly pine stands in south Arkansas. *Southern Journal of Applied Forestry*. 15: 10-17.
- Huang, C.-H.; Kronrad, G.D. 2004. Economic analysis of pruning and low-density management compared to traditional management of loblolly pine plantations in east Texas. *Southern Journal of Applied Forestry*. 28: 12-20.
- Hull, R.B.; Buhyoff, G.J. 1986. The scenic beauty temporal distribution method: an attempt to make scenic beauty assessments compatible with forest planning efforts. *Forest Science*. 32: 271-286.
- Loo, J.A.; Tauer, C.G.; van Buijtenen, J.P. 1984. Juvenile-mature relationships and heritability estimates of several traits in loblolly pine (*Pinus taeda*). *Canadian Journal of Forest Research*. 14: 822-825.
- Martin, S.W.; Brister, G.H. 1999. A growth and yield model incorporating hardwood competition for natural loblolly pine stands in the Georgia Piedmont. *Southern Journal of Applied Forestry*. 23: 179-185.
- Mattoon, W.R. 1915. Life history of shortleaf pine. Bulletin 244. Washington, DC: U.S. Department of Agriculture, Forest Service. 46 p.
- Miller, J.H.; Zutter, B.R.; Zedaker, S.M. [and others]. 2003. Growth and yield relative to competition for loblolly pine plantations to midrotation—a southeastern United States regional study. *Southern Journal of Applied Forestry*. 27: 237-252.

- Panshin, A.J.; de Zeeuw, C. 1970. Textbook of wood technology. 3<sup>rd</sup> ed. New York: McGraw-Hill Book Company. 705 p.
- Patterson, D.W.; Murphy, P.A.; Shelton, M.G. 2000. Effects of stand and site variables on the lumber value of uneven-aged loblolly pine stands. *Southern Journal of Applied Forestry*. 24: 202-206.
- Prestemon, J.P.; Abt, R.C. 2002. Timber products supply and demand. In: Wear, D.N.; Greis, J.G., eds. Southern forest resource assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 299-325.
- Rogers, W.R.; Munn, I.A. 2003. Forest management intensity: a comparison of timber investment management organizations and industrial landowners in Mississippi. *Southern Journal of Applied Forestry*. 27: 83-91.
- Rousseau, R.; Kaczmarek, D.; Martin, J. 2005. A review of the biological, social, and regulatory constraints to intensive plantation culture. *Southern Journal of Applied Forestry*. 29: 105-109.
- Ruark, G.A.; Saucier, J.R.; Campbell, R.G. 1991. Managing dense, seed-origin loblolly stands to utilize the favorable juvenile wood core for sawlog production: a case study. *Southern Journal of Applied Forestry*. 15: 5-9.
- Rudis, V.A.; Gramann, J.H.; Ruddell, E.J.; Westphal, J.M. 1988. Forest inventory and management-based visual preference models of southern pine stands. *Forest Science*. 34: 846-863.
- Schultz, R.P. 1997. Loblolly pine: the ecology and culture of loblolly pine (*Pinus taeda* L.). Agric. Handb. 713. Washington, DC: U.S. Department of Agriculture, Forest Service. 493 p.
- Shelton, M.G.; Cain, M.D. 2000. Regenerating uneven-aged stands of loblolly and shortleaf pines: the current state of knowledge. *Forest Ecology and Management*. 129: 177-193.
- Shelton, M.G.; Wittwer, R.F. 2004. Forecasting shortleaf pine seed crops in the Ouachita Mountains. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 119-123.
- Shiver, B.D.; Brister, G.H. 1996. Effects of hardwoods and pine density on natural loblolly pine yields and product distribution. *Southern Journal of Applied Forestry*. 20: 99-102.
- Siry, J.P. 2002. Intensive timber management practices. In: Wear, D.N.; Greis, J.G., eds. Southern forest resource assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 327-340.
- Skoller, D.L.; Bridgwater, F.E.; Lambeth, C.C. 1983. Fusiform rust resistance of select loblolly pine seedlots in the laboratory, nursery, and field. *Southern Journal of Applied Forestry*. 7: 198-203.
- South, D.B.; Buckner, E.R. 2003. The decline of southern yellow pine timberland. *Journal of Forestry*. 101(1): 30-35.
- Stanturf, J.A.; Kellison, R.C.; Broerman, F.S.; Jones, S.B. 2003. Productivity of southern pine plantations—where are we and how did we get here? *Journal of Forestry*. 101(3): 26-31.
- U.S. Department of Agriculture Forest Service. 1929. Volume, yield, and stand tables for second-growth southern pines. Misc. Publ. 50. Washington, DC: U.S. Department of Agriculture, Forest Service. 202 p.
- Walker, L.C.; Wiant, H.V. 1966. Silviculture of shortleaf pine. Bulletin 9. Nacogdoches, TX: Stephen F. Austin State College, School of Forestry Bulletin. 60 p.
- Wiley, S.; Zeide, B. 1992. Development of a loblolly pine plantation thinned to different density levels in southern Arkansas. Report 322. Fayetteville, AR: University of Arkansas, Arkansas Agricultural Experiment Station. 44 p.
- Yin, R.; Sedjo, R.A. 2001. Is this the age of intensive management? A study of loblolly pine on Georgia's Piedmont. *Journal of Forestry*. 99(12): 10-17.

# GROWTH FOLLOWING PRUNING OF YOUNG LOBLOLLY PINE TREES: SOME EARLY RESULTS

Ralph L. Amateis and Harold E. Burkhart<sup>1</sup>

**Abstract**—In the spring of 2000, a designed experiment was established to study the effects of pruning on juvenile loblolly pine (*Pinus taeda* L.) tree growth and the subsequent formation of mature wood. Trees were planted at a 3 m x 3 m square spacing in plots of 6 rows with 6 trees per row, with the inner 16 trees constituting the measurement plot. Among the treatments were an unpruned control and a treatment where half the live crown was removed at age 3 (live crown length was reduced by half). Measurements at the time of treatment and 1 year after treatment for each tree included d.b.h., total height, height to base of live crown, crown width within the row, and crown width between the rows. In addition, 1 and 2 years after treatment at ages 4 and 5, upper stem diameters at two positions in the crown were measured. Results are presented that show the initial impact of early pruning on tree growth. Additional measurements gathered over the life of the study, including wood samples, will provide a more complete understanding of the effects of pruning young loblolly pine trees.

## INTRODUCTION

Pruning affects wood quality of trees harvested from loblolly pine plantations (Gibson and others 2002). Pruning future crop trees during stand development removes limbs (both living and dead) that produce knots in wood products merchandized from harvested logs. Removing live branches may also affect the onset of the production of mature wood and thus change the density and strength properties of wood obtained from pruned trees.

Pruning live limbs also affects tree growth and stand development. Valenti and Cao (1986) showed that pruning reduced stem taper resulting in more cylindrical trees with more volume per tree. Burton (1981), as well as others such as Labyak and Schumacher (1954) and Marts (1949), showed that pruning vigorous, live limbs causes a real and significant effect on stem form and subsequent diameter growth, at least for a period of time following pruning.

Past studies on the impact of pruning on tree form, growth, and wood quality characteristics have been conducted in stands without intensive silviculture. Today's plantations are being intensively managed using cultural practices that produce very rapid growth rates, thus allowing pruning treatments to be applied earlier in the rotation when trees are growing most rapidly. It is unclear what impact pruning will have on these intensively managed stands and how they will grow and develop following treatments.

In order to examine the impact of pruning on loblolly pine trees growing in intensively managed plantations, a pruning study was established with three overall objectives: to examine the effect of early pruning on (1) tree growth and stand development, (2) stem form and taper, and, (3) wood specific gravity. Objective (3) will be met at the close of the study when trees can be destructively sampled. In this paper, however, we present some early results that relate to objectives (1) and (2).

## DATA

In the spring of 2000, two study sites in the Piedmont of Virginia (Appomattox and Patrick Counties) were identified

as being suitable for establishment of the study. Both sites were cutover areas, one of which was burned following harvest. At each site, four replications containing five future treatment plots were laid out and planted using genetically improved 1-0 loblolly pine seedlings. The five future treatments included (1) control (unpruned), (2) removing half the live crown at age 3, (3) removing half the live crown at age 6, (4) removing half the live crown at age 9, and (5) removing half the live crown at ages 3, 6, and 9. Square treatment plots (6 rows with 6 trees per row) were established; the interior 16 trees were measurement trees.

Herbicides were applied during the first 2 years after planting to control competing vegetation. Twenty pounds per acre of elemental phosphorous and 200 pounds per acre of elemental nitrogen were applied at age 3 to all plots. Annual measurements from age 2 included d.b.h., height to live crown, total height, and two measures of crown width. The age 3 treatment was applied to one randomly selected plot in each replication. At ages 4 and 5, in addition to d.b.h., height and crown measurements, two measures of upper stem diameter (one-third and two-thirds of the distance from d.b.h. to the top of the tree) were collected. Table 1 presents summary statistics at time of treatment (age 3).

## ANALYSES

A model was specified to examine five tree characteristics prior to treatment (age 3) using analysis of variance techniques:

$$C = b_0 + b_1 \text{Loc}_i + b_2 \text{Rep}_j + b_3 T_k + E_{ijk} \quad (1)$$

where

C = the characteristic of interest (d.b.h., total height, height to live crown, average crown width, or height to d.b.h. ratio),

Loc = the location effect (Appomattox or Patrick County, VA),

Rep = the Replication effect,

T = the treatment effect (pruned or control) and

E = the error term.

<sup>1</sup> Senior Research Associate and University Distinguished Professor, respectively, Virginia Polytechnic Institute and State University, Department of Forestry, Blacksburg, VA 24061.

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**Table 1—Before and after pruning statistics at time of pruning for the age three pruning plot treatment and the control plot**

	Mean	Std. dev.	Minimum	Maximum
----- control -----				
Dbh (cm)	1.85	0.83	0.51	4.06
Height to live crown (m)	0.19	0.08	0.10	0.40
Total height (m)	1.74	0.48	0.30	2.70
Crown width (m) <sup>a</sup>	1.19	0.36	0.10	2.25
----- pruned -----				
Dbh (cm)	1.75	0.70	0.51	3.56
Height to live crown before pruning (m)	0.19	0.08	0.10	0.40
Height to live crown after pruning (m)	1.09	0.08	0.20	1.90
Total height (m)	1.83	0.46	0.30	2.80
Crown width before pruning (m) <sup>a</sup>	1.23	0.34	0.20	2.00
Crown width after pruning (m) <sup>a</sup>	0.73	0.27	0.10	1.35

<sup>a</sup>Average of within and between row crown widths.

Results from applying Model (1) to the pre-treatment data indicated that only the location and, in some cases, the replication effect were significant ( $\alpha=0.05$ ). That is, immediately prior to treatment, there were no significant differences in tree characteristics between the pruned and the control treatment plots.

To examine the effect of the pruning treatments at ages 4 and 5 (1 and 2 years after treatment), Model (1) was again employed. In this case, the characteristics examined were periodic annual growth (PAI) of d.b.h., total height, and average crown width. In addition, two form quotients, defined as the ratio of upper stem diameter (at 0.33 and 0.66 percent of the distance from breast height to tip) to d.b.h., and the height over diameter ratio were examined:

$$FQ_{33} = D_{33}/dbh; FQ_{66} = D_{66}/dbh; HD = H/dbh$$

where  $FQ_{33}$  and  $FQ_{66}$  are the specified form quotients,  $D_{33}$  and  $D_{66}$  are the upper stem diameters just described, and H is total height.

D.b.h., total height, and mean crown width PAI from age 3 to age 4 were significantly different between treatments (table 2). From age 4 to age 5, only d.b.h. and total height PAI were significantly different. Neither of the form quotients was significantly different at year 4, and only  $FQ_{33}$  was significantly different at year 5. HD was not significantly different between treatments at either age 4 or age 5.

## DISCUSSION AND CONCLUSIONS

In the pruned plots, removal of 50 percent of the live crown length appeared to reduce crown mass, or volume, by considerably more than 50 percent (perhaps on the order of 60 to 70 percent), leaving many of the trees with only 1 whorl of live branches with which to begin the next growing season. This severe reduction in photosynthetic capacity resulted in a significant reduction of d.b.h. and total height PAI for the 2 years following treatment. The difference between the control and pruned treatments was, however, less significant the second year after treatment than it was the first year after treatment. This suggests that the pruned trees are recovering rapidly from the effects of the treatment.

**Table 2—Periodic annual increment (standard deviation in parentheses) for d.b.h., total height, and mean crown width; mean form quotient at one-third ( $FQ_{33}$ ) and two-thirds ( $FQ_{66}$ ) distance from breast height to tip and the height over d.b.h. ratio for the control and pruned plot (P value for F-test between treatment means)**

	Control	Pruned	P value
----- d.b.h. (cm) -----			
Year 4	2.80(0.59)	2.29(0.68)	< 0.0001
Year 5	2.52(0.64)	2.37(0.57)	0.0482
----- total height (m) -----			
Year 4	1.22(0.38)	1.04(0.41)	< 0.0001
Year 5	1.22(0.28)	1.13(0.31)	0.0070
----- mean crown width (m) -----			
Year 4	1.53(0.39)	1.27(0.37)	< 0.0001
Year 5	2.11(0.47)	1.87(0.39)	0.6007
----- $FQ_{33}$ -----			
Year 4	0.68(0.13)	0.69(0.11)	0.6944
Year 5	0.65(0.09)	0.68(0.11)	0.0150
----- $FQ_{66}$ -----			
Year 4	0.42(0.13)	0.40(0.10)	0.1925
Year 5	0.36(0.07)	0.36(0.09)	0.8485
----- height over d.b.h. ratio -----			
Year 4	0.31(0.09)	0.32(0.08)	0.5921
Year 5	0.27(0.07)	0.27(0.05)	0.9735

The difference in mean crown width PAI was also highly significant for the first growing season after treatment. During the second growing season, however, there was no difference in mean crown width expansion between the pruned and control treatments. This suggests that young trees initially respond to pruning by rebuilding crown before allocating resources to height and diameter growth.

The effect of the pruning treatment on stem form and taper appears to be negligible for these young trees. Both measures of stem form were taken well within the live crown at these early ages, and while  $FQ_{33}$  was significantly different at age 5 (2 years following treatment), no discernable trends in stem form could be discerned. No significant difference between treatments for the height to d.b.h. ratio supported this finding.

#### **ACKNOWLEDGMENTS**

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#### **LITERATURE CITED**

- Burton, J.D. 1981. Some short-term effects of thinning and pruning in young loblolly pine plantations. In: Barnett, J.P., ed. Proceedings of the first biennial southern silvicultural research conference. Gen. Tech. Rep. SO-34. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 111-114.
- Gibson, M.D.; Clason, T.R.; Hill, G.L.; Grozdits, G.A. 2002. Influence of thinning and pruning on southern pine veneer quality. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 165-169.
- Labyak, L.F.; Schumacher, F.X. 1954. The contribution of its branches to the main-stem growth of loblolly pine. *Journal of Forestry*. 52: 333-337.
- Marts, R.O. 1949. Effect of crown reduction on taper and density in longleaf pine. *Southern Lumberman*. 197: 206-209.
- Valenti, M.A.; Cao, Q.V. 1986. A comparison of the effects of one-step and two-step pruning on loblolly pine stem form. *Southern Journal of Applied Forestry*. 10: 251-253.

# THE EFFECTS OF SOWER AND BED DENSITY ON BAREROOT LOBLOLLY PINE SEEDLING MORPHOLOGY AND EARLY HEIGHT GROWTH

Hans M. Williams and Tim Stewart<sup>1</sup>

**Abstract**—Precision sowing is commonly used at forest tree nurseries in order to improve the growing space uniformity of seedlings in the beds. Temple-Inland Forest Products Corporation recently purchased a vacuum sower and requested a study be conducted comparing their new sower with a drill sower on the morphological characteristics of loblolly pine (*Pinus taeda* L.) at lifting. The study was conducted in 2000 and repeated in 2001. The seed were sown using the two sower types to achieve four densities of 161, 215, 269, and 323 seedlings/m<sup>2</sup>. Two half-sibling families were tested in 2000, and one half-sibling family was tested in 2001. For both studies, the experimental design was a randomized complete block with four replications. Cultural practices used to grow the seedlings were typical for the nursery. The seedlings were hand-lifted mid-winter for measurements of stem height, root-collar diameter, and oven-dry biomass. For the 2001 study, seedlings were hand-planted 1 week after lifting in a clearcut near Etoile, TX. The mean morphology of the seedlings was similar when comparing the two sowers. When averaged for all densities, more seedlings with small root-collar diameters ( $\leq 3$  mm) were sampled in the 2000 study from the drill sower plots than from the vacuum sower plots. For the 2001 study, slightly more seedlings with small diameters were sampled from the vacuum sower plots. At typical operational densities of 215 and 269 seedlings/m<sup>2</sup>, the use of the vacuum sower resulted in more seedlings at lifting, fewer small-diameter seedlings, and more large-diameter seedlings ( $\geq 5$  mm). As seedbed density was reduced, mean seedling root-collar diameter and oven-dry biomass increased. Seedlings grown in the nursery at 161 seedlings/m<sup>2</sup> were taller after the first and second growing season following planting.

## INTRODUCTION

Numerous studies have been conducted investigating the effects of bareroot southern pine seedling grade on field performance. South (2000) provides a review of many of these studies. In most cases, the authors report planting larger-diameter seedlings can result in better height and diameter growth. Precision sowing is just one nursery culture practice that should increase the proportion of seedlings at lifting with larger root-collar diameters. Precision sowing results in uniform seed placement giving each developing seedling an equal amount of growing space. Drill sowers cannot achieve the same level of uniform seed placement as precision sowers (Boyer and others 1985, May 1985). However, complaints regarding the use of precision sowers include a slower operating speed and more time spent on maintenance when compared to drill sowers. Temple-Inland Forest Products Corporation purchased a vacuum precision sower in 2000. This provided an opportunity to compare the vacuum sower with a drill sower at different seedling densities on morphology at lifting, field survival, and growth of loblolly pine (*Pinus taeda* L.).

## METHODS

For the 2000 study, two one-half sibling families of loblolly pine (Family LSG-008 and Family S4PT6-98M) were sown on May 5, 2000, in seed beds prepared at the Temple-Inland Clyde-Thompson Nursery, Jasper, TX. The seeds were sown using a drill sower or a vacuum sower to achieve four seedling densities of 161, 215, 269, and 323/m<sup>2</sup>. The study was conducted as a randomized complete block, 2 x 2 x 4 factorial experiment with four replications. Four beds in the middle of a section were used in the study with each bed being a replication of all family, sower and density combinations. The beds were in their second year of seedling production. The beds were covered in bark mulch following sowing. Cultural practices such as mineral nutrition, irrigation, weed control,

and undercutting applied to the seedlings were typical for the nursery during the 2000 growing season. In February, 2001, about 4 lineal-bed-feet of seedlings were hand-lifted from each plot. The interior six drills of seedlings were sampled. The two outside drills were not sampled. The seedling roots were dipped in water, and then the seedlings were placed in kraft storage bags, sealed, and transported to a cold storage room at the Arthur Temple College of Forestry and Agriculture Building, Stephen F. Austin State University (SFASU). Fifty seedlings were randomly sampled from each bag for morphology measurements. These measurements included height, root-collar diameter, number of first-order lateral roots, and root and shoot oven-dry weights. Statistical analysis was conducted and differences in morphology between families, sowers, and densities are discussed at the  $\alpha = 0.05$  probability level.

The 2001 study was conducted in a manner similar to the 2000 study. The factors tested were the same sower types and densities. Only one loblolly pine family was tested (LSG-008-98M). The seeds were sown on April 11, 2001. The study was conducted as a randomized complete block, 2 x 4 factorial experiment with four replications. Four beds in the middle of a section were used with each bed serving as a replication of all sower and seedling density combinations. The beds were in their first year of seedling production following a cover crop. Nursery cultural practices applied to the seedlings were typical for the 2001 growing season. Seedlings were hand-lifted from each plot in early January, 2002, roots dipped in water, seedlings placed in kraft bags, transported to SFASU, and placed into cold storage. Within a week following lifting, 20 seedlings were randomly selected from each kraft bag, placed in a plastic bag, and transported to a field site for planting. Fifty seedlings from each kraft bag were randomly sampled for morphology measurements.

<sup>1</sup> Professor, Stephen F. Austin State University, Arthur Temple College of Forestry and Agriculture, Nacogdoches, TX 75962; and Nursery Manager, Temple-Inland Forest Products Corporation, Clyde-Thompson Nursery, Jasper, TX 75951, respectively.

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The field planting for the 2001 study was conducted at a location near Etoile, Nacogdoches County, TX. The soil at the site is a Woodtell very fine sandy loam (fine, montmorillonitic, thermic Vertic Hapludalfs). Site preparation following harvest included chopping and burning. A mixture of imazapyr, triclopyr, and glyphosate was applied in fall, 2001. The seedlings were hand-planted using planting bars in January, 2002. Twenty-seedling row plots were established with each row in a replication representing a sower and density combination. An herbaceous weed control application of hexazinone and sulfo-meturon methyl was applied in spring, 2002. Height measurements were taken at the end of each growing season for 3 years after planting. Survival exceeded 90 percent for all treatment combinations, so no statistical analysis was performed on survival data. Statistical analysis was conducted and differences between sowers and among densities for seedling morphology and height growth in the field are discussed at the  $\alpha = 0.05$  probability level. Since for both studies the interactions between the sower and density treatments were not statistically significant, the interaction means will not be presented.

## RESULTS AND DISCUSSION

In August, 2000, and July, 2001, seedling counts were conducted in each plot in order to observe if the actual seedling densities were similar to the desired target densities (table 1). In the 2000 study, the vacuum sower plots averaged between 22 and 33 seedlings/m<sup>2</sup> more than desired in the lower density plots but averaged at the target densities in the higher density plots. In the drill sower plots, the target densities were achieved at the lower densities but averaged about 22 seedlings/m<sup>2</sup>

lower than desired in the higher density plots. In the 2001 study, seedling densities in the higher density plots for both sowers averaged about 32 to 54 seedlings /m<sup>2</sup> less than the desired target density. When comparing sowers, the seedling densities in the vacuum sower plots were consistently about 22 seedlings/m<sup>2</sup> higher, regardless of the target density, for each study. A potential advantage of vacuum, or precision, sowing is an improvement in seed efficiency. South (1987) defines the seed efficiency value as the quotient of the number of plantable seedlings produced divided by the number of pure live seed sown. The additional 22 seedlings/m<sup>2</sup> for the vacuum sower would indicate greater seed efficiency when compared to the drill sower but only if the additional seedlings are plantable.

A plantable seedling has a root-collar diameter  $\geq 3$  mm. Seedlings with root collar diameters  $< 3$  mm are considered unacceptable, or cull, and should not be planted. The use of vacuum or precision sowers increased in the 1980s because of the desire for more uniform growing space for each seedling developing in a nursery bed (Barnett 1989). This results in a more uniform seedling crop with a lower number of culls. Boyer and others (1985) reported that a vacuum sower provided more precise seed placement and lower cull percentage when compared to a drill sower. When comparing sowers, the mean morphological characteristics of seedlings sampled in both studies were similar (tables 2 and 3). However, when grouped into 1 mm diameter classes, a greater number of seedlings with small root-collar diameters ( $\leq 3$  mm) were sampled in the plots sown with the drill sower in 2000 (fig. 1). When averaged across all densities, about 11 percent of the seedlings sampled from the drill sower plots had small

**Table 1—Mean loblolly pine seedling density for the sower/seedbed density studies conducted at the Clyde Thompson Nursery, Temple-Inland Forest Products Corporation, Jasper, TX (N = 8)**

Sower	Target density	Actual density	Number of seedlings > 3 mm RCD
----- m <sup>2</sup> -----			
2000 study <sup>a</sup>			
Vacuum	161	194	185
Drill	161	172	158
Vacuum	215	237	217
Drill	215	215	190
Vacuum	269	269	260
Drill	269	247	213
Vacuum	323	323	281
Drill	323	301	270
2001 study <sup>b</sup>			
Vacuum	161	172	168
Drill	161	151	150
Vacuum	215	215	208
Drill	215	194	176
Vacuum	269	237	223
Drill	269	226	208
Vacuum	323	290	241
Drill	323	269	258

<sup>a</sup> 2000 study: families LSG-008-98M and S4PT6-98M.

<sup>b</sup> 2001 study: family LSG-008-98M.

**Table 2—Mean morphology of 1-0 bareroot loblolly pine seedling for the 2000 sower-density study conducted at the Temple-Inland Clyde Thompson Nursery. Fifty seedlings were sampled from each replication, sower, family, and density combination: 3,200 seedlings sampled. Interactions between sower, family, and density were not statistically significant**

Treatment	Height	Diameter	First-order lateral roots	Root oven-dry weight	Shoot oven-dry weight
	<i>cm</i>	<i>mm</i>	<i>no.</i>	----- <i>g</i> -----	
<b>Sower</b>					
Vacuum	23	5.20	10	1.39	3.98
Drill	22	5.02	10	1.38	3.68
(P > F)	0.5273	0.1287	0.1676	0.8188	0.1577
<b>Family</b>					
LSG-008	24	5.02	10	1.31	3.81
S4PT6	21	5.61	10	1.46	3.83
(P > F)	0.0028	0.0296	0.8178	0.0206	0.9423
<b>Density (m<sup>2</sup>)</b>					
161	22	5.48	11	1.72	4.28
215	23	5.18	10	1.37	4.01
269	22	4.97	10	1.30	3.50
323	24	4.82	9	1.14	3.50
(P > F)	0.5196	0.0010	0.0026	<0.0001	0.0298

**Table 3—Mean morphology of 1-0 bareroot loblolly pine seedlings from the 2001 sower/density study conducted at the Temple-Inland Clyde Thompson Nursery. Fifty seedlings were sampled from each replication, sower, and density combination: 1,600 seedlings sampled. Temple Family = LSG-008. Interactions between sower and density were not statistically significant**

Treatment	Height	Diameter	First-order lateral roots	Root oven-dry weight	Stem oven-dry weight	Needle oven-dry weight
	<i>cm</i>	<i>mm</i>	<i>no.</i>	----- <i>g</i> -----		
<b>Sower</b>						
Vacuum	29.3	4.51	10.0	0.76	1.47	2.12
Drill	29.9	4.59	10.6	0.83	1.58	2.25
(P>F)	0.1483	0.2862	0.1183	0.1832	0.0251	0.1548
<b>Density (m<sup>2</sup>)</b>						
161	29.8	4.92	11.6	0.96	1.77	2.62
215	29.4	4.55	10.2	0.76	1.50	2.15
269	29.8	4.50	9.6	0.82	1.51	2.14
323	29.4	4.24	9.8	0.64	1.33	1.83
(P > F)	0.5665	< 0.0001	0.1642	0.0003	0.0001	< 0.0001

diameters compared to 7 percent for the vacuum sower plots. However, the overall number of seedlings with small diameters in the vacuum sower plots was slightly higher for the 2001 study. The drill sower plots had more seedlings with small diameters in the 2000 study at densities of 161 (8 versus 5 percent), 215 (12 versus 8 percent), and 269 (14 versus 3 percent) seedlings/m<sup>2</sup>, and a lower number of seedlings at 323 seedlings/m<sup>2</sup> (10 versus 13 percent). In the 2001 study, the number of seedlings with small diameters was lower for the vacuum sower at 215 (3 versus 10 percent) and 269

(6 versus 8 percent) seedlings/m<sup>2</sup>, but higher at densities of 161 (2 versus 0.5 percent) and 323 (17 versus 4 percent) seedlings/m<sup>2</sup>. The much greater number of seedlings sampled with small root-collar diameters at the highest density may explain the overall higher number of seedlings with small diameters sampled from the vacuum sower plots in the 2001 study. Because more seedlings/m<sup>2</sup> were counted in the vacuum sower plots at each density, the actual number of seedlings/m<sup>2</sup> with root-collar diameters > 3 mm was higher for the vacuum sower plots, except for the highest density of the 2001 study

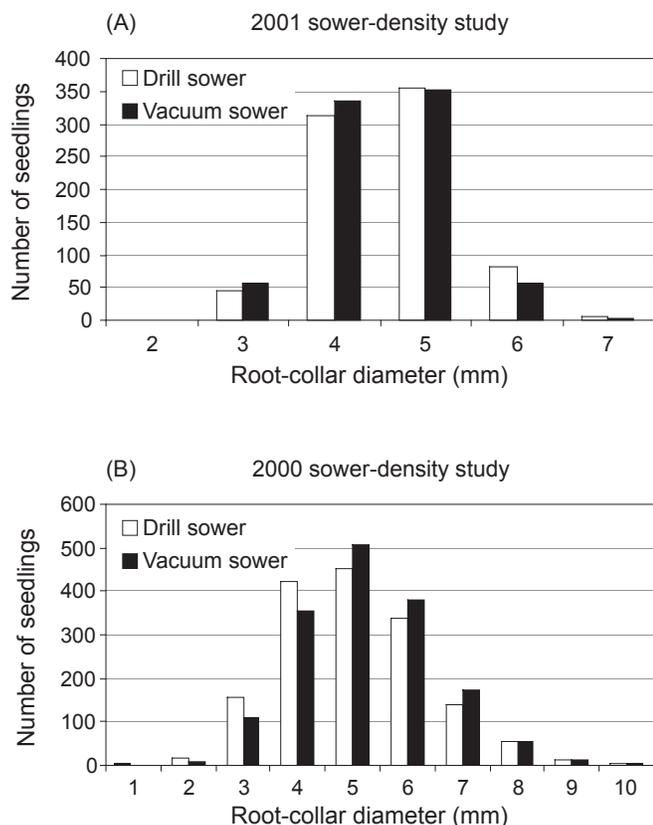


Figure 1—Averaged across all seedling densities, the loblolly pine seedling distribution by root-collar diameter for the 2001 (A) and 2000 (B) sower density studies conducted at the Temple-Inland Clyde-Thompson Nursery, Jasper, TX.

(table 1). While seedlings with root-collar diameters of 3 mm are plantable, cultural practices that can increase the number of seedlings with larger root-collar diameters would be desirable. After reviewing several studies, South (2000) reported that for each 1 mm increase in seedling root-collar diameter, the average gain in volume after 15 to 20 years may be 13 m<sup>3</sup>/ha. Plot volumes after 4 years were greater when loblolly pine seedlings 8.5 mm in root-collar diameter were planted compared to plots planted with seedling having a diameter of 5 mm (South and others 2001).

Morphologically improved bareroot loblolly pine seedlings are defined by South (2000) as being grown at low densities (< 215 seedlings/m<sup>2</sup>) with at least half the seedling population having a root-collar diameter > 5 mm and none < 3 mm. When averaged across all the densities, more than half the seedlings sampled in each study were ≥ 5 mm in diameter (large-diameter seedlings). Seventy-one percent of seedlings sampled for the 2000 study from the vacuum sower plots were ≥ 5 mm at the root collar compared to 62 percent of the seedlings sampled from the drill sower plots. A greater number of large-diameter seedlings were observed from the vacuum sower plots at 161, 215, and 269 seedlings/m<sup>2</sup>. At the highest density, the amount of large-diameter seedlings observed was equal. Overall, slightly fewer seedlings with ≥ 5 mm diameters were found in the vacuum sower plots for the 2001 study. At 215 and 269 seedlings/m<sup>2</sup>, a greater number of larger-diameter seedlings were observed from the vacuum sower plots. However, more large-diameter seedlings were observed from the drill sower plots at the lowest and highest density.

As seedling densities were reduced in the beds, the mean root-collar diameter and oven-dry weights of the lifted seedlings increased (tables 2 and 3). For the 2001 study, seedlings grown in the nursery at 161 seedlings/m<sup>2</sup> were significantly taller 2 years after planting than the seedlings grown at the higher densities (table 4). Rowan (1986) reported that loblolly pine seedlings grown at 108 or 161 seedlings/m<sup>2</sup> were significantly taller up to 5 years after planting when compared to seedlings grown in the nursery at higher densities.

**Table 4—Mean field height of loblolly pine from the 2001 sower/density study conducted at the Temple-Inland Clyde Thompson Nursery. Twenty 1-0 bareroot seedlings were planted in rows for each replication, sower, and density combination: 640 seedlings planted, Temple Family = LSG-008. Seedlings planted near Etoile, TX. Interactions between sower and density were not statistically significant**

Treatment	Initial	First-year	Second-year	Third-year
----- height in cm -----				
Sower				
Vacuum	17	45	113	241
Drill	18	46	117	244
(P>F)	0.5669	0.7670	0.3501	0.6809
Density (m <sup>2</sup> )				
161	19	50	126	252
215	18	45	111	236
269	17	42	111	244
323	16	45	112	238
(P>F)	0.3404	0.0125	0.0207	0.3157

## **SUMMARY**

For densities of 215 and 269 seedlings/m<sup>2</sup>, using the vacuum sower appears to improve seed efficiency when considering the combined results of the production of more seedlings, a fewer number of small-diameter seedlings, and a greater number of large-diameter seedlings. Only at the highest density did the drill sower appear to outperform the vacuum sower with regards to the proportion of small-diameter and large-diameter seedlings. Seedlings grown at 161 seedlings/m<sup>2</sup> in the nursery were statistically taller 2 years after planting and continued to be taller after 3 years.

## **ACKNOWLEDGMENTS**

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## **LITERATURE CITED**

- Barnett, J.P. 1989. Seed cultural practices, and seedling uniformity. *Forestry Supplement*. 62: 95-105.
- Boyer, J.N.; South, D.B.; Muller, C.A.; Vanderveer, H. 1985. A comparison of nursery sowers. *Tree Planters' Notes*. 36(3): 20-24.
- May, J.T. 1985. Chapter 6: sowing and mulching. In: *Southern pine nursery handbook*. Atlanta, GA: United States Department of Agriculture, Forest Service, Southern Region: 6-1 to 6-17.
- South, D.B. 1987. Economic aspects of nursery seed efficiency. *Southern Journal of Applied Forestry*. 11(2): 106-110.
- Rowan, S.J. 1986. Seedbed density affects performance of slash and loblolly pine in Georgia. In: South, D.B., ed. *Proceedings of the international symposium on nursery management practices for the southern pines*. Auburn University, AL: Alabama Agricultural Experiment Station: 126-135.
- South, D.B. 2000. Planting morphologically improved pine seedlings to increase survival and growth. *Forest and Wildlife Research Series* no. 1. Auburn University, AL: Alabama Agricultural Experiment Station. 12 p.
- South, D.B.; Rakestraw, J.L.; Lowerts, G.A. 2001. Early gains from planting large-diameter seedlings and intensive management are additive for loblolly pine. *New Forests*. 22: 97-110.

# LOBLOLLY PINE SEEDLING RESPONSE TO COMPETITION FROM EXOTIC VS. NATIVE PLANTS

Pedram Daneshgar, Shibu Jose, Craig Ramsey, and Robin Collins<sup>1</sup>

**Abstract**—A field study was conducted in Santa Rosa County, FL to test the hypothesis that an exotic understory would exert a higher degree of competition on tree seedling establishment and growth than native vegetation. The study site was a 60 ha cutover area infested with the invasive exotic cogongrass [*Imperata cylindrica* (L.) Raeusch.]. A completely randomized design was set up with five replications of three treatments: (1) control- plots that were kept weed free, (2) plots with only native vegetation, and (3) cogongrass infestation. On March 6, 2003, 1-year-old bare-root loblolly pine seedlings were planted at 1.8 x 1.1 m spacing, and initial root collar diameter (RCD) and height were measured. The seedlings were harvested in December, and final RCD, height and above- and below-ground biomass were measured. Seedlings had the lowest biomass growth in the cogongrass treatment and the highest in the control. The results of the study demonstrate that the exotic cogongrass is far more competitive than native vegetation.

## INTRODUCTION

Several studies have examined the impact of weeds on the growth and survival of pines all around the world. Radiata pine (*Pinus radiata* D. Don) in New Zealand grew more rapidly with the removal of Italian ryegrass (*Lolium multiflorum* Lam.), white clover (*Trifolium repens* L.), and sorrel (*Rumex acetosella* L.) (Mason and Kirongo 1999). Exclusion of bunchgrass [*Agropyron spicatum* (Pursh) Scribn. & J.G. Sm.] roots from 0.15-m and 0.30-m deep root zones of ponderosa pine seedlings resulted in 40 and 80 percent reductions in mortality, respectively (Kolb and Robberecht 1996). Martin and Jokela (2004) found control of competing vegetation resulted in dramatic increases in almost every measure of productivity investigated of loblolly pine in north-central Florida, including height, basal area, stemwood biomass accumulation, foliar nitrogen concentration, and leaf area index. Zutter and others (1999) demonstrated that decreases in woody and herbaceous competitors resulted in increases in foliar biomass of 2-year-old loblolly pine (*Pinus taeda* L.) in the Southeastern United States. Few studies have examined the impact of invasive plants on pine survival and growth in the Southeast.

Cogongrass [*Imperata cylindrica* (L.) Raeusch.] is a subtropical alien invasive grass which is spreading throughout natural and disturbed ecosystems in the Southeastern United States and Southeast Asia, infesting 500 million acres worldwide. The grass spreads mostly through rhizomes, which are resistant to breakage and heat: it can grow 1 m deep and in every direction, forming extensive rhizome networks (Holm and others 1977). These networks lead to dense monocultures in a forest understory, displacing all native vegetation and altering the structure and function of an ecosystem. Cogongrass infestation is suspected to play a major role in affecting the productivity of forest trees as well. The objective of this study was to quantify the effect of cogongrass on the survival and growth of loblolly pine seedlings.

## MATERIALS AND METHODS

### Study Site

This field study was conducted on an industrial cutover site in Santa Rosa County, FL. The area quickly became infested with cogongrass after harvesting. A completely randomized design was set up with five replications of three treatments: (1) control - plots that were kept weed free by hand weeding, (2) plots with only native vegetation, and (3) plots with cogongrass infestation. In March, 2003, 1-year-old bare-root loblolly pine seedlings were planted at 1.8 x 1.1 m spacing. There were 4 rows of 8 seedlings in each plot (32 seedlings per plot).

### Measurements

The initial root collar diameter (RCD) and height were measured for every seedling at planting. The seedlings grew for one full growing season. In December, 2003, the RCD and height were re-measured, and survival of seedlings was assessed. Analysis of variance within the framework of a completely randomized design was used to analyze the data.

## RESULTS AND DISCUSSION

After one full growing season, it was evident that the presence of native and exotic weeds greatly impacted the productivity and establishment of 1-year-old loblolly pine seedlings. Survival was 72.5 percent in both the native and weed-free treatments after a full growing season, while it was only 55 percent in the cogongrass treatment. Some mortality was expected after planting for all treatments; however, cogongrass exerted a higher competitive pressure for soil water and/or nutrients, resulting in greater mortality in this treatment.

The presence of cogongrass greatly impacted the overall growth of the seedlings after one growing season. The pine seedlings growing in the cogongrass treatment showed the least amount of growth, with only a 30 percent increase in RCD and a 26 percent increase in height (table 1). The native vegetation exerted moderate competitive pressure on the seedlings. Seedlings in this treatment had a 64 percent increase in RCD and a 30 percent increase in height at the

<sup>1</sup> Graduate Research Assistant, Associate Professor, Post-Doctoral Scientist, and Graduate Student, respectively, University of Florida, Institute of Food and Agricultural Sciences, Gainesville, FL 32611.

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**Table 1—Mean root collar diameter (RCD) and height of loblolly pine seedlings after 9 months under different treatments**

Treatment	RCD	Height
	<i>mm</i>	<i>cm</i>
Weed free (control)	12.77	47.64
Native vegetation	6.95	36
Cogongrass	5.52	34.96

end of 9 months. The weed-free treatment resulted in the largest seedlings, with a 200 percent increase in RCD and 72 percent increase in height after 9 months.

Our preliminary data clearly show that cogongrass is far more aggressive competition for loblolly pine seedlings than native vegetation. If cogongrass grows unchecked in plantations, productivity and sustainability can be severely impacted. Integrated control strategies recommended for cogongrass control (Jose and others 2002) need to be followed to ensure

plantation success when cogongrass infestations are detected on cutover sites.

**LITERATURE CITED**

Holm, L.G.; Plucknett, D.L.; Pancho, J.V.; Herberger, J.P. 1977. The world's worst weeds: distribution and biology. Honolulu, HI: University Press of Hawaii. 609 p.

Jose, S.; Cox, J.; Miller, D.L. [and others]. 2002. Alien plant invasions in southeastern forests. The story of cogongrass. *Journal of Forestry*. 100: 41-44.

Kolb, P.F.; Robberecht, R. 1996. *Pinus ponderosa* seedling establishment and the influence of competition with the bunchgrass, *Agropyron spicatum*. *International Journal of Plant Sciences*. 157: 509-515.

Martin, T.A.; Jokela, E.J. 2004. Stand development and production dynamics of loblolly pine growing on spodosols in North-Central Florida USA. *Forest Ecology and Management*. 192: 39-58.

Mason, E.G.; Kirongo, B. 1999. Responses of radiata pine clones to varying levels of pasture competition in a semi-arid environment. *Canadian Journal of Forest Research*. 29: 934-939.

Zutter, B.R.; Miller, J.H.; Allen, H.L. [and others]. 1999. Fascicle nutrient and biomass responses of young loblolly pine to control of woody and herbaceous competitors. *Canadian Journal of Forest Research*. 29: 917-925.

# UNDERSTORY GROWTH AND COMPOSITION RESULTING FROM SOIL DISTURBANCES ON THE LONG-TERM SOIL PRODUCTIVITY STUDY SITES IN MISSISSIPPI

R.H. Stagg and D. Andrew Scott<sup>1</sup>

**Abstract**—The response of understory plant communities to forest management can have important impacts on crop tree production, biodiversity, wildlife habitat, and water and nutrient cycling. Soil disturbance caused by harvesting and site preparation can alter soil fertility and porosity and may change understory species composition. At the Long-Term Soil Productivity study in Mississippi, we measured woody biomass by species on plots that had been subjected to three levels of experimental soil compaction. Although soil compaction at harvest reduced understory biomass at ages 5 and 10 years, planted pine biomass was unaffected. The relative dominance of individual species was altered by stand establishment and by soil compaction treatments; soil compaction favored early successional species while reducing the biomass and dominance of hardwood trees.

## INTRODUCTION

Within the forest management community, many legal and ecological concerns have come to light over the past two decades about the specific effects of soil disturbances on long-term site productivity. Powers and others (1990) identified organic matter removal/displacement and soil compaction as key factors affected by forest management activities and which alter site productivity. In 1989, officials with the U.S. Department of Agriculture Forest Service National Forest System Deputy area and the agency's Research and Development branch began investigating these factors. Their efforts were directly in response to policies resulting from the Forest Management Act of 1976, as well as other statutes and directives. In 1990, the first Long-Term Soil Productivity Study (LTSP) sites were installed. This nationwide study focused on the impacts of organic matter removal associated with harvesting, site preparation for regeneration, and other activities, as well as soil compaction associated with equipment traffic during timber harvest and site preparation. The removal of organic matter potentially reduces site productivity by altering nutrient cycles, biological functions, and other soil processes. Soil compaction potentially reduces soil productivity by increasing soil strength and reducing soil porosity, which together reduce water and air interchange, thereby diminishing root growth (Greacen and Sands 1980).

Site productivity commonly is indexed by measuring total aboveground biomass. Early in a rotation, noncrop vegetation may constitute most of the standing biomass, and understory species may have different responses to soil compaction than crop trees. Therefore, it is important to study not only the overstory but also to investigate the effect of soil disturbances on the woody understory vegetation. Additionally, understory vegetation plays an important and valuable role in crop tree survival and growth, wildlife habitat and abundance, fuel loads, and nutrient cycling, all of which can be considered part of site productivity. This paper explores how soil compaction affects the growth and composition of crop tree and woody understory vegetation.

## MATERIALS AND METHODS

### Study Sites

The study site is the Mississippi installation of the LTSP, which was established in 1993. It is located in the DeSoto National Forest, Chickasawhay Ranger District, in Jones County, MS. The soil is a Freest series, which is in the fine-loamy, siliceous, thermic family of Aquic Paleudalfs. This series is somewhat poorly drained and formed in loamy clay sediments in uplands. The preharvest stand was a well-stocked slash pine plantation established in 1935. The site had received prescribed burns at 3- to 5-year intervals during the previous rotation, although the site had not been burned for 10 years prior to establishment of the LTSP study.

Twenty-seven 0.2-ha study plots were established in a split-plot, randomized complete block design. The general plot layout is a three by three factorial arrangement of organic matter removal and soil compaction. Each plot was split in half. One half was maintained as monoculture pine only; herbicides (glyphosate and triclopyr) were applied as necessary to control woody and herbaceous plants. The other half was treated as a natural plantation; no herbicides were applied after plantation establishment. This paper only considers the effect of compaction treatments on the woody understory and pine-stand productivity within the natural plantation plots.

### Treatments

Compaction treatments were no compaction (control), moderate compaction, and severe compaction. No equipment traffic was allowed during harvest on the control treatment. Trees were removed by chain-saw felling, and logs were lifted off each plot with a log loader or crane. Only foot traffic was allowed on the control plots. The moderate and severe compaction plots were logged using a chassis-mounted shear and grapple skidders. Prior to harvesting, treatments were applied by towing a pneumatic-tire roadbed compactor with a crawler tractor over the designated plots. The roadbed compactor had a rolling width of 1.52 m. The ballast in the roadbed compactor was adjusted to meet the requirements of the

<sup>1</sup> Forester and Research Soil Scientist, respectively, USDA Forest Service, Southern Research Station, Pineville, LA 71360.

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treatment. Field trial tests determined that a load of 3.0 Mg was required to initiate soil compaction in the Freest soil series. The severe load was set at 6.4 Mg and the moderate load at a logarithmic average between these two points, or 3.6 Mg. To ensure complete coverage and uniform compaction, each plot received three passes in one direction and then three more passes in a perpendicular direction for a total of six passes.

One herbicide application on each plot comprised the planting preparation. Technicians applied a mix of Garlon 4 (Triclopyr) and Cidekick (surfactant) at a rate of 8.867 l ha<sup>-1</sup> and 1.446 l ha<sup>-1</sup>, respectively. Following treatments, study plots were hand planted with 1-0 containerized loblolly pine (see Appendix for scientific plant names) seedlings from 10 known families on 2.5- by 2.5-m spacing.

### Measurements

Tree heights and diameters of planted pine trees were measured every year up to age 5 and then again at age 10. At preharvest, understory biomass was destructively sampled within five randomly located 1-m<sup>2</sup> sampling areas. The understory was collected, oven dried, weighed, and saved for nutrient analysis. All understory species < 7.6 cm diameter at breast height were collected, but the biomass was not separated by species. Percent cover by species was measured on six 30.5-m transects on each of the plots.

At age 5 years, understory vegetation biomass was collected from four randomly placed 1.56-m<sup>2</sup> sample areas on the non-herbicide subplots. No species coverage data was collected at sampling.

A more intense understory vegetation biomass measurement was made at age 10 years. All woody understory species < 1.37 m tall were clipped, bagged, and tallied by species and number of stems in each of three 6.25-m<sup>2</sup> sampling areas on each subplot. All woody understory species > 1.37 m tall were tallied by species, height, and diameter within three 56-m<sup>2</sup> sampling areas randomly placed within each study plot. Plot-level biomass was determined from these measurements using biometric equations developed from the sites.

### Data Analysis

The impact of soil compaction was determined on pine biomass, understory vegetation biomass, and species relative dominance by analysis of variance using  $\alpha = 0.1$  and Duncan's Multiple Range test to separate the means when differences were found (SAS Institute 2000).

## RESULTS AND DISCUSSION

The compaction treatments had no effect on the growth of the pine overstory at 5 and 10 years, respectively. At 5 and 10 years, the loblolly pine overstory averaged 6.7 and 26.9 Mg ha<sup>-1</sup>, respectively (table 1).

The preharvest total understory vegetation biomass was equal across all treatment plots and averaged 2.67 Mg ha<sup>-1</sup>. By age 5 years, the total understory vegetation biomass averaged 3.11 Mg ha<sup>-1</sup> across all plots, but the moderate and severe compaction treatments reduced the total woody understory biomass by 65 and 67 percent, respectively, compared to the uncompacted control plots. At age 10 years, the understory biomass had grown to 6.5 Mg ha<sup>-1</sup> on the control plots. Understory biomass was still significantly less on the severely compacted plots (3.9 Mg ha<sup>-1</sup>) and intermediate on the moderately compacted plots (4.7 Mg ha<sup>-1</sup>) (table 1).

**Table 1—Aboveground biomass (Mg/ha) response to three levels of experimental soil compaction through 10 years of stand development**

Age	Strata	Soil compaction		
		None	Moderate	Severe
----- Mg/ha -----				
Preharvest	Overstory <sup>a</sup>	149.6	138.5	146.5
	Understory <sup>b</sup>	<u>2.7</u>	<u>2.7</u>	<u>2.6</u>
	Total	152.3	141.2	149.1
5 years	Overstory	5.9a <sup>c</sup>	7.2a	7.1a
	Understory	<u>5.6a</u>	<u>2.0b</u>	<u>1.8b</u>
	Total	11.5a	9.2a	8.9a
10 years	Overstory	23.6a	28.7a	28.4a
	Understory	<u>6.5a</u>	<u>4.7ab</u>	<u>3.9b</u>
	Total	30.1a	33.4a	32.3a

<sup>a</sup> Overstory was defined as the planted pine trees on each plot, regardless of size.

<sup>b</sup> Understory was defined as all other woody vegetation.

<sup>c</sup> Means within a row followed by the same letter are not significantly different at  $\alpha = 0.10$  based on Duncan's Multiple Range tests.

At 5 years, the planted pine biomass averaged > 80 percent of the total woody biomass on the compacted plots but only 50 percent on the control plots (table 1). By 10 years, the loblolly pine biomass averaged about 87 percent of the total biomass across the compacted plots but only 78 percent of the total vegetation biomass on the control plots (table 1). Total biomass was not significantly affected by the compaction treatments at any age, indicating that the understory vegetation was much more susceptible to soil compaction than the planted pine trees.

Not only was the understory vegetation more susceptible to compaction than the planted pines, but individual species were quite different in their susceptibility. Soil compaction reduced flowering dogwood, winged sumac, red oak, and red maple biomass by 95, 95, 92, and 65 percent, respectively, although only the red oak biomass showed a statistical difference, due to the high variability of individual species biomass across the plots (table 2). Conversely, eastern baccharis, black gum, and yaupon were positively affected by soil compaction. They had 616, 477, and 111 percent more biomass on the compacted plots than on the uncompacted plots, although only eastern baccharis showed a significant difference (table 2). This species-specific tolerance to soil compaction had important effects on the understory's overall species composition.

At preharvest, 25 woody understory species were identified. At 10 years, only 19 species were found on the moderately compacted plot and 17 species on both the control and severely compacted treatment plots. Also, six species were present at preharvest but were no longer present at 10 years. These species were common privet, hickory, sassafras,

arrowwood, winged elm, and ironwood. One species, eastern redcedar, was not present at establishment but was found at 10 years.

At establishment of the LTSP study, gallberry dominated the woody understory species with nearly 60 percent relative dominance before harvest (fig. 1). All other recorded species represented < 10 percent relative dominance. After compaction treatments and 10 years of growth, gallberry still dominated the woody understory composition, although its relative dominance had decreased to 35 percent on the control and 37 percent on the compacted treatments. Compaction treatments did not affect the relative dominance of gallberry in the understory, but there was a significant statistical difference in other understory species. Soil compaction decreased the relative dominance of flowering dogwood and red oaks but increased the relative dominance of black gum, eastern baccharis, and American beautyberry.

These changes in understory composition due to soil compaction may affect wildlife habitat, timber production, and have implications for successional dynamics, all of which are especially important for nonindustrial private landowners. The increase in eastern baccharis, American beautyberry, and yaupon would benefit bird habitat, although the loss of red oak would be detrimental to many species that need hard mast, such as white-tailed deer (*Odocoileus virginianus*) and eastern wild turkey (*Meleagris gallopavo silvestris*). Similarly, the reduction in red oak and red maple could have implications for timber value, although the planted pines would still likely be the preferred timber species. Ecologically, soil compaction appeared to retard succession; early successional,

**Table 2—Understory vegetation biomass by species at age 10 years as affected by three soil compaction levels**

Species	Soil compaction		
	None	Moderate	Severe
	----- kg/ha -----		
American beautyberry	49.4a <sup>a</sup>	116.1a	51.9a
American holly	36.1a	52.5a	20.4a
Black cherry	3.3a	0.0a	0.8a
Blackgum	23.5a	72.4a	135.7a
Eastern baccharis	17.2b	86.1ab	122.9a
Eastern redcedar	0.0a	2.5a	0.0a
Flowering dogwood	494.5a	32.8a	23.8a
Gallberry	1937.8a	1329.0a	1416.5a
Hawthorn	11.5a	13.9a	31.6a
Loblolly pine	54.0a	42.7a	61.6a
Persimmon	16.6a	97.8a	23.3a
Red maple	1467.7a	1036.1a	519.9a
Red oak	747.2a	213.0b	63.1b
Sweetbay	0.0a	0.6a	0.0a
Sweetgum	306.8a	171.1a	60.8a
Vaccinium	291.6a	114.1a	207.3a
Wax myrtle	574.2a	576.8a	547.9a
White oak	0.0a	22.2a	0.0a
Winged sumac	190.0a	6.4a	8.8a
Yaupon	305.5a	704.6a	644.7a

<sup>a</sup> Means within a row followed by the same letter are not significantly different at  $\alpha = 0.10$  based on Duncan's Multiple Range tests.

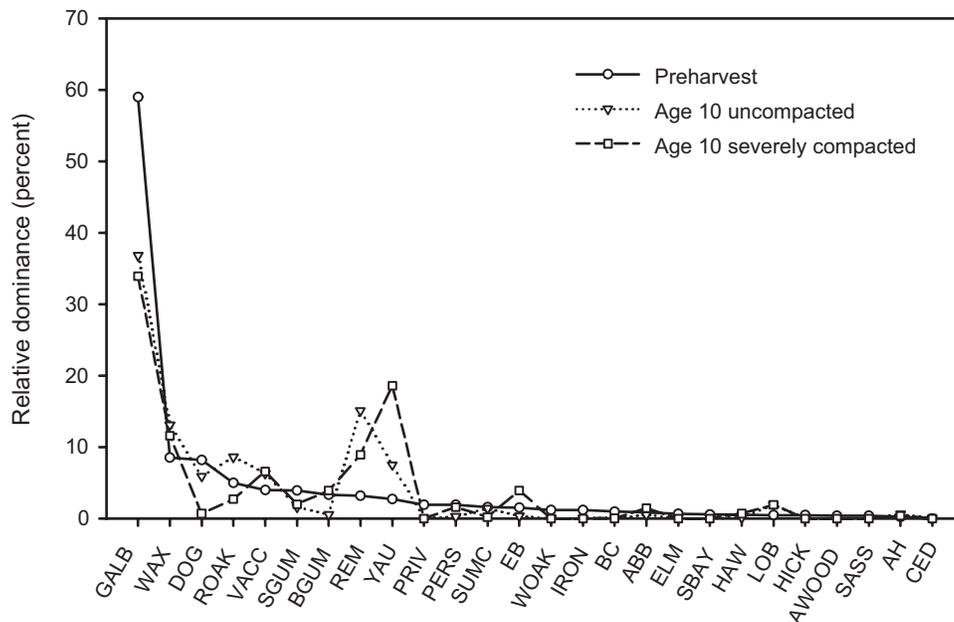


Figure 1—Relative dominance of understory species before harvesting and after 10 years of stand development and two soil compaction levels.

increasing species—such as American beautyberry, eastern baccharis, and yaupon—were more dominant on the compacted sites, while later successional species such as red maple, flowering dogwood, and red oak were less dominant (fig. 1).

## CONCLUSIONS

Soil compaction significantly reduced woody understory biomass while having little impact on planted pine biomass growth. However, compaction affected individual understory species quite differently, causing understory composition to change. Generally, early successional species with good qualities for bird habitat were more dominant on the compacted plots, while later-successional, mast-producing species were reduced. These changes could be quite important, especially for nonindustrial private landowners who are interested in managing their land for both timber and wildlife habitat.

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## LITERATURE CITED

- Greacen, E.L.; Sands, R. 1980. Compaction of forest soils. A review. *Australian Journal of Soil Research*. 18: 163-189.
- Powers, R.F., Alban, D.H.; Miller, R.E. [and others]. 1990. Sustaining site productivity in North American forests: problems and prospects. In: Gessel, S.P.; Lacate, D.S.; Weetman, G.F. [and others], eds. *Sustained productivity of forest soils. Proceedings of the seventh North American forest soils conference*. Vancouver, BC: University of British Columbia: 49-79.
- SAS Institute. 2000. *SAS/STAT user's guide*. Version 8. Cary, NC: SAS Institute.

**Appendix—Codes, common names, and scientific names of woody understory plant species found on the Mississippi Long-Term Soil Productivity Study site**

Code	Common name	Scientific name
ABB	American beautyberry	<i>Callicarpa americana</i> L.
AH	American holly	<i>Ilex opaca</i> Ait.
AWOOD	Arrowwood	<i>Viburnum dentatum</i> L.
BC	Black cherry	<i>Prunus serotina</i> Ehrh.
BGUM	Black gum	<i>Nyssa sylvatica</i> Marsh.
CED	Eastern redcedar	<i>Juniperus virginiana</i> L.
DOG	Flowering dogwood	<i>Cornus florida</i> L.
EB	Eastern baccharis	<i>Baccharis halimifolia</i> L.
ELM	Winged elm	<i>Ulmus alata</i> Michx.
GALB	Gallberry or inkberry	<i>Ilex glabra</i> L.
HAW	Hawthorn <sup>1</sup>	<i>Craetagus</i> spp.
HICK	Hickory <sup>2</sup>	<i>Carya</i> spp.
IRON	Ironwood or American hornbeam	<i>Carpinus caroliniana</i> Walt.
LOB	Loblolly pine	<i>Pinus taeda</i> L.
PERS	Persimmon	<i>Diospyros virginiana</i> L.
PRIV	Common privet	<i>Ligustrum vulgare</i> L.
REM	Red maple	<i>Acer rubrum</i> L.
ROAK	Red oak <sup>3</sup>	<i>Quercus</i> spp.
SASS	Sassafras	<i>Sassafras albidum</i> (Nutt.) Nees
SBAY	Sweetbay	<i>Magnolia virginiana</i> L.
SGUM	Sweetgum	<i>Liquidambar styraciflua</i> L.
SUMC	Winged sumac	<i>Rhus copallinum</i> L.
VACC	Deerberry <sup>4</sup>	<i>Vaccinium</i> spp.
WAX	Wax myrtle	<i>Morella cerifera</i> (L.) Small
WOAK	White oak	<i>Quercus alba</i> L.
YAU	Yaupon	<i>Ilex vomitoria</i> Ait.

<sup>1</sup>Hawthorn plants were not separated by species.

<sup>2</sup>Hickories were not separated by species but were dominated by mockernut hickory [*Carya alba* (L.) Nutt. ex Ell.].

<sup>3</sup>Red oaks were not separated by species but included southern red oak (*Quercus falcata* Michx.) and water oak (*Quercus nigra* L.).

<sup>4</sup>*Vaccinium* species were not separated by species but were dominated by deerberry (*Vaccinium stamineum* L.) and highbush blueberry (*Vaccinium corymbosum* L.).

# CURRENT KNOWLEDGE ON EFFECTS OF FOREST SILVICULTURAL OPERATIONS ON CARBON SEQUESTRATION IN SOUTHERN FORESTS

John D. Cason, Donald L. Grebner, Andrew J. Londo, and Stephen C. Grado<sup>1</sup>

**Abstract**—Incentive programs to reduce carbon dioxide (CO<sub>2</sub>) emissions are increasing in number with the growing threat of global warming. Terrestrial sequestration of CO<sub>2</sub> through forestry practices on newly established forests is a potential mitigation tool for developing carbon markets in the United States. The extent of industrial and non-industrial private timberland in parts of the southeastern United States is increasing rapidly with the reforestation of marginal or abandoned croplands. The afforestation or reforestation potential of Mississippi and the rest of the Lower Mississippi Alluvial Valley may play a significant role in the creation of new sequestration forests in Mississippi. This study reviews research pertaining to the effects of various forest management practices on the above- and below-ground carbon fluxes of southern forests.

## INTRODUCTION

The level of carbon dioxide (CO<sub>2</sub>) in the atmosphere currently averages 365 parts per million (ppm) which is approximately 35 percent greater than the pre-industrial revolution levels of 270 ppm (Groninger and others 1999). Burning of fossil fuels such as oil, coal, and natural gas is the primary man-made source of this greenhouse gas. This accelerated release of carbon (C) into the atmosphere alters the global C cycle, resulting in higher atmospheric CO<sub>2</sub> levels (Post and others 1990). Deforestation due to land use changes such as urbanization and agriculture convert areas that either (1) have an essentially neutral C flux, but contain large amounts of stored C (as in the case of old-growth forests) or (2) are young forests that act as C sinks to sources of CO<sub>2</sub> to the atmosphere (World Resources Institute 2003). The release of CO<sub>2</sub> from tropical deforestation is the forest's largest contributor to climate change. This is amplified by practices associated with forest clearing such as burning, fertilizing agricultural fields, and the rotting of slash material which produce other greenhouse gases as well (World Resources Institute 2003).

Other greenhouse gases are less abundant in the atmosphere than CO<sub>2</sub> but have more potent effects. Nitrous oxide, for example, is only 0.001 as common as CO<sub>2</sub>, but is 200 to 300 times as effective at trapping heat; it also remains in the atmosphere far longer than CO<sub>2</sub> (Cambridge Scientific Abstracts 2004). Chlorofluorocarbons, which were not present in the atmosphere prior to the Industrial Revolution, have warming effects ranging from 3,000 to 13,000 times that of CO<sub>2</sub> and persist for up to 400 years. Other greenhouse gases include hydrofluorocarbons, methane, sulfur hexafluoride, and perfluorocarbons. Directly reducing the emission of these greenhouse gases is currently the only effective method of reducing their concentration in the atmosphere. CO<sub>2</sub> is unique in that it occurs naturally in higher concentrations and is sequestered by photosynthetic organisms in both terrestrial and marine environments.

CO<sub>2</sub> levels are maintained naturally in the atmosphere where the gas acts as a barrier trapping radiant heat from escaping back into space. This phenomenon is referred to as the "greenhouse effect" and is an important natural process which regulates and maintains the Earth's climate (World Resources

Institute 2003). Rapid increases in the atmospheric level of CO<sub>2</sub> due to human activity results in an increased amount of radiant heat trapped near the Earth's surface. This may potentially increase the mean global temperature causing significant climatic changes as atmospheric levels of CO<sub>2</sub> rise.

Silvicultural practices such as reforestation, afforestation, and the management of existing forests have enormous potential for sequestering atmospheric C. Existing projects vary in scale and are located throughout Europe and the Americas. Currently, C sequestration programs in Mississippi offer landowners an initial one-time payment of \$400 to \$450 per acre for placing their land in a 70-year easement (The Carbon Fund 2003). However, the magnitude of C that may be stored in terrestrial ecosystems is not fully understood.

The effects of most silvicultural practices on the soil C pool are poorly understood, and research results from such studies conclude only short term effects. Also, these effects have typically been studied individually, so the amount of C storage resulting from plantation forestry over many rotations and silvicultural operations has yet to be quantified. This paper addresses the results of studies conducted to quantify C fluxes resulting from silvicultural practices as well as those attempting to place an economic value on stored C.

Market impacts resulting from this increased value of forests and probable increase in plantation forest area are also discussed in light of available research. In some cases, taxes on fossil fuel use are used to provide additional incentive to implement plantation forestry and move toward more emission-free technologies.

## SOIL CARBON

Soil possesses the greatest capability of storing C for long periods of time, and silvicultural practices directly affect the rate and amount of C stored in the soil. Therefore the relationship between belowground storage and common silvicultural practices is one that must be fully understood before forestry's use as a CO<sub>2</sub> emission mitigation tool can be valued. Aboveground storage rates have been established with the understanding that the temporal scale at which C in aboveground biomass is stored depends on whether the material is

<sup>1</sup> Graduate Student, Associate Professor, Associate Professor, and Professor, respectively, Mississippi State University, Department of Forestry, Mississippi State, MS 39762.

harvested or what the final products are if it is harvested. However, total belowground storage capacity and how different types of forestry operations affect it, is not fully understood. This section therefore identifies general methods by which C is stored in soil and reviews research regarding the storage or loss of C under various cover types and management regimes.

There is tremendous capacity for the storage of C in soils. World soils contain an estimated 3.2 trillion tons of C within the top 6 feet. Approximately 2.5 trillion tons of this C is in the form of soil organic matter; the rest is comprised of inorganic forms such as calcium and magnesium carbonates (Wojcik 1999). Soil organic matter is easily affected by land use practices and can be divided into two major categories: stabilized organic matter, which is highly decomposed and stable, and the active fraction, which is being actively used and transformed by living plants, animals, and microbes (University of Minnesota Extension Service 2004).

## VEGETATIVE CARBON

Delcourt and Harris (1980) constructed a C budget of the Southeastern United States biota from 1750 to 1950 to determine the pre-settlement C pool, document losses from deforestation, and determine whether the region is a source or sink for atmospheric CO<sub>2</sub>. U.S. agricultural census statistics and forest survey records provided the data for determining land use changes during the settlement of the region. Estimates of the total volume of virgin and secondary forests were used to calculate total C content, including detrital soil C. Due to the rapid clearing of forests and prairies during European settlement, from 1750 to 1950 the southeast was a net source of atmospheric C at an average rate of 0.13 gigatons per year. However, due to the increased acreage and productivity of commercial forests in the last 20 to 30 years, the region has become a net sink of 0.07 gigatons of CO<sub>2</sub> per year. Such general measurements are useful, but more precise means of monitoring and verifying quantities of stored C are needed. Measurements on a smaller scale are especially needed when determining effects of different site disturbances.

An important aspect of implementing a large-scale C storage program to mitigate emissions is determining where C is stored in a tree. Slash material and root systems left after harvesting constitute a large amount of the total biomass accumulated over a rotation. Laclau (2003) developed regression equations relating root dry weight, root volume, and C storage to tree diameter for ponderosa pine plantations. Laclau's equations produced a total root biomass estimate of 0.688 mg acre<sup>-1</sup> with 0.324 mg acre<sup>-1</sup> of total root C for a 10-year-old stand. Total root biomass for a 20-year-old stand was estimated at 10.93 mg acre<sup>-1</sup> with 5.18 mg acre<sup>-1</sup> of total root C. The range of data collected for this experiment limits the application of its results since varying age class, tree size, and other site factors disrupt the predictive capabilities of the regression equations.

The potential for C sequestration through forestry practices varies by region and depends mainly on the soil type and growth rates of each region's predominant plantation species. All trees, regardless of species or age, have approximately the same C to dry weight ratio. Matthew's (1993) research suggests that C contents tend to range between 49 and 51 percent with broadleaved species having a slightly lower C content than conifers and tropical species. Therefore, a value of 50 percent or 0.5 times the dry tree weight is probably an appropriate estimate for most large-scale calculations.

## SILVICULTURAL IMPACTS ON CARBON STORAGE

Schroeder (1991) used computer simulation models to estimate the effects of thinning on C storage. Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] and loblolly pine (*Pinus taeda* L.) were the example species. Thinning was generally shown to cause a decrease in C storage with the exception of very dense young stands. A 35-year rotation with an initial planting density of 607 trees per acre was assumed, with 20 and 40 percent basal area removals occurring at age 20. At the lighter thinning level, the final C yield was about the same as the unthinned stand. At the 40 percent thinning level, there was a 12 to 18 percent decrease in final yield. However, if the thinnings are included in the final totals (assuming long-lived products), there is little difference between thinned and unthinned plantations.

## Harvesting

The effects of harvesting on soil C content have been examined in many studies with varying results. Johnson (1992) summarized the effects of harvesting alone in 13 different studies. Despite the expected significant change in forest floor mass, the majority of studies reported little (<10 percent) or no change in mineral soil C. However, other studies reported either increased or decreased C contents. Cultivation or intense fires are noted as having the most dramatic effect on soil C. Cultivation alone resulted in significant losses (at least 20 percent) of C in soils that had relatively high C contents and a slight increase in soils with an initially low C content (e.g., 11 percent in Udolls of the Central United States).

## Site Preparation

Site preparation (burning, chopping, windrowing, disking, bedding) studies on soil C content have provided varying results. Morris and Pritchett (1983) found only slight changes in mineral soil C on a Florida slash pine (*Pinus ellioti* Engelm.) site. However, Burger and Pritchett (1984) found significant (20 to 40 percent) reductions in soil C following site preparation on another Florida slash pine site. The effects of fire on soil C is very dependant on the intensity of the fire, with greater fire intensities resulting in greater C loss (Johnson 1992). Site preparation may become less of a mechanical operation due to the advent of herbicides with forestry labels and the realization of the negative site impacts of mechanical operations. This is especially true for the reforestation or afforestation of conifers that many times replace natural hardwood stands.

## Species Composition

Species composition has been shown to have extremely variable effects on soil C (Johnson 1992). Results suggest in some instances that soil C was significantly greater (35 to 57 percent) in radiata pine (*Pinus radiata* D. Don) plantations than in native eucalyptus forests. Other studies involving the same species resulted in the reverse effects, and some instances showed little or no difference. Turner and Lambert (1988) attributed these results to the initial site fertility with results that suggested radiata pine plantations have a higher soil C (than eucalyptus forest soil) content on low fertility sites and lower soil C on high fertility sites. Lane (1989) showed the soil C content to be unchanged 23 years after the conversion of a hardwood forest to loblolly pine. Converting hardwood stands to pine may involve implementation of silvicultural practices, such as fertilization, that typically do not apply to hardwood stands due to the length of time the investment must be carried. This, along with shorter rotations and greater site

adaptability of pine species, give pine plantations a significant role in future C sequestration projects.

### **Fertilization**

The fertilization of southern pine forests is increasing rapidly, from 40,031 acres in 1988 to 850,660 acres in 1998 (Johnsen and others 2001). Fertilization increases C sequestration by increasing standing biomass, increasing C stored in forest products, and increasing belowground C pools. Johnsen's 2001 study focused on the latter and presented data from 5 experiments ranging spatially from the Virginia Piedmont to the Alabama Coastal Plain and ranging in age from 1 to 17 years. Fertilization increased belowground biomass by 250 percent. All experiments resulted in an increase of below and aboveground mean biomass (ranges from 120 to 300 percent increase). It is noted here that research needs include studying the long-term fertilization effects and designing optimal fertilization methods for forestry practices. Fertilization increases the rate of C storage; but long-term storage is more practical in hardwood stands that are generally not fertilized and, unlike pine, may be left indefinitely to mature into old-growth climax forests.

### **Rotation Length**

Optimal rotation length for C sequestration can potentially conflict with the financially optimal harvest age. Liski and others (2001) examined the effects of shortening the rotation age of Scots pine (*Pinus sylvestris* L.) and Norway spruce [*Picea abies* (L.) H. Karst.] in Finland from 90 to 60 years. Results suggest shortening the rotation length towards the peak age of mean annual increment decreased the C stock of trees but increased the C stock of soil, because the production of litter and harvest residues increased. They concluded longer rotation ages would be favorable for C sequestration at the cost of decreased revenue for landowners. Cooper (1982) also concluded that harvesting stands at financial maturity by shortening rotation length reduced lifetime C storage to perhaps 20 percent of the potential maximum. This trend will probably continue to grow with the genetic or other manipulation of existing stock to select for faster growing genotypes.

### **Tree Improvement**

Genetic improvements in seedling stock positively affect production as well as C sequestration. Jayawickrama (2001) estimated the gains in C sequestration by applying genetic improvement to radiata pine plantations in New Zealand. By selecting the best 50 of 500 parents for dry-weight production and the best 10 of 1,000 parents (and making crosses between these parents), 14.6 and 22.2 percent gains were achieved, respectively. Gains varied by region and management regime and were compared to a baseline estimation of unimproved stock calculated using the C\_Change option in the stand growth simulator STANDPAK.

### **CARBON INCENTIVE PROGRAMS**

The particular silvicultural practices allowed under a given C sequestration agreement can affect incentives needed to promote a sufficient amount of plantation forestry and resulting C storage. Rotation age, species composition, allowed thinnings, and other harvesting requirements that affect the landowner's potential income can positively or negatively affect their willingness to enter a C sequestration program. Dixon (1997) assessed 40 nations to determine the impact of silvicultural

practices on the amount of C stored in forest systems. Impacts of silvicultural practices on C flux, added C sequestration resulting from silvicultural practices, economic costs of applied silvicultural practices, and the area of land suitable for application of these practices were identified. Results suggested that additional C sequestered and the cost of additional sequestration varied greatly, but practices such as weeding, fertilization, drainage, thinning, and modified harvesting increased C sequestered on a given tract of land. Also acknowledged was the fact that large areas of the southeast are suitable for improved C storage, but the silvicultural techniques used and the cost of implementing improvement practices varied greatly by region. This implies that, depending on the particular restrictions of a C storage easement and the region in which the agreement is applied, the amount of C potentially sequestered and the resulting compensation possible varies greatly. This indicates the compensation (and resulting incentive to enter a C storage agreement) to an individual landowner depends significantly on the location of the land holding and restrictions set forth by available C sequestration programs.

Given that forest management as a whole typically increases the amount of C stored over other land uses, and the fact that there is a developing market for C storage, landowners and other entities are likely to take advantage of the additional income this may provide. However, the value of this additional C storage, and the impacts to the timber market that significantly increasing the number of forested acres will have, must now be quantified. This will ensure existing and future projects will not have a negative effect in other areas thereby negating any initial positive contributions.

### **DISCUSSION**

CO<sub>2</sub> levels in the atmosphere are increasing at a rate that makes forestry practices alone an inadequate means of stabilization. However, terrestrial sinks of C, such as natural and plantation forests, have a significant potential for emission mitigation. Despite the existence of current C sequestration programs, there has been no standard economic value assigned to a given unit of stored C. Researchers examining the effects of including C revenues into forestry investments have varied the value applied to a unit of stored C as well as the discount rate applied.

Research does exist, however, concerning the management and policy effects these potential revenues have on forestry investments. Since growth rate and C sequestration rate are positively correlated, most silvicultural practices that are traditionally implemented to improve timber production also improve the amount of C stored per unit time on a given tract. Also, the additional revenues obtained from marketing stored C make these silvicultural practices more economically attractive and can therefore potentially improve the health of forests on a very large geographic scale. However, some restrictions may apply to silvicultural practices under a C storage agreement, and a thorough management plan must be prepared upon entering a C sequestration easement.

Implementing large scale plantation forestry for the purpose of removing CO<sub>2</sub> from the atmosphere certainly will have impacts on timber prices as well as the price assigned to a unit of sequestered C. Creating plantation forests on a large enough scale to significantly affect the concentration of atmospheric CO<sub>2</sub> could flood the market with timber (if harvested)

and C credits, effectively reducing the value of each. This could have negative effects on the incentive of private and industrial landowners to invest in forestry projects.

Current limitations of C sequestration programs resulting from the variability of C unit values does not remove the incentive for landowners to enter such programs. However, given the length of such an agreement (70+ years) and the uncertainty of future C sequestration programs, it would seem imprudent to enter an agreement such as the one available to Mississippi landowners, which offers \$400 to \$450 per acre, before knowing what the near future holds for C values. Nevertheless, given the ability to manage and harvest timber as specified in an approved management plan, C values can only improve the attractiveness of forestry as an investment opportunity. This fact should increase the incentive to practice forestry thereby expanding forested areas while simultaneously allowing silvicultural practices that maximize timber growth. This would result in a terrestrial ecosystem more capable of sequestering C from the atmosphere.

Other limitations to using terrestrial ecosystems to mitigate CO<sub>2</sub> emissions are the absence of sufficient data regarding the capacity of different soil types to store C over long periods of time. Each soil type (and corresponding cover type) reaches a different C storage equilibrium depending on factors such as climate, nutrient availability (particularly the C:N ratio), species, and soil physical properties. However, little information exists on just how much C the soil can store and how each of these factors, as well as others, affects this storage. Information on this subject, in addition to those areas currently being studied (i.e. soil C fluxes resulting from management practices), will certainly have to be better understood before the extent of forestry's contribution to global greenhouse gas reductions can be defined.

## CONCLUSIONS

Research conducted to better understand the terrestrial C cycle and how it may be affected by land use practices, coupled with the growing incentive to remove CO<sub>2</sub> from the atmosphere through natural processes, should improve the incentive for landowners to practice forestry. Potential C payments and recently implemented fossil fuel taxes (where they apply) are the primary motivation for storing C in forests. C payment incentives can significantly improve the financial profitability of forestry projects. The Southeastern United States has a large amount of land suitable for reforestation or afforestation and should have a major role in the creation of C sequestration forests and tradeable C credits for the purpose of greenhouse gas emissions mitigation.

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## LITERATURE CITED

Burger, J.A.; Pritchett W.L. 1984. Effects of clearfelling and site preparation on nitrogen mineralization in a southern pine stand. *Soil Science Society of America Journal*. 48: 1432-1437.

- Cambridge Scientific Abstracts. 2004. Greenhouse gas concentrations. Online. <http://www.csa.com>. [Date accessed: April 3, 2004].
- Cooper, F.C. 1982. Carbon storage in managed forests. *Canadian Journal of Forest Research*. 13: 155-166.
- Delcourt, H.R.; Harris W.F. 1980. Carbon budget of the Southeastern U.S. biota: analysis of historical change in trend from source to sink. *Science*. 210(17): 321-322.
- Dixon, R.K. 1997. Silvicultural options to conserve and sequester carbon in forest systems: preliminary economic assessments. *Critical Reviews in Environmental Science and Technology*. 27(special): s139-s149.
- Groninger, J.W.; Johnsen K.H.; Seiler J.R. [and others]. 1999. Elevated carbon dioxide in the atmosphere: what might it mean for plantation forestry? *Journal of Forestry*. 97(7): 4-10.
- Jayawickrama, K.J.S. 2001. Potential genetic gains for carbon sequestration: a preliminary study on radiata pine plantations in New Zealand. *Forest Ecology and Management*. 152: 313-322.
- Johnsen K.H.; Butnor J.R.; Maier, C. [and others]. 2001. Fertilization increases below-ground carbon sequestration of loblolly pine plantations. In: *Proceedings of first national conference on carbon sequestration*. [http://www.net1.doe.gov/publications/proceedings/01/carbon\\_seq/carbonseq01.html](http://www.net1.doe.gov/publications/proceedings/01/carbon_seq/carbonseq01.html). [Date accessed unknown].
- Johnson, D.W. 1992. Effects of forest management on soil carbon storage. *Water, Air and Soil Pollution*. 64: 83-120.
- Laclau, P. 2003. Root biomass and carbon storage of ponderosa pine in a northwest Patagonia plantation. *Forest Ecology and Management*. 173(1): 353-360.
- Lane, C.L. 1989. Forest stand conversion from hardwoods to pine: twenty-three years later. In: Gessel, S.P.; LeCate, D.S.; Weetman, G.F.; Powers, R.F., eds. *Sustained productivity of forest soils*. Seventh North American forest soils conference. Vancouver, BC: University of British Columbia: 253-256.
- Liski, J.; Pussinen, A.; Pingoud, K. [and others]. 2001. Which rotation length is favorable to carbon sequestration? *Canadian Journal of Forest Research*. 31: 2004-2013.
- Matthews, G. 1993. The carbon content of trees. *Forestry Commission Technical Paper No. 4*. Edinburgh: [Publisher unknown]: [Pages unknown].
- Morris, L.A.; Pritchett, W.L. 1983. Effects of site preparation on *Pinus elliotii* – *P. palustris* flatwoods forest soil properties. In: Ballard, R.; Gessel, S.P., eds. *IUFRO symposium on forest site and continuous productivity*. Gen. Tech. Rep. PNW-163. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest Experiment Station: 243-251.
- Post, W.M.; Peng, T.H.; Emanuel W.R. [and others]. 1990. The global carbon cycle. *American Scientist*. 78: 310-326.
- Schroeder, P. 1991. Can intensive management increase carbon storage in forests? *Environmental Management*. 15(4): 475-481.
- The Carbon Fund. 2003. Carbon sequestration: developing forest accounting principals that are effective, sequester additional carbon and improve biodiversity. A program overview. <http://www.thecarbonfund.org>. [Date accessed: December 5, 2003].
- Turner, J.; Lambert, M.J. 1988. Soil properties as affected by *Pinus radiata* plantations. *New Zealand Journal of Forest Research*. 18: 77-91.
- University of Minnesota Extension Service. 2004. Organic matter management. 10 p. <http://www.extension.umn.edu/distribution/cropsystems/DC7402.html>. [Date accessed unknown].
- Wojick, D.E. 1999. Carbon storage in soil, the ultimate no regrets policy? A report to greening earth society. 16 p. <http://www.greeningearthsociety.org/Articles/1999/carbon1.htm>. [Date accessed: February 18, 2004].
- World Resources Institute. 2003. The global carbon cycle. 2 p. <http://www.wri.org/wri/climate/carboncy.html>. [Date accessed: September 24, 2003].

# HARVEST INTENSITY AND COMPETITION CONTROL IMPACTS ON LOBLOLLY PINE FUSIFORM RUST INCIDENCE

Robert J. Eaton, Paula Spaine, and Felipe G. Sanchez<sup>1</sup>

**Abstract**—The Long Term Soil Productivity experiment tests the effects of soil compaction, surface organic matter removal, and understory control on net primary productivity. An unintended consequence of these treatments may be an effect on the incidence of fusiform rust [*Cronartium quercuum* (Berk.) Miy. ex Shirai f. sp. *fusiforme* Burdsall et Snow]. Loblolly pine (*Pinus taeda* L.) is highly susceptible to rust infection, and the combination of soil disturbances and the absence of understory may provide an environment favorable to fusiform rust. This paper describes the treatment effects on the annual incidence of fusiform rust in an 11-year-old loblolly pine plantation at the Croatan National Forest near New Bern, NC. Generally, increasing levels of organic matter removal resulted in increased incidence of fusiform rust. This trend was consistent throughout the experiment, but the magnitude of this effect diminished with time. Soil compaction did not have an effect on fusiform rust occurrence at any time during this study. Competition control resulted in significantly higher occurrence of stem galls after the trees were 5 years old.

## INTRODUCTION

Fusiform rust disease reduces the growth and yield of pine plantations in the Southeastern United States. The rust occurs from Maryland south to Florida and west to southern Arkansas and Texas and causes widespread damage to loblolly (*Pinus taeda* L.) and slash pine (*P. elliotti* Engelm). The causal agent of fusiform rust is the fungus *Cronartium quercuum* (Berk.) Miy. ex Shirai f. sp. *fusiforme* Burdsall et Snow. The fungus is native to the Southeastern United States and became an economic threat when plantation forestry expanded in the 1940s (Powers and Matthews 1980, Starkey and others 1997, Tainter and Baker 1996). Increased use of fertilizers led to an increase in fusiform rust incidence in southern plantations, largely due to the increased rust susceptibility of rapidly growing trees (Rowan 1977, Rowan and Steinbeck 1977, Schmidt 1998). Some authors recommend that fertilizer application be delayed or eliminated in high rust hazard sites to minimize losses from the disease (Schmidt 1998, Tainter and Baker 1996). However, other studies note that the increased growth of fertilized trees often compensates for the increased incidence of rust in a plantation (Froelich and Schmidting 1998).

The fusiform rust fungus completes its life cycle by alternating between pine and oak hosts. Pine hosts are infected through succulent new tissues that swell and form a gall in the wood tissue. The fungal infection increases resin flow in the wood and causes a reduction in wood density as the infection consumes the living wood cells (MacFall and others 1994). The sticky and often sweet sporulation by the fungus on the surface of the wood attracts secondary insects and fungi, which feed on the gall secretions and cause secondary damage to the tree. An infection often reduces the quality of the tree's wood and weakens the stem, increasing its susceptibility to breakage in wind and ice storms. The fusiform rust pathogen is a long-lived, perennially sporulating fungus that continues to invade more host tissue each year for the life of the tree. Often stem galls that appear after the tree is 5 years old develop from branch galls that have grown into the stem

(Froelich and Schmidting 1998). What starts as a gall on stem or branch tissue becomes a canker as the tree ages and secondary damage progresses.

The incidence of fusiform rust levels off after 6 years in young plantations. At that point, tree mortality increases as galls girdle the stems and branches. Many of the remaining galls are on trees that are described as "tolerant" because they manage to survive the initial 5 years of infection by growing and adapting their vascular system around the infection site. The probability of rust infection is not related to site quality or stand density variation but is heavily dependent on timing and severity of infection (Froelich and Schmidting 1998). These parameters are influenced by fertilization application and subsequent production of succulent tissues where the fungus infects the young tree (Rowan 1977, Rowan and Steinbeck 1977).

Economic losses of wood quality and yield by fusiform rust are difficult to quantify since they include the value of aggregate increases in standing timber, merchandise products (saw timber), and losses to nursery stock and seed production. The combination of values translates into \$20 to \$35 million of annual losses to fusiform rust infection in southern pines (Anderson and others 1986, Powers and others 1974). Estimates by Pye and others (1997) have put that figure as high as \$92 million per year.

The objective of this study was to quantify the effects of organic matter removal, compaction, and competition control on the incidence of fusiform infection on loblolly pine trees on the study site. This analysis was conducted as part of the Long Term Soil Productivity (LTSP) experiment. This LTSP study is part of an international effort designed to examine the effects of soil compaction, organic matter removal, and competition control on site productivity. Three levels of organic matter removal and three levels of soil compaction were chosen to represent disturbance regimes that ranged from minimal to severe. The competition control treatment was included to quantify plant growth potential on the site.

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<sup>1</sup> Biologist, USDA Forest Service, Southern Research Station, 3041 Cornwallis Rd., Research Triangle Park, NC 27516; Plant Pathologist, USDA Forest Service, Southern Research Station, 320 Green St., Athens, GA 30602; and Chemist, USDA Forest Service, Southern Research Station, 3041 Cornwallis Rd., Research Triangle Park, NC 27516, respectively.

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## METHODS

The study site was installed in 1992 and is located on the Croatan National Forest, near New Bern, NC. This area is part of the lower Coastal Plain and typically has cool winters and hot, humid summers (Goodwin 1989). The study design is a 3 by 3 factorial, split-plot, randomized complete block replicated on three blocks. Soils in Block 1 are predominately Goldsboro (fine-loamy, siliceous, thermic, Aquic Paleudults), and soils in Blocks 2 and 3 are predominately Lynchburg (fine-loamy, siliceous, thermic, Aeric Paleudults). Main effect treatments are organic matter removal (bole only – OM0; whole tree – OM1; whole tree and total forest floor removal – OM2), and soil compaction (none – C0; moderate – C1; severe – C2). Plots were split for competition control treatments (no competition control – H0; total competition control – H1). Each treatment plot is 0.2 ha and contains an 0.08-ha measurement plot. 1-0 loblolly half-sibling seedlings were planted in February 1992 at 3- by 3-m spacing. There were 80 trees per measurement plot, and each measurement plot was buffered on each side by 3 rows of trees. A complete description of treatment application is found in Eaton and others (2004).

Annual tree measurements and damage assessments were first made in January 1993 and continued through January 2002, with an additional damage assessment made in January 2004. Measurements and damage assessment were only performed on live trees. To reduce observer bias, the same person performed all damage assessments. Initially, only the most severe damage for each tree was recorded; after 3 years, the three most severe damages were recorded. For the purpose of this analysis, only trees that had stem infections as the most severe damage were classified as infected. Stem-infected trees were those with stem galls or branch galls located < 6 inches from the stem. There were no reports of fusiform infection at age 1.

Data were segregated by block and treatment and expressed as percentage of live trees infected with stem infections. Percentage data were transformed using the square root of the percentage + 1/2 (Steel and Torrie 1980). Analysis of variance and PROC MIXED were performed on the transformed data using SAS statistical software (SAS Institute, Cary, NC). Data were also separated by organic matter removal and competition control treatments, and additional analysis was performed. Only the highlights of the analyses are shown.

## RESULTS

### Organic Matter Removal Treatment

The temporal pattern of fusiform rust incidence was similar across all levels of organic matter removal (fig. 1). After age 2, rust infection on stems affected from between 5 and 15 percent of all live trees. The incidence of rust increased at age 3 then declined until age 6. There was a spike at age 7, largest in OM2 (3 percent) and smallest in OM0 (< 1 percent) followed by a slight decline through the age 11. The percentage of trees with rust was significantly higher ( $P < 0.05$ ) in OM2 than OM1 and OM0 for all years except age 6. The rate of rust incidence for OM0 was significantly different from OM1 only for age 2.

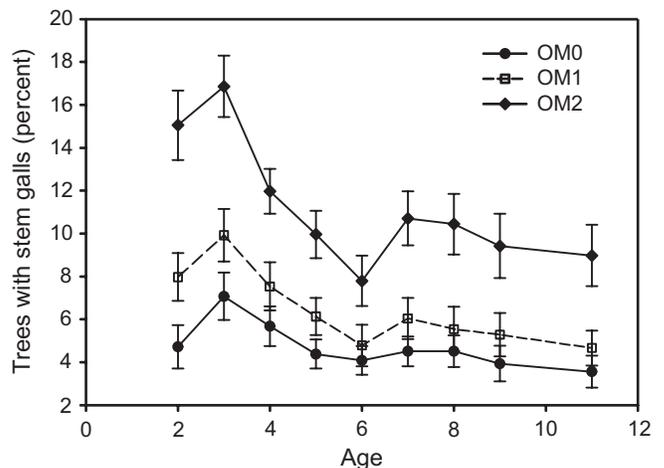


Figure 1—Percentage of trees with stem galls by age for three organic matter removal treatments (OM0 – bole only; OM1 – bole and branch; OM2 – bole, branch, and forest floor).

### Compaction Treatment

At age 2, the level of rust infection ranged from 7 to 11 percent of the total number of live trees (fig. 2). The incidence of rust increased at age 3 and then declined until age 6. The spike in incidence at age 7 was largest in the C1 plots (2 percent) and smallest in the C0 plots (< 1 percent). This spike was followed by a slight decline in fusiform rust incidence through age 11 at all compaction levels. The percentage of trees with stem galls was higher for C2 than for the other compaction treatments in all years, but it was significantly different ( $P = 0.049$ ) from C0 and C1 only at age 5.

### Competition Control Treatment

For treatment H0, the incidence of stem infections generally decreased from age 3 through age 11 (fig. 3). For treatment H1, incidence of stem infections increased substantially from age 6 to age 8 and then declined through age 11. By age 7, and through the end of the measurement period, the infection incidence rate for H0 differed significantly ( $P < 0.001$ ) from H1.

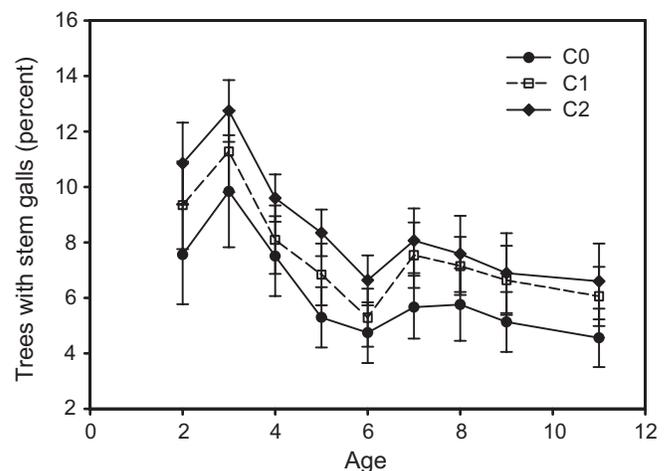


Figure 2—Percentage of trees with stem galls by age for three compaction treatments (C0 – no compaction; C1 – moderate compaction; C2 – severe compaction).

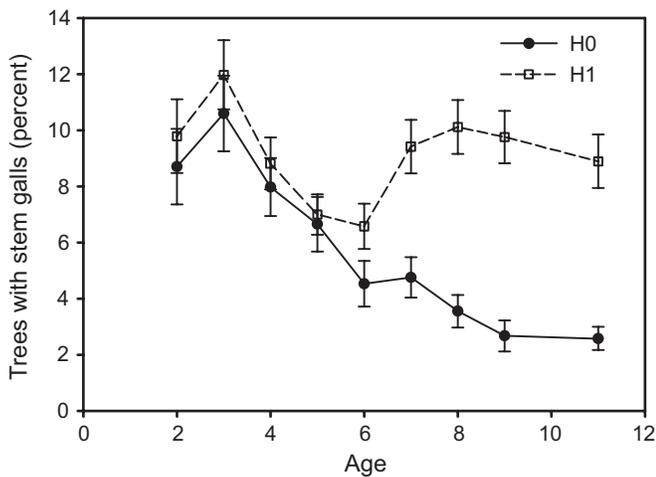


Figure 3—Percentage of trees with stem galls by age for two competition control treatments (H0 – no competition control; H1 – total competition control).

### Treatment Interactions

There were no significant treatment interactions in fusiform rust incidence until age 11 ( $P < 0.02$ ). However, after age 6 the differences between infection incidence on H0 and H1 were greater on the OM0 treatment plots than on the OM1 and OM2 plots (fig. 4).

### DISCUSSION

Previous analysis showed the OM removal and compaction treatments did not affect height or diameter growth but that competition control treatment affected both height and diameter growth significantly (Sanchez and others 2005). We expected this analysis to show the incidence of fusiform infection to reflect tree growth rate. Instead we found significant differences by OM removal treatments, and the incidence of infection was higher on the most severely disturbed sites for both the OM removal and compaction treatments. Additional investigation showed that factors generally associated with

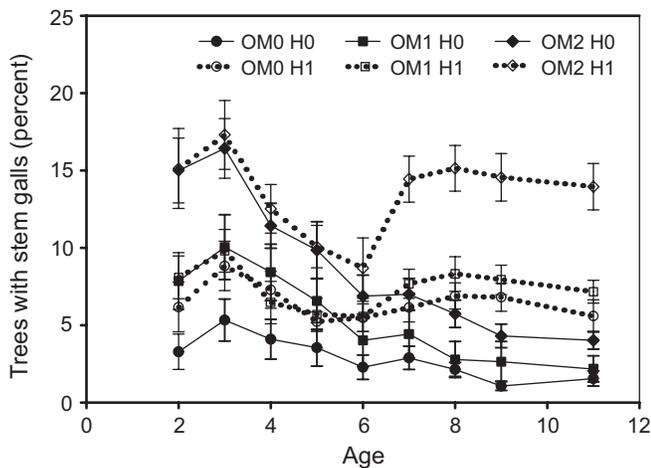


Figure 4—Percentage of trees with stem cankers by age for organic matter removal and competition control treatments (OM0 – bole only; OM1 – bole and branch; OM2 – bole, branch, and forest floor; H0 – no competition control; H1 – total competition control).

increased rate of tree growth, including soil and foliar nutrient levels, did not vary significantly from treatment to treatment.

Fusiform incidence was the same for both competition control treatments prior to age 7, although galls were more numerous in the H1 treatment. Height growth was significantly greater for H1 trees over this period (Sanchez and others 2005). This indicates that the infection rates may not be solely a function of growth. Starting at age 7, there was a significantly higher incidence of fusiform in the H1 plots than in the H0 plots (fig. 3). There is no obvious reason for this difference, although measurements show the height to live crown measurement of the planted pine trees increased by almost 2 m between ages 6 and 7 in the H1 treatment plots (Unpublished data. 2004. Robert Eaton, Biologist, USDA Forest Service, Southern Research Station, 3041 Cornwallis Road, Research Triangle Park, NC 27709). The height to live crown measurement in the H0 plots was always high due to competing vegetation and did not change as dramatically during the same time period. In addition, measurements taken at age 5 show significantly greater grass biomass and lower shrub biomass in the OM2 plots than in the other organic matter removal plots (Ludovici and others 2005). The comparatively low height of the major component of the understory in the OM2 and the decrease in the number of live lateral branches of the planted pine in the H1 plots when the time of infection rate increased indicate that the higher incidence of infection may have been the result of increased air movement through the treatment plots and increased transport of spores to susceptible tree tissue.

### CONCLUSIONS

The incidence of fusiform infection was higher in the plots where the most intensive treatments were applied and significantly higher in the OM removal treatments. Faster growing trees are generally thought to be at higher risk for infection, and more rapid tree growth was associated with competition control in this study. Even though the competition control treatment had significantly higher growth rates, there was no significant difference in fusiform infection incidence until age 7 years. Characteristics that can affect air movement through the stand, such as height of the major understory component or height to live crown, were different or changed at the same time that fusiform infection rates changed. Amount of susceptible tissue, although important, may not be the only factor that affects incidence of fusiform rust infection. Although use of rust-resistant clones and moderation in site preparation and fertilization reduce the incidence of fusiform infection, it may be desirable to reduce accessibility to susceptible tissue, especially in areas of high rust occurrence.

### ACKNOWLEDGMENTS

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### LITERATURE CITED

- Anderson, R.L.; McClure, J.P.; Cost, N.D.; Uhler, R.J. 1986. Estimating fusiform rust losses in five southeastern states. *Southern Journal of Applied Forestry*. 10: 237-240.
- Eaton, R.J.; Barberchek, M.; Buford, M.; Smith, W. 2004. Effects of organic matter removal, soil compaction, and vegetation control on collembolan populations. *Pedobiologia*. 48: 121-128.
- Froelich, R.C.; Schmidtling, R.C. 1998. Survival of slash pine having fusiform rust disease varies with year of first stem infection and severity. *Southern Journal of Applied Forestry*. 22(2): 96-100.

- Goodwin, R.A. 1989. Soil survey of Craven County, North Carolina. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service, U.S. Government Printing Office. 157 p.
- Ludovici, K.L.; Tiarks, A.; Ponder, F., Jr. [and others]. 2005. Understory responses to soil compaction and organic matter removal treatments across LTSP sites at age 5. *Canadian Journal of Forestry*.
- MacFall, J.S.; Spaine, P.; Doudrick, R.; Johnson, G.A. 1994. Alterations in growth and water-transport processes in fusiform rust galls of pine, determined by magnetic resonance microscopy. *Phytopathology*. 84: 288-293.
- Powers, H.R., Jr.; Matthews, F.R. 1980. Comparison of six geographic sources of loblolly pine for fusiform rust resistance. *Phytopathology*. 70: 1141-1143.
- Powers, H.R., Jr.; McClure, J.P.; Knight, H.A.; Dutrow, G.F. 1974. Incidence and financial impacts of fusiform rust. *Southern Journal of Forestry*. 72(7): 398-401.
- Pye, J.M.; Wagner, J.E.; Holmes, T.P.; Cubbage, F.W. 1997. Positive returns from investment in fusiform rust research. Res. Pap. SRS-4. Asheville, NC: Southern Research Station. 61 p.
- Rowan, S.J. 1977. Fertilization and inoculation density affect susceptibility to fusiform rust and gall development in slash and loblolly seedlings. *Plant Disease Reporter*. 61: 609-612.
- Rowan, S.J.; Steinbeck, K. 1977. Seedling age and fertilization affect susceptibility of loblolly pine to fusiform rust. *Phytopathology*. 67: 242-246.
- Sanchez, F.G.; Scott, D.A.; Ludovici, K.H. [In press]. Negligible effects of severe organic matter removal and soil compaction on loblolly pine growth over 10 years. *Forest Ecology and Management*.
- Schmidt, R.A. 1998. Fusiform rust disease of southern pines: biology, ecology and management. *Agric. Exp. Sta. Bull. (Tech)* 903. Gainesville, FL: University of Florida. 14 p.
- Steel, R.G.; Torrie, J.H. 1980. Principles and procedures of statistics: a biometrical approach. New York, NY: McGraw-Hill, Inc. 633 p.
- Starkey, D.A.; Anderson, R.L.; Young, C.H. [and others]. 1997. Monitoring incidence of fusiform rust in the South and change over time. Southern Region Report R8-PR-30. Atlanta, GA: Forest Health Protection. 29 p.
- Tainter, F.H.; Baker F.A. 1996. Principles of forest pathology. New York: John Wiley. 805 p.

# DESCRIPTION OF A LAND CLASSIFICATION SYSTEM AND ITS APPLICATION TO THE MANAGEMENT OF TENNESSEE'S STATE FORESTS

Glendon W. Smalley, S. David Todd, and K. Ward Tarkington III<sup>1</sup>

**Abstract**—The Tennessee Division of Forestry has adopted a land classification system developed by the senior author as the basic theme of information for the management of its 15 state forests (162,371 acres) with at least 1 in each of 8 physiographic provinces. This paper summarizes the application of the system to six forests on the Cumberland Plateau. Landtypes are the most detailed level in the hierarchical system and represent distinct units of the landscape (mapped at a scale of 1:24,000) as defined by physiography, climate, geology, soils, topography, and vegetation. Each of the 39 landtypes are described in terms of geographic setting, dominant soils, parent material, depth to bedrock, soil texture, soil drainage, relative soil water supply, relative fertility, and forest type. Additional information includes species suitable, site productivity, and operability for management activities. The maps aid the delineation of stands, streamside management zones, and “conservation” and other special use areas; the location of rare, threaten and endangered (RTE) species; the design of harvests; and the modeling of future forest conditions. The landtypes are an integral element in modeling wildlife habitat, in siting game food plots, and planning other wildlife management activities, particularly on forests that are dual wildlife and forest management areas. The maps are excellent training devices and extremely useful in explaining management plans to legislators and the public.

## INTRODUCTION

The Tennessee Division of Forestry (TDF) has adopted a land classification system developed by the senior author (Smalley 1991a) as the basic theme of information for the management of its 15 state forests (SFs). At least one SF occurs in each of eight physiographic provinces—Southern Appalachian Mountains, Ridge and Valley, Cumberland Plateau, Eastern Highland Rim, Nashville Basin, Western Highland Rim, Upper Coastal Plain, and Mississippi River Embayment. In this paper we describe the system, how it has been modified and expanded from the original regional guides, and how it is being applied in the management of six state forests on the Cumberland Plateau and in the Cumberland Mountains.

## THE LAND CLASSIFICATION SYSTEM

In the mid 1980s, Smalley (1986b) developed a land classification system for the 29 million acres of the Cumberland Plateau and Highland Rim/Pennyroyal physiographic provinces in parts of Alabama, Georgia, Tennessee, Kentucky, and Virginia. The system, which was adapted from Wertz and Arnold's (1975) Land System Inventory, can best be described as a process of successive stratifications of the landscape. Stratifications are based on the interactions among and controlling influences of ecosystem components—physiography, climate, geology, soils, topography, and vegetation. Macroclimate does not vary much across the two physiographic provinces, but microclimate varies because of local relief. This experience reinforced Rowe's (1996) maxim “...that every part of the terrain has to be confronted; there is no avoiding those in-between and odd ball units...”. Since the current species composition and structure of Rim and Plateau forests was more a function of repeated disturbances than an indication of succession and site potential, vegetation was relegated to a minor role in the development of the land classification system. Application of the system to other physiographic provinces represents an extension of the original concept (Smalley 1991b).

The five levels of Smalley's system proceeding from the least-detailed to the most-detailed are: physiographic province, region, subregion, landtype association, and landtype. These five levels approximate the lower five levels of the National Hierarchical Framework of Ecological Units (NHFEU) (Avers and others 1993) that is also known as the Bailey-Forest Service classification (Bailey 2002). In Smalley's hierarchical system, landtypes are the most detailed level. They represent distinct units of the landscape and are mapped at a scale of 1:24,000. To date, nearly 750,000 acres of state forest, state wildlife management areas, and private and forest industry lands have been mapped with the system.

Compared with the NHFEU (Bailey and others 1994, McNab and Avers 1994), Smalley's (1982, 1986a) combined Mid- and Northern Cumberland Plateau regions are equivalent to the Northern Cumberland Plateau section (221H), his Southern Cumberland Plateau region (Smalley 1979) is equivalent to the Southern Cumberland Plateau section (231C), and his Cumberland Mountain region (Smalley 1984) is equivalent to the Southern Cumberland Mountains Section (221I).

## SELECTED STATE FORESTS

This system was applied to six SFs (proceeding south to north) – Franklin (FSF), Prentice Cooper (PCSF), Bledsoe (BSF), Lone Mountain (LMSF), Scott (SSF), and Pickett (PSF) (fig. 1). Four are in the Mid-Cumberland Plateau region (Smalley 1982); Lone Mountain is located at the junction of the Mid-Cumberland Plateau and the Cumberland Mountain regions (Smalley 1984). Pickett is located at the extreme southern end of the Northern Cumberland Plateau region (Smalley 1986a). Pickett SF surrounds Pickett State Park administered by the Department of Conservation and Environment. Prentice Cooper SF is also a wildlife management area, administered by the Tennessee Wildlife Resources Agency under a cooperative agreement. Scott SF borders the Big South Fork National River and Recreation Area administered

<sup>1</sup> Emeritus Scientist, USDA Forest Service, Southern Research Station and Consultant, Sewanee, TN 37375; and State Forest Unit Leader and Forest Information System Specialist, respectively, Tennessee Department of Agriculture, Division of Forestry, Ellington Agricultural Center, Nashville, TN 37204.

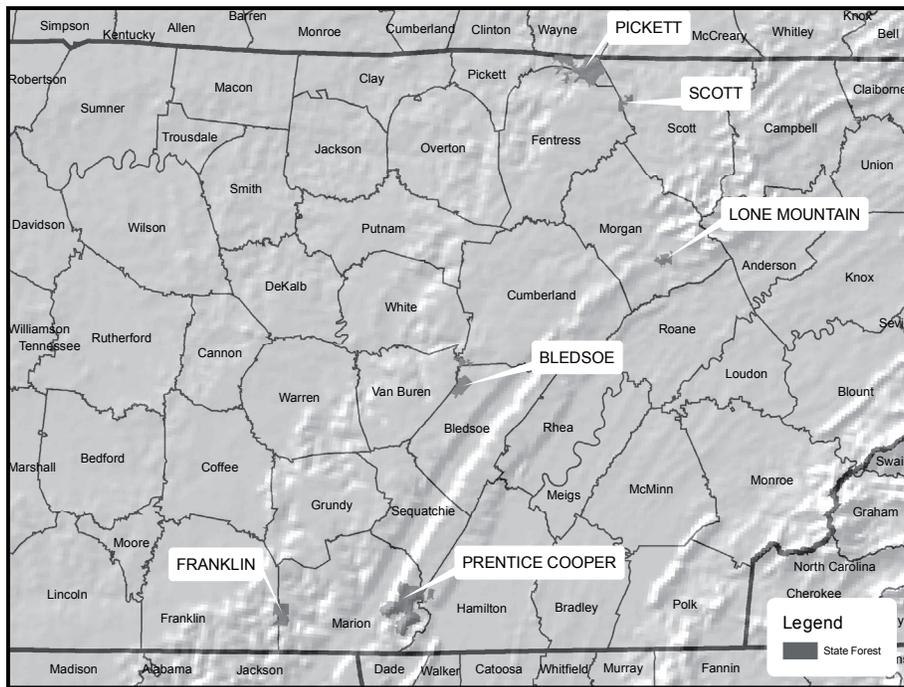


Figure 1—Locations of state forests on the Cumberland Plateau of Tennessee.

by the U.S. Park Service. When these forests were acquired, they were in old fields or pastures, cut-over, or abused as a result of poor farming practices, surface mining, or high-grade logging.

### LANDTYPES

Based on experience, some of the original landtypes were combined, others were divided into two or more landtypes, and some new ones were described. Altogether, 39 distinct landtypes were identified on the 6 SFs. The occurrence of landtypes on each SF, their general topographic location, and their relation to the original regional guides are shown in table 1.

### CHARACTERISTICS OF THE CUMBERLAND PLATEAU/CUMBERLAND MOUNTAINS

#### Geology

The Cumberland Plateau is underlain by nearly level Pennsylvanian strata dominated by sandstones along with siltstones, shales, and coal (Swingle and others 1966) (fig. 2). Usually the Warren Point sandstone forms the escarpment (free-face) of the Plateau. Lone Mountain SF rises above the top of the Plateau and is underlain with three younger shale-dominated Pennsylvanian strata. Below the Pennsylvanian rocks are older Mississippian strata dominated by limestone and dolomite with some siltstone, shale, and thin strata of sandstone. Most of these Mississippian rocks are covered with colluvium. The Monteagle limestone is exposed only on the lower slopes of the Plateau escarpment and in river gorges (BSF). Below the Monteagle are the St. Louis and Warsaw limestones which form the rolling surface of the Eastern Highland Rim to the west of the Cumberland Plateau. These older Mississippian rocks plus Silurian and Ordovician strata are exposed along the margins of the Sequatchie Valley anticline west of PCSF

and along the Plateau escarpment facing east into the Ridge and Valley province.

#### Soils

As expected, general soil associations delineated at a scale of 1:750,000 (Springer and Elder 1980) show a strong correlation to major topographic features and are equivalent to the landtype association level in the hierarchy. Also, greater interest in forested landscapes by the National Resource Conservation Service has resulted in more detailed and useful soil surveys of Plateau counties, e.g., Bledsoe (Davis 1993), Grundy (Prater 2001), Pickett, and Fentress (Campbell and Newton 1995).

Residual soils common to the Plateau surface and the crest and upper slopes of Lone Mountain are mostly siliceous and mesic Ultisols and Inceptisols. Textural class varies from fine-loamy to coarse-loamy and loamy skeletal. Deep colluvial soils common to the upper escarpment slopes of the Plateau and lower slopes of Lone Mountain are siliceous and mesic Ultisols with high coarse fragment content. Mixed, thermic Alfisols and occasionally Mollisols formed in the exposed Mississippian limestone on the lower sides of the Plateau. These soils are shallow to deep with loamy skeletal texture.

#### Topography

The Plateau surface is weakly to moderately dissected with undulating to rolling topography. Elevation of the surface is highest (1,660 to 1,700 feet) on FSF and PCSF and decreases northward to 1,300 to 1,400 feet on LMSF before rising slightly near the Tennessee-Kentucky State line on PSF to 1,500 to 1,600 feet. Local relief on the surface is 100 to 200 feet. Most streams are intermittent and flow in U- or broad V-shaped valleys. The stream channels become narrow V-shaped and rock-strewn near the escarpment. When flowing, these streams plunge over the nearly vertical sandstone

**Table 1—Unified landtype numbering system for the Cumberland Plateau**

Landtype name	Original guide number	Unified LT number	State Forests					
			Franklin	Prentice Cooper	Bledsoe	Scott	Lone Mountain	Pickett
----- Landtypes above the escarpment -----								
<b>From Mid-Cumberland Plateau Guide (Smalley 1982)</b>								
Undulating sandstone uplands	1	1	1	1	1	1	1	1
Broad sandstone ridges and convex upper slopes	2	2	2	2	2	2	2	2
Narrow sandstone ridges and convex upper slopes	4	4	4	4	4	4	4	4
North sandstone slopes	5	5	5	5	5	5	5	5
South sandstone slopes	6	6	6	6	6	6	6	6
Shallow soils and sandstone outcrops above the escarpment	7	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Footslopes, terraces, streambottoms w/good drainage - above the escarpment	14	14.1	14.1	14.1	14.1	14.1	14.1	14.1
Terraces, streambottoms w/poor drainage - above the escarpment	15	15.1	15.1		15.1			
<b>From Cumberland Mountain Guide (Smalley 1984)</b>								
Surface mines - orphan	26	26.1		26.1				
Surface mines - reclaimed	26	26.2		26.2	26.2		26.2	
----- Landtypes below the escarpment -----								
<b>From Mid-Cumberland Plateau Guide (Smalley 1982)</b>								
Sandstone escarpment - north aspect		7.2		7.2	7.2	7.2		7.2
Sandstone escarpment - south aspect		7.3		7.3	7.3			7.3
Escarpment colluvial slopes - north aspect	16	16.1	16.1	16.1	16.1	16.1	16.1	16.1
Escarpment benches - north aspect	16	16.2	16.2	16.2	16.2	16.2	16.2	16.2
Escarpment colluvial slopes - south aspect	17	17.1	17.1	17.1	17.1	17.1	17.1	17.1
Escarpment benches - south aspect	17	17.2	17.2	17.2	17.2	17.2	17.2	17.2
Lower escarpment slopes - north aspect	18	18.1	18.1		18.1			18.1
Lower escarpment benches - north aspect	18	18.2	18.2		18.2			8.2
Lower escarpment slopes - south aspect	19	19.1	19.1		19.1			19.1
Lower escarpment benches - south aspect	19	19.2	19.2		19.2			19.2
Limestone spur ridges and knobs	20	28	28	28	28			28
Limestone rockland (outcrops) and shallow soils	20	20	20		20			20
Cherty slopes - north aspect		29		29	29			
Cherty slopes - south aspect		30		30	30			
Undifferentiated Sequatchie Valley		31		31	31			
Footslopes, terraces, streambottoms w/good drainage - in gorges		14.2			14.2	14.2	14.2	
Footslopes, terraces, streambottoms w/poor drainage - in gorges		15.2			15.2	15.2		
Terraces - Tennessee River gorge		24		24	24			
Sinkholes on lower escarpment slopes		25	25	25	25			
<b>From Eastern Highland Rim Guide (Smalley 1983)</b>								
Footslopes, terraces, streambottoms w/good drainage - in coves	21	21	21	21				21
----- Landtypes in the mountains -----								
<b>From Cumberland Mountains Guide (Smalley 1984)</b>								
Narrow shale ridges and convex upper slopes	27	32						32
Broad shale ridges and convex upper slopes	28	33						33
Upper mountain slopes - north aspect	24	34						34
Upper mountain slopes - south aspect	25	35						35
Colluvial mountain slopes and benches - north aspect		36						36
Colluvial mountain slopes and benches - south aspect		37						37
----- Miscellaneous landforms -----								
Water - streams, rivers, lakes, ponds - not associated w/surface mining		23.1	23.1	23.1	23.1	23.1	23.1	23.1
Water - lakes, ponds - associated w/surface mining		23.2			23.2			
Pits, dumps, quarries		27		27				

Period	Formation	State Forest			
P e n n s y l v a n i a n  P e r i o d	Graves Gap	F r a n k l i n & B l e d s o e  F o r e s t s	P r e n t i c e  C o o p e r  F o r e s t	S c o t t  F o r e s t	L o n e  M o u n t a i n  F o r e s t
	Indiana Bluff				
	Slatestone				
	Crooked Fork Group - 6 strata				
	Crab Orchard Mtn Group - 5 strata				
	Gizzard Group - 3 strata				
M i s s i p p i a n  P e r i o d	Pennington				
	Bangor Limestone				
	Hartselle				
	Monteagle				
	St. Louis				
	Warsaw				
	Fort Payne				
	Chattanooga Shale				

Figure 2—Stratigraphy of the six state forests found on the Cumberland Plateau in Tennessee.

escarpment in dramatic waterfalls. Below the escarpment are steep talus slopes extending one-half to two-thirds of the distance down to the adjacent valleys. These slopes are strewn with boulders and punctuated with narrow benches. The lower escarpment slopes are dominated by thin limestone ledges and, in places, limestone rockland. These lower limestone slopes do not occur on BSF and are mostly covered by Nickajack Lake on PCSF. Lone Mountain rises 800 to 900 feet above the Plateau surface to an elevation of 2,530 feet and is flanked with steep talus slopes. Aspect is of minor significance on the undulating to rolling Plateau surface but is a significant site factor on the steep escarpment slopes and the sides of Lone Mountain.

### Vegetation

These SFs typify much of the Cumberland Plateau which has been subjected to indiscriminate cutting, burning, grazing, and clearing for subsistence farming. The current forests are a mosaic of stand conditions with seemingly fortuitous species composition. Generally, productivity is below potential due to poor stocking, a less than desirable mix of species,

and a high proportion of defective and low-vigor trees. Few stands exist that represent site potential. In general, forests on top of the plateau, on the south-facing upper escarpment slopes, and on south-facing slopes of Lone Mountain are composed of mixed red and white oaks (*Quercus* spp.). In upland drainages and depressions, sweetgum (*Liquidambar styraciflua* L.), red maple (*Acer rubrum* L.), white oak (*Quercus alba* L.), and yellow-poplar (*Liriodendron tulipifera* L.) are common depending on soil drainage. A mixed mesophytic forest is common on the north-facing upper escarpment slopes, in shaded gorges like Bee Creek (BSF), and on north-facing slopes of Lone Mountain. A cedar (*Juniperus Virginia* L.)-mixed hardwood forest occupies the lower escarpment slopes. Preliminary estimates of productivity (site index and mean annual increment) and management limitations were derived from NRCS Woodland Suitability data for the soils common to each landtype or from experience.

### APPLICATION

Earlier research showed that the land classification system divided the PCSF landscape into distinct ecological units with relatively discreet plant communities (Arnold and others 1996). Additionally, the system grouped soils on the Catoosa Wildlife Management Area into landform units having relatively homogeneous chemical and physical properties (Hammer and others 1987).

Cleland and others (1997) listed ecosystem mapping, resource assessments, environmental analyses, watershed analyses, desired future conditions, resource management, and monitoring as uses of the NHFEU system. These uses also apply to Smalley's system. Currently, TDF is focusing on ecosystem delineation, resource assessment, desired future conditions, and resource management and monitoring. Much more data needs to be obtained before meaningful environmental and watershed analyses can be made.

### Current Uses

**Stand delineation**—Stands are delineated at the same scale as the landtype maps (1:24,000). Stands (silvicultural management units) have similar forest type and productivity and may range in size from 5 to 40 acres. Stand boundaries are typically roads and streams. Consequently, ridge landtypes (LTs-1 and 2) and upland hollows (LTs-14 and 15) are split. Some individual units of a landtype, conversely, may cover 50+ acres and, because of size restrictions, several stands may be defined with a single LT unit.

An immediate benefit of the landtype maps has been to reduce the time required to delineate stand boundaries. Heretofore stand delineation required several weeks of field work. With the availability of landtype maps, the task has been reduced to a few days (fig. 3).

**Management type determination**—Stands are characterized by a single forest type, often an association of two or more species where hardwoods are dominant. Because of past abuses, the current forest type may not be the desired management type. The ancillary information about desired species and estimated productivity for each LT will enable forest managers to formulate appropriate silvicultural strategies to achieve desired future stand conditions.

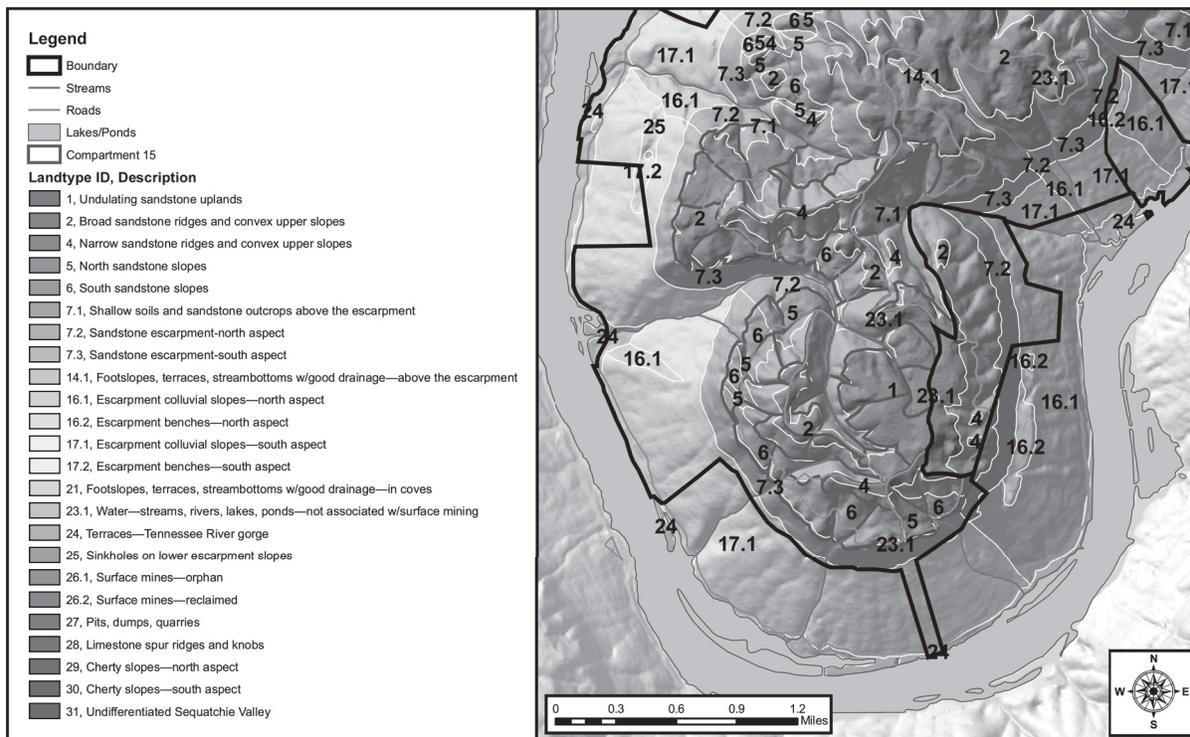


Figure 3—Stand delineation of compartment 15 on Prentice Cooper State Forest with the benefit of landtype mapping. Landtype and stand boundaries regularly coincide. Time to complete – a few days.

## Future Uses

**Forest Inventory**—The TDF is in the process of developing a state forest inventory. Assessment and monitoring of the resources on state forests is critical to making sound management decisions. An inventory and monitoring system based on the land classification system will provide better information at less cost. Since most stand and landtype boundaries coincide, species composition and productivity should be reasonably uniform within a stand. This uniformity will result in fewer inventory plots needed to achieve the same level of accuracy for timber volume and other forest characteristics compared to inventories not stratified by landtypes.

**Yield predictions**—We anticipate modeling future forest conditions by examining alternative management scenarios and the impact of disturbances such as insects, diseases, and fire. Plans include using the species desirability and productivity data for each LT as inputs to growth and yield prediction models. Results can be depicted using database and visualization software to view stands and landscapes through time enabling TDF to see to what extent alternative management strategies achieve stated objectives. This is the kind of information that TDF needs to promote current management decisions, the results of which may not be realized for several decades.

**Ecosystem delineation**—The concept of an ecosystem is subjective and dependent on scale and the organism(s) in question. An ecosystem can vary from a few square feet to hundreds and thousands of acres. Each SF is composed of several ecosystems at larger scales while at the same time each SF is part of a much larger ecosystem at a landscape scale. The land classification system provides a common

language and framework at multiple scales. Ecosystem delineation through the use of landtypes should also help in the locating rare, threatened and endangered (RTE) species and/or associated habitat(s) along with understanding how best to manage for their needs. Others have shown that landtypes or landtype associations can help locate suitable habitats for some RTE species (DeMeo 2001).

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## LITERATURE CITED

- Arnold, D.H.; Smalley, G.W.; Buckner, E.R. 1996. Landtype-forest community relationships: a case study on the Mid-Cumberland Plateau. *Environmental Monitoring and Assessment*. 39: 339-352.
- Avers, P.E.; Cleland, D.; McNab, W.H. [and others]. 1993. National hierarchical framework of ecological units. Washington, D.C. U.S. Department of Agriculture, Forest Service. 20 p.
- Bailey, R.G. 2002. *Ecosystem-based design for sustainability*. New York, NY: Springer-Verlag. 222 p.
- Bailey, R.G.; Avers, P.E.; King, T. [and others], eds. 1994. *Ecoregions and subregions of the United States (map)*. Washington, DC: U.S. Geological Survey. 1:7,500,000; colored. Accompanied by a supplementary table of map unit descriptions compiled and edited by McNab, W.H., and Bailey, R.G. Prepared for the U.S. Department of Agriculture, Forest Service.
- Campbell, J.F.; Newton, D.L. 1995. *Soil survey of Fentress and Pickett counties, Tennessee*. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 117 p. + maps.

- Cleland, D.T.; Avers, P.E.; McNab, W.H. [and others]. 1997. National hierarchical framework of ecological units. In: Boyce, M.S.; Haney, A., eds. *Ecosystem management: applications for sustainable forest and wildlife resources*. New Haven and London, CT: Yale University Press: 181-200.
- Davis, H.C. 1993. Soil survey of Bledsoe County, Tennessee. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 121 p. + maps.
- DeMeo, T. 2001. Use of landtype associations as a course filter for ranking quality of Indiana Bat habitat on the Monogahela National Forest, West Virginia. In: Proceedings, landtype associations conference: development and use in natural resources management, planning and research. Gen. Tech. Rep. NE-294. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeast Research Station: 71-80.
- Hammer, R.D.; O'Brien, R.G.; Lewis, R.J. 1987. Temporal and spatial soil variability on three forested landtypes on the Mid-Cumberland Plateau. *Soil Science Society of America Journal*. 51: 1320-1326.
- McNab, W.H.; Avers, P.E., comps. 1994. Ecological subregions of the United States: Section descriptions. Admin. Publ. WO-WSA-5. Washington, DC: U.S. Department of Agriculture, Forest Service. 267 p.
- Prater, J.L. 2001. Soil survey of Grundy County, Tennessee. Washington, DC: U.S. Department of Agriculture, Natural Resource Conservation Service. 154 p. + maps.
- Rowe, J.S. 1996. Land classification and ecosystem classification. *Environmental Monitoring and Assessment*. 29:11-20.
- Smalley, G.W. 1979. Classification and evaluation of forest sites on the southern Cumberland Plateau. Gen. Tech. Rep. SO-23. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 59 p.
- Smalley, G.W. 1982. Classification and evaluation of forest sites on the Mid-Cumberland Plateau. Gen. Tech. Rep. SO-38. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 58 p.
- Smalley, G.W. 1984. Classification and evaluation of forest sites in the Cumberland Mountains. Gen. Tech. Rep. SO-50. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 84 p.
- Smalley, G.W. 1986a. Classification and evaluation of forest sites on the northern Cumberland Plateau. Gen. Tech. Rep. SO-60. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 74 p.
- Smalley, G.W. 1986b. Site classification and evaluation for the Interior Uplands; forest sites of the Cumberland Plateau and Highland Rim/Pennyroyal. Tech. Publ. R8-TP9. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station and Southern Region. 518 p.
- Smalley, G.W. 1991a. No more plots; go with what you know; developing a forest land classification system for the Interior Uplands. In: Mengle, D.; Tew, T., ed. *Ecological land classification: applications to identify the productive potential of southern forests*, proceedings of a symposium. Gen. Tech. Rep. SE-68. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 48-58.
- Smalley, G.W. 1991b. Classification and evaluation of forest sites on the Natchez Trace State Forest, State Resort Park, and Wildlife Management Area in west Tennessee. Gen. Tech. Rep. SO-85. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 73 p.
- Springer, M.E.; Elder, J.A. 1980. *Soils of Tennessee*. Agricultural Experiment Station Bulletin 596. Knoxville, TN: University of Tennessee Agricultural Experiment Station. 66 p. + map.
- Swingle, G.D.; Miller, R.A.; Luther, E.T. [and others], comps. 1966. *Geology map of Tennessee, east-central sheet*. Scale 1:250,000. Nashville, TN: State of Tennessee, Department of Conservation, Division of Geology.
- Wertz, W.A.; Arnold, J.F. 1975. Land stratification for land-use planning. In: Bernier, G.; Winget, C.H., eds. *Forest soils and forest land management*. Proceedings, fourth North American forest soils conference. Quebec, Canada: Les Presses de l'Universite Laval: 617-629.

# A COMPARISON OF TOOLS FOR REMOTELY ESTIMATING LEAF AREA INDEX IN LOBLOLLY PINE PLANTATIONS

Janet C. Dewey, Scott D. Roberts, and Isobel Hartley<sup>1</sup>

**Abstract**—Light interception is critical to forest growth and is largely determined by foliage area per unit ground, the measure of which is leaf area index (LAI). Summer and winter LAI estimates were obtained in a 17-year-old loblolly pine (*Pinus taeda* L.) spacing trial in Mississippi, using three replications with initial spacings of 1.5, 2.4, and 3.0 m. Direct estimates of summer LAI were made in August of 2001 using allometric methods. Monthly litter trap collections were used to determine the change in LAI between August and January; winter LAI was derived by subtraction from summer values. Indirect estimates of LAI were made using a LI-COR LAI-2000 Plant Canopy Analyzer (PCA) and hemispherical photography in conjunction with Delta-T HemiView 2.1 software. As remote estimators of LAI, both the PCA and hemispherical photographs underestimated summer maximum LAI, and neither tool appeared to be sensitive to seasonal change in LAI.

## INTRODUCTION

Estimates of leaf area index (LAI) have been used to measure radiation interception, photosynthetic capacity, forested stand stress levels, net canopy carbon gain, and stand productivity. Stand management decisions and stand growth predictions require accurate determination of LAI, thus a rapid inexpensive estimation of LAI is desirable. Numerous methods have been employed to estimate LAI: destructive biomass harvesting, allometric relationships based on tree and stand attributes, litterfall collections, remote sensing approaches, instantaneous measures of light transmittance (such as the LI-COR LAI-2000 or light ceptometer), and gap fraction analysis of canopy hemispherical photographic images. Several workers have compared methods of LAI estimation, (Chason and others 1991; Chen and others 1991, 1997; Fassnacht and others 1994; Gatch and others 2002; Gower and Norman 1991; Hebert and Jack 1998; Lopez-Serrano and others 2000; Machado and Reich 1999; Macfarlane and others 2000; Sampson and others 2003; Sampson and Allen 1995; Wang and others 1992), and most agree that a number of these methods have site-specific limitations.

Loblolly pine (*Pinus taeda* L.) canopies present a unique set of challenges to the measurement of LAI. LAI in loblolly pine stands varies annually with foliage cohort. In a study of loblolly pine in North Carolina, Sampson and others (2003) reported that foliage development occurred in three distinct stages, each transpiring over a 4-month growth cycle. LAI should thus peak around August, prior to fall foliage abscission. Minimum LAI should occur during the winter months, prior to needle accretion. Compounding seasonal variations in LAI are variations associated with climatic regime. In loblolly pine stands, the rate and quantity of foliage abscission may be a function of water availability (Albaugh and others 1998, Sampson and others 2003, Sampson and Allen 1998), while nutrient availability can strongly influence shoot-clumping (Hebert and Jack 1998, Sampson and Allen 1995, Sampson and Allen 1998). Additionally, estimates of LAI may be influenced by stand basal area (Gatch and others 2002), and thus these estimates may also be influenced by stand management and/or mortality in mature stands. The net result is that the timing of LAI measurement will influence the measurement

outcome, and the ability to accurately estimate LAI in mature loblolly pine stands tends to decrease with increasing LAI.

Sampson and others (2003) hypothesized that of the methods available to estimate LAI in forest stands, instantaneous methods such as those using the PCA should provide the best estimates of seasonal variations in LAI. Rich (1990) suggested that hemispherical photography might also be effectively used to measure seasonal changes in foliage densities. Few studies have actually compared seasonal values in loblolly pine stands (Harrington and others 2002, Hebert and Jack 1998, Sampson and others 2003). Our objectives were: (1) to compare the capabilities of two remote estimators of LAI relative to summer maximum LAI estimates derived from standard allometric approaches, and (2) to compare the sensitivity of remote estimators of LAI to seasonal changes in LAI as estimated from litter trap collections.

## METHODS

### Site Descriptions

The study is located in Winston County, MS, on the Mississippi State University John W. Starr school forest (33°16' N, 88°52' W). The study area is situated in an interior flatwood site with an average precipitation of 1,430 mm and a site index of 23 m in 25 years for loblolly pine (Roberts and others 2003). The study was conducted in a 17-year-old loblolly pine plantation (established in 1986). Average heights ranged from 16 to 20 m, and stands generally had closed canopies with the exception of localized mortality gaps. The study design included three replicates of three treatments consisting of loblolly pine at initial square spacings of 1.5 m, 2.4 m, and 3.0 m. Twenty-four 149 m<sup>2</sup> plots of each spacing, for a total of 72 plots, were included in the study.

### Direct Estimates

Direct measurements of LAI were obtained through allometric approaches. Summer maximum individual tree leaf areas (LA) were calculated from diameter at breast height (d.b.h.) and tree height (HT) using locally derived (based on destructive sampling) allometric equations. In August, 2001, all trees from each plot (n range = 4 to 50 trees, average = 22 trees)

<sup>1</sup> Research Associate III, Associate Professor, and Research Associate I, respectively, Department of Forestry, Mississippi State University, Mississippi State, MS 39762.

were measured for d.b.h. and HT. Tree HT and d.b.h. were used to calculate individual tree LA in m<sup>2</sup> as follows:

$$LA = 0.000313 \times dbh^{2.2919} \times height^{-0.1971} \quad (1)$$

Total LA for the plot was obtained by summing the LA of all trees on the plot. Summer maximum LAI was obtained by dividing total plot LA by plot area.

Winter LAI values were derived from summer allometric data and litterfall data for 5 months. Three 0.5 m<sup>2</sup> litter traps were placed at random within each plot. Litter was collected monthly from August, 2001, to January, 2002. Litter collections were combined to yield a single composite sample per plot. Samples were pre-dried in preparation for sorting. Samples were sorted into needles and other materials (twigs, bark, catkins, and other debris) to remove all material except whole needles and needle fragments. The pine needles were then dried at 70 °C for a minimum of 48 hours to achieve constant weight and weighed to the nearest 0.1 g. Total per-plot monthly weights were summed to provide needle-fall weights on a per-plot basis for the interval of August 2001-January 2002. Seasonal change in leaf area ( $\Delta LA$ ) was calculated as:

$$\Delta LA = [\text{dry weight (g)/trap area (m}^2\text{)}] \times [43\text{cm}^2/\text{g}] \times [1\text{m}^2/10000\text{cm}^2] \quad (2)$$

Winter LAI was determined by subtracting  $\Delta LA$  from the summer maximum LAI values.

### Indirect Estimation of LAI using Plant Canopy Analyzer (PCA)

In September, 2001, and January, 2002, LAI was estimated using a pair of Licor LAI-2000 plant canopy analyzers (PCA, Licor Inc., Lincoln, NE). Simultaneous readings were taken inside and outside of the canopy. All readings were taken in the early morning hours, from dawn until direct sunlight began reflecting from the tops of the crowns. LAI-2000 readings were taken with a 45° view cap attached to the lens and the center of the 45° view cap facing due north at 1.37 m above ground. Within the canopy, readings were taken along the southern border of the plot, with a sampling range of 4.75 m in the east-west direction and 1.0 m in the north-south direction. Five readings were taken within the sampling range: two readings within tree rows and three readings between tree rows.

Data were processed using LI-COR C2000 software. Data were filtered for “bad pairs” (for example pairs in which the ratio of sensor A to sensor B differed from other pair readings within the same ring), which may result from sensor obstruction or deviation from level position. The results of the outside-plot values were examined and, when determined to deviate from zero, a correction multiplier was applied to simultaneous within-plot readings. All data were processed with a mask on ring five. LAI was calculated using the LI-COR software.

### Indirect Estimation of LAI using Hemispherical Photography

In summer 2001 and winter 2002, hemispherical photographic images were taken following general procedural recommendations for vertical photographs in forest canopies (Becker and others 1989, Chen and others 1991). Images were taken from plot center at a height of 1.37 m above ground level with a Nikon Coolpix990 digital camera equipped with a fisheye lens. The camera was mounted on a self-leveling tripod and

aligned to magnetic north. Images were photographed at a resolution of 2,048 x 1,536 pixels, with focus set at infinity and shutter speed and aperture set automatically. Images were taken using three image quality settings: fully automatic color, black and white with high-sharpness, and color with reduced-contrast and high-sharpness. It was later determined that the reduced-contrast, high-sharpness images yielded the best images for processing; i.e., sky appeared as white and foliage elements appeared as black. All images were taken in early morning hours or in overcast conditions, so the sky background was evenly illuminated, and no sunlight was reflected by vegetation.

Prior to analysis, images were processed using Adobe Photoshop 7.0. Images were examined for evidence of “washed-out” areas due to reflected sunlight. Washed-out areas, which occurred in 10 of 144 images, were adjusted to match the rest of the image using Photoshop’s lasso tool and image adjustment features. An opaque circle overlay was created to exclude portions of the image outside of a 58° zenith angle which was the portion of the image determined trigonometrically to be outside of the plot area. Images were saved as jpeg files and imported into HemiView 2.1 canopy analysis software (Delta-T Devices Ltd.) for analysis. The HemiView software was used to estimate LAI from the images based on image gap fraction, using eight azimuth and seven zenith sectors within the unmasked portion.

## RESULTS AND DISCUSSION

### Comparison of the Capabilities of Two Remote Estimators of LAI Relative to Summer Maximum LAI Estimates Derived from Standard Allometric Approaches

Most reported LAI values are understood to have been acquired at maximum leaf area display, which for loblolly pine would be during August in normal years (Sampson and others 2003) and up to 2 months earlier during dry years (Hebert and Jack 1998). August summer maximum estimates of LAI in this study derived from standard allometric approaches ranged from 1.50 to 5.41, which is within the expected range for loblolly pine (Sampson and Allen 1995). Summer LAI for 1.5 m, 2.4 m, and 3.0 m spacings averaged 4.20, 4.13, and 3.99, respectively, with an overall mean of 4.07 (fig. 1). Differences were not significant at  $\alpha = 0.05$ .

Estimates of summer LAI from the PCA (range = 1.57 to 5.57) and hemispherical photography (range = 2.73 to 4.55) were also within the expected range for loblolly pine (Sampson and Allen 1995). The two remote estimators compared well with each other: means for the PCA and hemispherical photography were 3.39 and 3.33, respectively. However, the remote methods underestimated the allometric mean by 17 and 18 percent, respectively (fig. 2). This is typical of remote estimates in most conifer stands (Chen 1996, Fassnacht and others 1994, Gower and Norman 1991). Both methods have been reported to be biased due to blockage of light by boles and non-random distribution of foliage elements (Barclay and others 2000, Chen 1996, Fassnacht and others 1994, Gower and Norman 1991). Gower and Norman (1991) developed a procedure for determining a stand-specific “clumping factor” which could be used to ameliorate this effect; however, we made no attempt to correct the remote estimates as the method is costly to estimate and has not performed well in

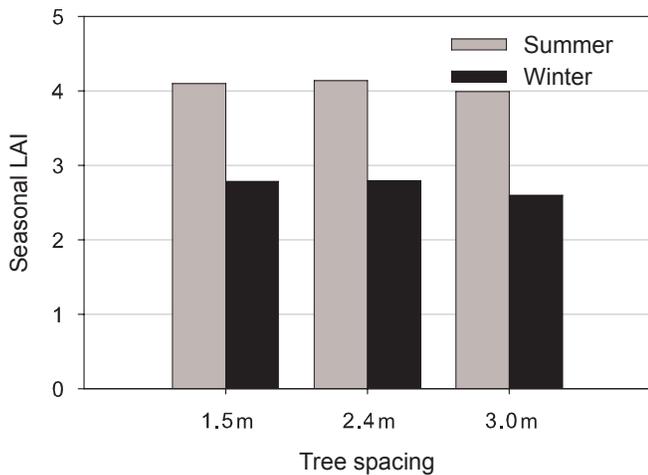


Figure 1—Direct estimates of mean summer and winter LAI ( $m^2/m^2$ ) by initial spacing. Differences among spacing within seasons were not significant at  $\alpha = 0.05$ .

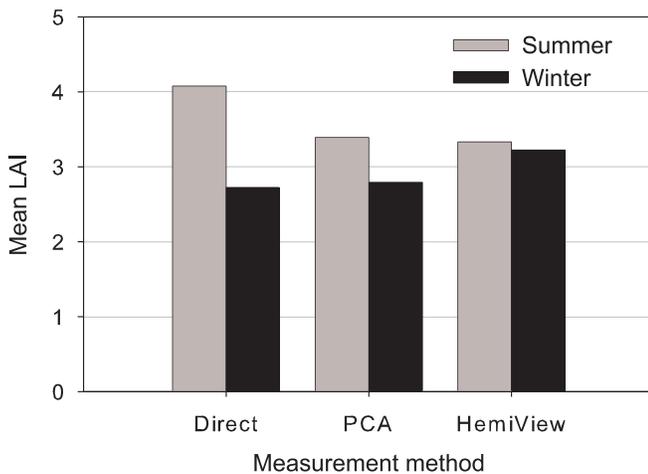


Figure 2—Comparison of means for direct and remote estimates of LAI ( $m^2/m^2$ ), for summer and winter measurements, combined across plots.

some studies (Fassnacht and others 1994, Hebert and Jack 1998).

### Comparison of the Sensitivity of Two Remote Estimators of LAI to Seasonal Changes in LAI as Estimated from Litter Trap Collections

Litterfall-based estimates of seasonal change in LAI by spacing treatment yielded  $\Delta$ LAI values of 1.32, 1.34, and 1.39 for 1.5 m, 2.4 m, and 3.0 m spacings, respectively. Winter estimates of LAI ranged from 0.85 to 3.97. Mean winter LAI for 1.5 m, 2.4 m, and 3.0 m spacings were 2.78, 2.79, and 2.60, respectively, with an overall mean of 2.73. Differences were not significant at  $\alpha = 0.05$ .

Estimates of winter LAI from the PCA (range = 1.49 to 5.06) and hemispherical photography (range = 2.71 to 4.00) were also within the expected range for loblolly pine (Sampson and Allen 1995); however, in contrast to the underestimated summer values (fig. 2), neither the PCA nor hemispherical

photographs underestimated winter values. Winter versus summer correlation plots for all three methods are presented in figure 3.

The PCA overestimated winter LAI by 2 percent (overall mean = 2.79). Mean winter LAI values for 1.5 m, 2.4 m, and 3.0 m spacings were 2.92, 2.79, and 2.67, respectively. Differences were not significant at  $\alpha = 0.05$ . A strong relationship, though not 1:1, was found between the direct estimates for summer and winter LAI with little scatter (fig. 3a). Summer and winter LAI values, as measured by the PCA, had a weaker correlation ( $r^2 = 0.7554$ ) than that of the direct estimates, and the slope and y-intercept were lower (fig. 3b). Sampson and others (2003) hypothesized that of the methods available to estimate LAI in forest stands, instantaneous methods such as the PCA should prove the best estimate of seasonal variations in LAI. In this loblolly pine stand, the PCA was a weak estimator of summer LAI but appeared to provide reliable estimates of winter LAI.

Underestimation of LAI by the PCA is often attributed to clumping and nonrandom distribution of foliage (Fassnacht and others 1994, Gower and Norman 1991, Sampson and Allen 1995, van Gardingen and others 1999). Workers have attempted to apply correction factors to the results, with limited success. Sampson and others (2003) stated that while site-specific corrections to PCA estimates may be valid and necessary, there is insufficient evidence that the corrections are easily and reliably applicable. The results from this study suggest that there is a threshold level of LA above which the LAI-2000 is unreliable, and that the threshold level lies somewhere between the winter and summer values for these loblolly pine stands. As needle abscission increases, the canopy appears to approach a more random distribution of foliage elements. This is consistent with the findings of Sampson and Allen (1995).

Hemispherical photography overestimated winter LAI by 18 percent (mean = 3.22); mean winter LAI values for 1.5 m, 2.4 m, and 3.0 m spacings were 3.22, 3.12, and 3.22, respectively. Differences were not significant at  $\alpha = 0.05$ . There was no correlation between winter and summer LAI estimates obtained from hemispherical photography (fig. 3c). The change in mean LAI from summer to winter represented a decrease of only 0.11, indicating that the hemispherical photography was not sensitive to seasonal changes in these loblolly pine stands. There is typically a roughly 40 percent drop in LAI from summer to winter for loblolly pine. LAI values obtained from hemispherical photography were 18 percent lower than direct estimates in the summer and 18 percent higher than direct estimates in the winter. This suggests that mean LAI as determined from hemispherical photography may represent a value midway between “true” summer and winter LAI.

### SUMMARY AND CONCLUSIONS

Spacing effects on LAI were not seen for any of the estimation approaches used: allometry, LAI-2000 plant canopy analyzer, or hemispherical photography. Both the PCA and hemispherical photographs were comparable as estimators of summer LAI in these loblolly pine stands, although both methods underestimated LAI by approximately 20 percent. This result is most likely the result of foliage clumping in these closed-canopy loblolly pine stands.

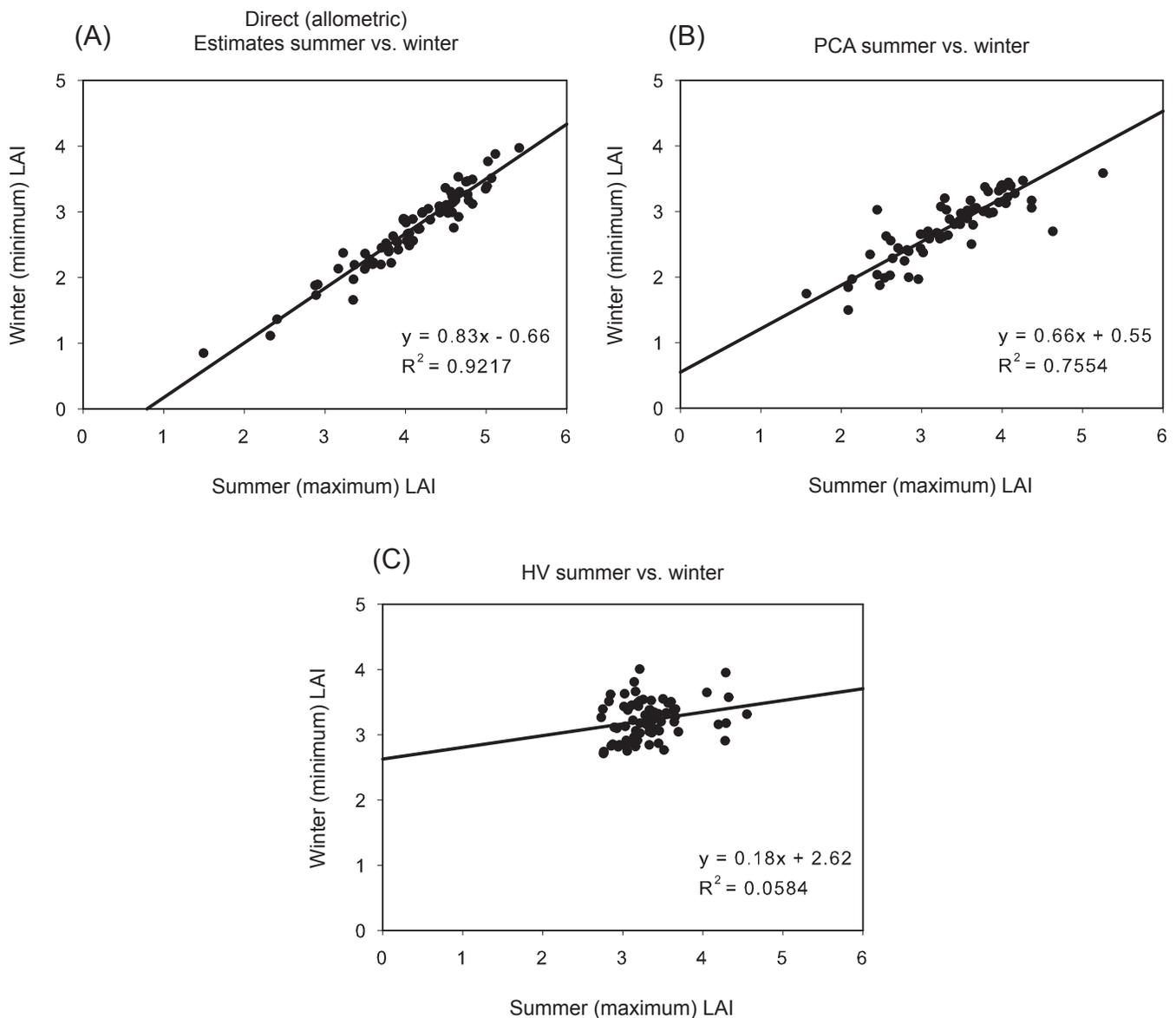


Figure 3—Correlation between estimates of summer and winter LAI ( $m^2/m^2$ ): (A) Relationship between summer and winter direct measurements, (B) relationship between summer and winter PCA measurements and (C) relationship between summer and winter hemispherical photography measurements.

Of the two indirect estimation approaches examined, the PCA was more sensitive to seasonal changes in LA. The PCA yielded a mean winter LAI of 2.79 as compared to the mean direct winter estimate LAI of 2.73. LAI measurements using the PCA yielded a seasonal change of 18 percent (from 3.39 in summer to 2.79 in winter) as compared to a 33 percent seasonal change yielded by direct methods. Hemispherical photography was not sensitive to seasonal change in LA, greatly overestimating winter LAI. Hemispherical photography yielded a mean winter LAI of 3.22 as compared to the direct estimate value of 2.73. The measured seasonal change was only 4 percent (from 3.33 in summer to 3.22 in winter), as compared with 33 percent from direct methods.

LA of mature, closed-canopy loblolly pine stands in this region may be too high for remote methods of LAI determination to be effective in summer. Following fall needle abscission, the

LAI-2000 PCA appeared to be more accurate at measuring winter LAI, suggesting that there is a threshold level of LA above which the LAI-2000 is unreliable. That threshold level appears to lie somewhere between the winter and summer values for loblolly pine stands in north-central Mississippi.

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#### LITERATURE CITED

Albaugh, T.J.; Allen, H.L.; Dougherty, P.M. [and others]. 1998. Leaf area and above- and belowground growth responses of loblolly pine to nutrient and water additions. *Forest Science*. 44(2): 317-328.

- Barclay, H.J.; Trofymow, J.A.; Leach, R.I. 2000. Assessing bias from boles in calculating leaf area index in immature Douglas-fir with the LI-COR canopy analyzer. *Agricultural and Forest Meteorology*. 100: 255-260.
- Becker, P.; Erhart, D.W.; Smith, A.P. 1989. Analysis of forest light environments part I. Computerized estimation of solar radiation from hemispherical canopy photographs. *Agricultural and Forest Meteorology*. 44: 217-232.
- Chason, J.W.; Baldocchi, D.D.; Huston, M.A. 1991. A comparison of direct and indirect methods for estimating forest canopy leaf area. *Agricultural and Forest Meteorology*. 57: 107-128.
- Chen, J.M. 1996. Optically based methods for measuring seasonal variation of leaf area index in boreal conifer stands. *Agricultural and Forest Meteorology*. 80: 135-163.
- Chen, J.M.; Black, T.A.; Adams, R.S. 1991. Evaluation of hemispherical photography for determining plant area index and geometry of a forest stand. *Agricultural and Forest Meteorology*. 56: 129-143.
- Chen, J.M.; Rich, P.M.; Gower, S.T. [and others]. 1997. Leaf area index of boreal forests: techniques, and measurements. *Journal of Geophysical Research*. 102(D24): 29,429-29,443.
- Fassnacht, K.S.; Gower, S.T.; Norman, J.M.; McMurtrie, R.E. 1994. A comparison of optical and direct methods for estimating foliage surface area index in forests. *Agricultural and Forest Meteorology*. 71: 183-207.
- Gatch, J.A.; Harrington, T.B.; Castleberry, J.P. 2002. LAI-2000 accuracy, precision, and application to visual estimation of leaf area index of loblolly pine. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 77-78.
- Gower, S.T.; Norman, J.M. 1991. Rapid estimation of leaf area index in conifer and broad-leaf plantations. *Ecology*. 72(5): 1896-1900.
- Harrington, T.B.; Gatch, J.A.; Borders, B.E. 2002. Seasonal dynamics in leaf area index in intensively managed loblolly pine. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 79-80.
- Hebert, M.T.; Jack, S.B. 1998. Leaf area index and site water balance of loblolly pine (*Pinus taeda* L.) across a precipitation gradient in East Texas. *Forest Ecology and Management*. 105: 273-282.
- Lopez-Serrano, F.R.; Landete-Castillejos, T.; Martinez-milan, J.; del Cerro-Barja, A. 2000. LAI estimation of natural pine forest using a non-standard sampling technique. *Agricultural and Forest Meteorology*. 101: 95-111.
- Macfarlane, C.; Coote, M.; White, D.A.; Adams, M.A. 2000. Photographic exposure affects indirect estimation of leaf area in plantations of *Eucalyptus globulus* Labill. *Agricultural and Forest Meteorology*. 100: 155-168.
- Machado, J.L.; Reich, P.B. 1999. Evaluation of several measures of canopy openness as predictors of photosynthetic photon flux density in deeply shaded conifer-dominated forest understory. *Canadian Journal of Forest Research*. 29: 1438-1444.
- Rich, P.R. 1990. Characterizing plant canopies with hemispherical photographs. *Remote Sensing Reviews*. 5(1): 13-29.
- Roberts, S.D.; Dean, T.J.; Evans, D.L. 2003. Family influences on leaf area estimates derived from crown and tree dimensions in *Pinus taeda*. *Forest Ecology and Management*. 172: 261-270.
- Sampson, D.A.; Albaugh, T.J.; Johnsen, K.H. [and others]. 2003. Monthly leaf area index estimates from point-in-time measurements and needle phenology for *Pinus taeda*. *Canadian Journal of Forest Research*. 33: 2477-2490.
- Sampson, D.A.; Allen L.H. 1995. Direct and indirect estimates of leaf area index (LAI) for lodgepole and loblolly pine stands. *Trees*. 9: 119-122.
- Sampson, D.A.; Allen, H.L. 1998. Light attenuation in a 14-year-old loblolly pine stand as influenced by fertilization and irrigation. *Trees*. 13: 80-87.
- Van Gardingen, P.R.; Jacksin, G.E.; Hernandez-Dumas, S. [and others]. 1999. Leaf area index estimates obtained for clumped canopies using hemispherical photography. *Agricultural and Forest Meteorology*. 94: 243-257.
- Wang, Y.S.; Miller, D.R.; Welles, J.M.; Heisler, G.M. 1992. Spatial variability of canopy foliage in an oak forest estimated with fisheye sensors. *Forest Science*. 38: 854-865.

# USING FOREST VEGETATION SIMULATOR TO AID COMMUNICATIONS BETWEEN NATURAL RESOURCE MANAGERS AND STAKEHOLDERS

Randall P. Rawls and Edward F. Loewenstein<sup>1</sup>

**Abstract**—Due to differences in perspective, natural resource managers and members of the general public often find it difficult to communicate with each other concerning alternative management scenarios. Natural resource managers often consider and describe the forest in numeric terms such as number of trees, basal area, and volume per acre. Members of the general public are more likely to consider management implications from a visual perspective. With the ability to produce computer-generated, graphical images of the stand over time, the Stand Visualization System (SVS) and the Forest Vegetation Simulator (FVS) may provide an interactive means of communication that bridges the gap between these two perspectives. To demonstrate the potential of this tool, FVS was used to project future stand conditions based on five different real estate cuts applied in a pine plantation. The graphical and numeric information produced by SVS and FVS was then used to determine relative stakeholder preference for each regime over time.

## INTRODUCTION

Rapid population growth and urbanization of once rural areas have become a great concern to forest managers operating near the wildland-urban interface (WUI). Despite the fact that the forested setting of WUI is often cited as one of the amenities attracting people to these areas, care and maintenance of the forest is often of very low priority for the new stakeholders. Typical manipulation of the forest in an urbanizing area centers on the facilitation of real estate and infrastructure development, with little or no consideration given to how the forest will respond to urbanization over time. Wear and Gries (2002) cite urbanization as the leading threat to southern forest land for the next 40 years.

As once-rural pine plantations are being converted to residential developments, social resistance to traditional plantation management practices may limit the range of alternative management practices available to natural resource managers. The resistance of WUI stakeholders to nonindustrial forest management may be due, in part, to the fear of aesthetic results as well as adverse economic factors and distrust in traditional forest management practices. A further limiting factor may be the forest managers' inability to effectively communicate aesthetic outcomes from alternative management practices to those unfamiliar with forest operations. This is perhaps because forest managers are trained to consider management implications in numeric terms, such as number of trees, basal area, and volume per acre while such abstract terms mean little to the lay person. Instead, they are more likely to consider potential management implications from a visual perspective (e.g. what will it look like?). With the ability to produce computer-generated, graphical images of the stand over time, the Stand Visualization System (SVS) module of the Forest Vegetation Simulator (FVS) may offer forest managers and their constituents an interactive means of communication that bridges the gap between these two perspectives.

To demonstrate the potential of this tool, FVS was used to project future stand conditions based on five different management regimes applied in a pine plantation at the wildland-urban interface in the Piedmont region of central Alabama.

The graphical and numeric information produced by FVS was then used to determine relative stakeholder preference for the aesthetics, economics, and wildfire potential associated with each regime over time.

## METHODS

### Study Area

The study was located within a 40-ha stand belonging to Alabama Power Company that was of high real estate value due to its proximity to Lake Martin near Dadeville, AL. The site consisted of an 18-year-old pine plantation containing approximately 27.5 m<sup>2</sup> ha<sup>-1</sup> of pine basal area in the overstory and another 1.9 m<sup>2</sup> ha<sup>-1</sup> of hardwood basal area in the understory. Soils on this site are typical of the Piedmont physiographic region of central Alabama. Slopes are moderate, and the site is transected by a stream that empties directly into Lake Martin at the edge of the property.

### Treatments

Five treatments representing a gradient of removal intensities and spatial distributions were applied to the stand. These same treatments were projected 20 years into the future using the FVS growth and yield software. The treatments are as follows:

1. No removal—no removal was simulated throughout the projection period. The stand was allowed to continue growing without management. Regeneration is not expected to occur in this stand.
2. Conventional removal—a typical fifth-row thin with operator select on the residual rows, reducing the residual basal area to approximately 16.0 m<sup>2</sup> ha<sup>-1</sup>. This treatment left most of the larger trees and provided them with resources needed for growth but relatively little regeneration is expected to occur.
3. Heavy thin—a typical fifth-row thin with operator select on the residual rows reduced the residual basal area to approximately 9.2 m<sup>2</sup> ha<sup>-1</sup>. This treatment left only the largest trees and provided them with resources needed for growth; moderate amounts of regeneration are expected to occur.

<sup>1</sup> Graduate Research Assistant and Assistant Professor of Silviculture, respectively, School of Forestry and Wildlife Sciences, 602 Duncan Drive, Auburn University, Auburn, AL 36849-5418.

4. Strip removal—complete removal of two strips totaling one third of the stand at each of three entries. The Conventional thin was applied to the residual portion of the stand at each 10-year cycle. This treatment is the quickest means of converting the stand to mixed species and provides a protected view of the ongoing forest conversion from a downhill perspective. Large amounts of regeneration are expected in the strips.
5. Maintenance removal—a typical fifth-row thin with operator select on the residual rows reduced the residual basal area to approximately 16.0 m<sup>2</sup> ha<sup>-1</sup> and maintained this amount throughout the life of the stand. This treatment results in progressively fewer but larger trees in the stand throughout time. Relatively little regeneration is expected during the projection period.

### Factors of Interest

Three pieces of information from the projections are of particular interest:

1. Aesthetics—SVS used FVS output to produce several images for each treatment. The time series of images included: initial stand conditions prior to any removal treatments, the post-treatment stand, and an image of the stand at each 10-year interval. Two view perspectives, a profile view and a perspective view, of each image were produced.
2. Wildfire hazard—Using the fire and fuel extension of FVS, we produced a relative wildfire fire hazard based on flame length. Each image was assigned to one of three wildfire hazard categories including: low (0 to 1.19 m), moderate (1.20 to 1.83 m), and high ( $\geq 1.84$  m).
3. Economics—Each time the prescription called for a removal, a cost and revenue for each image and a net present value of each management regime was calculated over the entire projection cycle.

Additionally, an estimate of wildlife species one might expect to find utilizing the forest structure existing at each point in time, for each management regime, is presented. Each of these factors was included in the survey instrument.

### Survey Instrument

A survey instrument consisting of two parts was produced to determine the preferences for each of the management regimes. Part I collected demographic data, knowledge of forest management, and experience with forest management. Part II asked the respondent to rate their preference for each image on a Likert scale and to rank their preference for each alternative relative to the others. Each image included the aesthetic, economic, fire hazard, and wildlife information outlined above. This section of the survey also included a time series of images for each management regime.

Four different stakeholder groups were included in the target population including: (1) an urban residence group, (2) a rural residence group, (3) a wildland-urban interface residence group, and (4) all county commissioners in Alabama. The first three groups provide an idea of how the preference for each strategy will change across a population density gradient, while the commissioner group provides a policy perspective.

### RESULTS

We are currently in the data collection phase of the project. The management scenarios have been developed, the research protocol was submitted and approved by the Office of Human Subjects Research, the survey instrument has been finalized and tested, and the target population has been contacted and invited to participate in the survey. Completion of the study is projected for August 2005.

### LITERATURE CITED

Wear, D.N.; Greis, J.G. 2002. Southern forest resource assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 635 p.

# EFFECTS OF PLANTING DENSITY ON THE BIOMASS PARTITIONING OF INTENSIVELY MANAGED LOBLOLLY PINE STANDS ON THE PIEDMONT AND UPPER COASTAL PLAIN OF GEORGIA

Rodney E. Will, Nikhil Narahari, Robert O. Teskey,  
Barry D. Shiver, and Matthew Wosotowsky<sup>1</sup>

## Poster Summary

Increased planting density enhances overall stand growth by increasing resource capture and use. However, planting density also may affect the proportion of biomass partitioned to stem growth, a main factor controlling stand growth and yield. During the fourth growing season, we determined the biomass partitioned to leaf, branch, stem, and fine root (> 0.5mm) of intensively managed loblolly pine (*Pinus taeda* L.) stands in the Upper Coastal Plain and Piedmont of Georgia growing at 6 densities ranging from 740 to 4,440 trees ha<sup>-1</sup> (5 replications). Current annual increment during the fourth growing season increased from 4,573 to 12,671 kg ha<sup>-1</sup> as stand density increased from 740 to 4,440 trees ha<sup>-1</sup>. Stem, leaf, and branch

biomass all significantly increased with increasing planting density. However stem biomass increased to a greater extent. Therefore, biomass partitioning to stem relative to other stand components increased with increasing stand density. As stand density increased, the ratio of stem growth per foliage biomass increased from 1.02 to 1.54, the ratio of standing stem biomass to branch biomass increased from 1.77 to 3.27, and the ratio of standing stem biomass to fine root biomass increased from 3.56 to 7.79. These results indicate that in addition to increasing growth due to greater resource capture, planting density increases growth and yield by shifting production to stem growth.

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<sup>1</sup> Associate Professor, University of Georgia, Warnell School of Forest Resources, Athens, GA 30602; Research Coordinator, North Carolina State University, Department of Botany, 2214 - A Gardner Hall, Raleigh, NC 27695; and Professor, Professor, and Graduate Research Assistant, respectively, University of Georgia, Warnell School of Forest Resources, Athens, GA 30602.

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## **Longleaf Pine**

*Moderator:*

**DEAN GJERSTAD**  
Auburn University



# SEPARATING LIVE FROM DEAD LONGLEAF PINE SEEDS: GOOD AND BAD NEWS

James P. Barnett and R. Kasten Dumroese<sup>1</sup>

**Abstract**—Of all southern pine seeds, longleaf pine (*Pinus palustris* Mill.) are the most difficult to collect, process, treat, and store while maintaining good seed quality. As a result, interest in techniques for separating filled dead from live longleaf pine seeds has developed. The good news is that new technologies are becoming available to evaluate seed quality, but the bad news is that they seem to have limited application to longleaf pine. Tests suggest that incubating, drying, and separating, chlorophyll fluorescence, and near infrared techniques do not help improve longleaf pine seed quality. The incubating-drying-separating method is inefficacious because variability in the seed coat wing stub affects seed flotation. The chlorophyll fluorescence method measures changes in chlorophyll content as seeds mature or are damaged, but such changes do not seem to occur in pine seeds. The near infrared method seems to offer the best potential. The use of near infrared scanning technologies can determine changes in seed constituents, but we have not been able to determine which measurable seed constituents may change as viability declines.

## INTRODUCTION

Techniques to improve seed quality, such as winnowing (commonly used for millennia), have as an ultimate goal the capability to separate filled dead from live seeds. Generally, those of us interested in improving the performance of tree seeds have followed the lead of scientists working with agricultural and horticultural seeds. We are working to identify methodologies for improving seed quality, which may address forestry needs.

For decades, the most effective means of improving southern pine seed quality has been to remove all unfilled seeds and then separate damaged or poorly developed seeds from filled seeds. Technology to accomplish these tasks has been based on seed flotation or the use of mechanical equipment. Aspirator and specific gravity table techniques work well for many tree species, but the most effective quality improvements have been achieved by density separation processing. Typically, poor viability is common in some lots of longleaf (*Pinus palustris* Mill.) and other southern pine species, so newer technologies are being sought to improve seed-lot performance. The increased demand for longleaf pine seeds over the last decade has reinforced the need for better separation technology. The primary use of containers for longleaf pine seedling production—and the resulting economic benefits of sowing only one filled seed per container cavity—necessitate techniques to cull filled but dead seeds. Of course, the ultimate goal is to achieve 100 percent germination. But is it possible to determine which of two seemingly identical filled seeds is dead, and which is alive?

This paper reports on a series of evaluations of longleaf pine seeds using newer technologies that potentially could improve seed quality. We considered three different approaches. The first is incubating-drying-separating (IDS) fluid separation. Certain IDS procedures have been used for a number of years, and IDS can help separate nonviable from viable seed lots of a number of coniferous species (Bergsten 1987, Downie and Wang 1992, Simak 1984). This methodology, however, has not been critically evaluated with longleaf pine seeds.

The second approach, chlorophyll fluorescence (CF), is used to measure plant photosynthetic health. Studies have found that CF scans can be used as a noninvasive method for determining seed maturity and quality. Jalink and others (1998) reported that CF scanning may be a new sorting technique to improve the quality of some species of agricultural seeds. This method has yet to be evaluated for sorting southern pine seeds.

Near infrared (NIR) spectroscopy is the third approach to evaluating seed quality. Williams and others (1985) found NIR a suitable, noninvasive technique to measure protein content of whole grains. Other applications of NIR technology continue to be developed for seed, plant, and forest products use. Portable equipment now available can scan seeds in milliseconds, making NIR attractive as a potential commercial technology.

Research on all three technologies is good news, because they provide possible ways to improve the quality of southern pine seeds. We present the results of our evaluations of each technology using longleaf pine seeds.

## INCUBATING-DRYING-SEPARATING

The IDS process is based on the principle that water imbibed by live seeds is lost at a slower rate than water imbibed by dead filled seeds when both are subjected to uniform drying conditions. Ideally, seeds can then be separated in a liquid medium into a nonviable floating fraction and a viable sinking fraction based on the resulting density differences between the two fractions.

Previous studies of IDS technology have shown limited success with southern pine seeds. Karrfalt (1996) reported that his attempts using IDS to remove fungus-damaged seeds from slash pine (*P. elliottii* Engelm.) failed completely. Donald (1985) achieved positive results, but with slash pine seeds in South Africa. His results indicated that the IDS technique is of little value for low-viability lots, but that separation of a better quality seed lot will improve its germination capacity.

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<sup>1</sup> Research Forester, USDA Forest Service, Southern Research Station, 2500 Shreveport Highway, Pineville, LA 71360; and Research Plant Physiologist, USDA Forest Service, Southern Research Station, 1221 South Main Street, Moscow, ID 83843, respectively.

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McRae and others (1994) studied IDS treatment of loblolly (*P. taeda* L.) and slash pine seeds and its effect on seed cost and efficiency in the nursery. They reported the IDS treatment was used successfully to separate filled-dead from filled-live seeds, but information was inadequate to determine if an economic advantage could be expected from the treatment. McRae and others (1994) wrote that the wing stub and seed size of longleaf made it difficult to evaluate seeds using IDS technology.

Our objective is to determine the optimal IDS and related technology to sort filled-dead from filled-live seeds of longleaf pine. We conducted a series of tests with three lots of longleaf pine seeds: South Carolina 1992, Mississippi 1987, and Mississippi 2000. The application of IDS to the lots failed because of excessive and erratic flotation patterns caused by wing and seed coat characteristics (Creasey 2002). Further evaluations used a combination of Prevac (pressure vacuum system) and imbibitional density separation process (DSP).

Prevac is a treatment used to improve the quality of seeds from many tree species. It mechanically separates damaged seeds and debris in a lot by means of a partial vacuum. The vacuum forces water into damaged seeds, causing them to be heavier and sink when the vacuum is released. The DSP method is an alternative to IDS, but generally it is less reliable. It is a method of separating filled-dead seeds from filled-live ones by monitoring moisture uptake and establishing a sink/float relationship over time. Filled-live seeds sink, while weak, dead, or empty seeds remain floating at a predetermined cut-off time.

Incubation-drying-separating, Prevac, and imbibitional DSP treatments were not successful with longleaf pine seeds. Neither Prevac treatment for 30 or 60 seconds of vacuum at 27 inches mercury nor imbibitional DSP for 24, 43, or 60 hours provided any consistent improvement in seed performance (Creasey 2003) (fig. 1). As McRae and others (1994) found

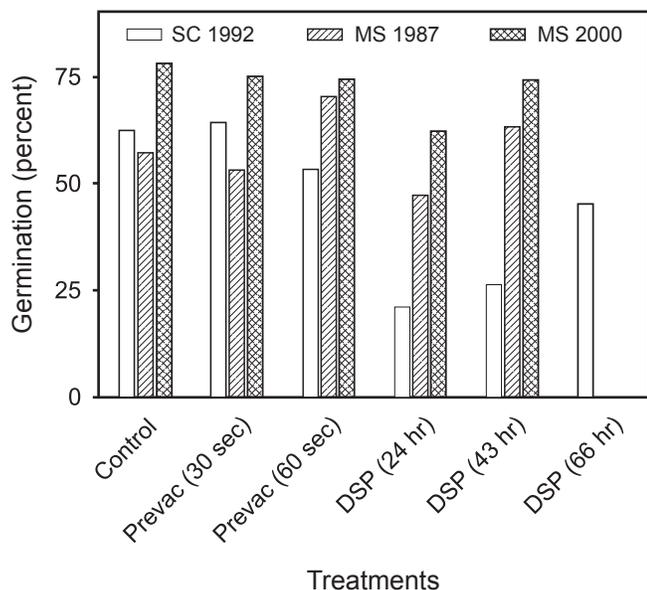


Figure 1—Germination of three lots of longleaf pine seeds subjected to no treatment, Prevac treatment for 30 seconds, and imbibitional density separation processing (DSP) for 24, 43, and 66 hours.

for IDS, the variability of the seed coat and its attached wing stub created flotation problems that prevented the successful application of these techniques.

## CHLOROPHYLL FLUORESCENCE

Chlorophyll fluorescence is a nondestructive and instantaneous method to measure differences in plant function by assessing the magnitude of chlorophyll fluorescence signals. When chlorophyll molecules absorb light during photosynthesis, a small portion of that light is re-emitted, or fluoresced. Numerous studies have used CF to estimate photosynthetic efficiency, which is an indirect measure of plant stress (Adams and others 1990, Gentry and others 1989).

More recently, Ward and others (1995) and Steckel and others (1989) have used CF to estimate seed maturation. For many species, the amount of chlorophyll in the seed coat decreases during maturation, and for carrot (*Daucus carota* L.) and cabbage (*Brassica oleracea* L.) seeds, the change has been related to germination (Jalink and others 1998, Steckel and others 1989).

Because longleaf pine seeds have large embryos with considerable amounts of chlorophyll, we decided to evaluate CF as a method of sorting for viability improvement. Chlorophyll fluorescence was evaluated using Satake Corporation's SeedScan™ technology (Satake Corporation 2002). The SeedScan™ is a tabletop seed-by-seed maturity sorter that is designed to separate seeds based on their germination potential. The unit separates a seed lot into six fractions based on levels of chlorophyll fluorescence. We scanned individual longleaf pine seeds and tracked them through germination tests, enabling us to determine the relationship between the scanning spectra and germination. We evaluated several replications of 100 seeds each. Although CF is related to germination in some species, we could demonstrate no such relationship when scanning longleaf pine seeds.

## NEAR INFRARED SPECTROSCOPY

Near infrared radiation is in the wavelength range of 780 to 2,500 nm, where 400 to 7,800 nm is visible light and above 2,500 nm is infrared. A commercial breakthrough for NIR spectroscopy came when it was shown that this technology could be used to determine the protein content in whole grains (Williams and others 1985).

Today, NIR technology is widely used not only in chemical, pharmaceutical, and food industries, but also in agriculture and wood technology (Downy 1985). The reason for the popularity of NIR spectroscopy is that little or no sample preparation is needed, saving both time and the cost of chemicals (Lestander 2003).

The main use of NIR spectroscopy within the field of seed science is quantifying seed moisture content and chemical constituents like proteins and oils (McClure 1994, Norris 1988). It is now being used as a quantitative tool that relies on chemometrics to develop calibrations relating reference analysis of the seed or plant material to that of the NIR optical spectrum. In other words, germination data have to be correlated to the measured spectrum on the same seeds.

Lestander (2003) has demonstrated the potential of using multivariate NIR spectroscopy for conifer seed classification.

He found that filled viable and nonviable Scots pine (*P. sylvestris* L.) seeds could be separated with an accuracy of < 95 percent.

We have evaluated NIR technology both in informal tests with U.S. Department of Agriculture Forest Service Forest Products scientists and more formally with Brimrose Corporation's Seed Meister™ system. Brimrose's Seed Meister™ AOTF-NIR spectrometer is specially designed for high-speed discrimination, quantification, and sorting of hybrid agricultural seeds (Brimrose Corporation 2002a). The spectrometer has a six-port sorter controlled and selectable by software and can evaluate 16,000 wavelengths (30 scans) per second. The NIR scanning technology can determine oleic and linoleic acid content in sunflower (*Helianthus* spp.) and protein and oil content of soybean (*Glycine* spp.) seeds (Brimrose Corporation 2002a, 2002b).

If the chemical composition of dead seeds were different from live ones, it would be feasible to use NIR methodology to sort them based on viability. We scanned individual seeds from several lots of 100 using NIR systems and had them germinate. We could not discern relationships among scanning spectra and germination potential for longleaf pine seeds.

## SUMMARY

Three different technologies were evaluated to determine the feasibility of separating filled-dead from filled-live longleaf pine seeds. The results of the IDS tests were negative primarily because of the nature of the seeds. Portions of the seed coat wings are retained after seed processing, and the wing stubs vary markedly in both size and shape, making separation using flotation problematic. Although IDS is effective in sorting seeds of some tree species, the technology has shown little potential with longleaf pine. Even with other southern pine species, IDS is a complicated procedure that will be restricted to few commercial operations and may be hard to justify economically.

Chlorophyll fluorescence and NIR techniques are new approaches to evaluating seed quality. Both techniques are nondestructive and instantaneous and offer excellent opportunities for commercial application. Chlorophyll fluorescence depends upon changes in chlorophyll content within the seed coat. In some agricultural species, the technique effectively separates dead from live seeds, because chlorophyll content changes as the seed matures—normally declining as maturity is reached. Conifer seed physiology is such that these changes in chlorophyll content do not occur, so the content is similar in both dead and live mature seeds.

Near infrared technology would seem to offer the best potential for a fast, effective means of sorting seed. We think it logical that as viability in a seed is lost, the composition of some major biochemical component would change, although we have found no chemical change that relates to loss of viability. So, even though NIR has some potential for rapid sorting of seeds on a commercial scale, we have yet to find any relationship between scanning spectra and viability for longleaf pine.

## LITERATURE CITED

- Adams, W.W., III; Demmig-Adams, K.; Winter, K.; Schreiber, U. 1990. The ratio of variable to maximum fluorescence from photosystem II, measured in leaves at ambient temperature and at 77K, as an indicator of the photon yield of photosynthesis. *Planta*. 180: 155-174.
- Bergsten, U. 1987. Incubation of *Pinus sylvestris* L. and *Picea abies* (L.) Karst. seed at controlled moisture content as an invigoration step in the IDS method. Umea, Sweden: Swedish University of Agricultural Sciences, Department of Silviculture. 98 p. Ph.D. dissertation.
- Brimrose Corporation. 2002a. Determination of percent oleic and linoleic acid in sunflower seeds using AOTF-NIR spectroscopy. Application Report #7. Baltimore, MD: Brimrose Corporation of America. 17 p.
- Brimrose Corporation. 2002b. Determination of percent protein and oil in soybean seed using AOTF-NIR spectroscopy. Application Report #8. Baltimore, MD: Brimrose Corporation of America. 11 p.
- Creasey, Kim. 2002. Seed enhancement/upgrading techniques: read the seed. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., tech. coords. National proceedings: Forest and Conservation Nursery Association—1999, 2000, and 2001. Proceedings RMRS-P.24. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 187-195.
- Creasey, Kim. 2003. Exploring longleaf pine—seed upgrading potentials. USFOR Report. Barrie, Ontario, Canada: Nature's Common Elements. 3 p.
- Donald, D.G.M. 1985. The separation of full dead seed from live seed in *Pinus elliotii*. In: South, D.B., ed. Proceedings of the international symposium on nursery management: practices for the southern pines. Auburn, AL: Auburn University School of Forestry: 83-87.
- Downie, B.; Wang, B.S.P. 1992. Upgrading germinability and vigour of jack pine, lodgepole pine, and white spruce by the IDS technique. *Canadian Journal Forestry Research*. 22(8): 1124-1131.
- Downy, G. 1985. Estimation of moisture in undried wheat and barley by near-infrared reflectance. *Journal of the Science of Food and Agriculture*. 36: 951-958.
- Gentry, B.; Briantais, J.M.; Baker, N.R. 1989. The relationship between the quantum yield of photosynthetic electron transport and quenching of chlorophyll fluorescence. *Biochimica et Biophysica Acta*. 990: 87-92.
- Jalink, H.; van der Schoor, R.; Frandas, A. [and others]. 1998. Chlorophyll fluorescence of *Brassica oleracea* seeds as a non-destructive marker for seed maturity and seed performance. *Seed Science Research*. 8: 437-443.
- Karrfalt, R.P. 1996. Upgrading seeds with IDS: a review of successes and failures. In: Landis, T.D.; South, D.B., tech. coords. National proceedings, Forest and Conservation Nursery Associations. Gen. Tech. Rep. PNW-389. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 183-186.
- Lestander, T. 2003. Multivariate NIR studies of seed-water interaction in Scots pine (*Pinus sylvestris* L.). Umea, Sweden: Swedish University of Agricultural Sciences, Department of Silviculture. 63 p. Ph.D. dissertation.
- McClure, W.F. 1994. Near-infrared spectroscopy—the giant is running strong. *Analytical Chemistry*. 66: A43-A53.
- McRae, J.B.; Bergsten, U.; Lycksell, S. 1994. The use of the IDS-treatment on southern pine seeds and its effect on seed cost and efficiency in the seed bed. In: Landis, T.D.; Dumroese, R.K., tech. coords. National proceedings, Forest and Conservation Nursery Associations. Gen. Tech. Rep. RM-257. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 73-79.
- Norris, K.H. 1988. History, present status, and future prospects of NIR. In: Creaser, C.S.; Davies, A.M.C., eds. Analytical applications of spectroscopy. London, UK: Royal Society of Chemistry: 3-8.
- Satake Corporation. 2002. SeedScan™. Houston, TX: Satake Corporation USA, Inc.
- Simak, M. 1984. A method for removal of filled-dead seeds from a sample of *Pinus contorta*. *Seed Technology*. 12: 767-775.

Steckel, J.R.A.; Gray, D.; Rowse, H.R. 1989. Relationships between indices of seed maturity and carrot seed quality. *Annals of Applied Biology*. 114: 177-183.

Ward, K.; Scarth, R.; Daun, J.K.; Vessey, J.K. 1995. Chlorophyll degradation in summer oilseed rape and summer turnip rape during seed ripening. *Canadian Journal of Plant Science*. 75: 413-420.

Williams, P.C.; Norris, K.H.; Sobering, D.C. 1985. Determination of protein and moisture in wheat and barley by near-infrared transmission. *Journal of Agriculture and Food Chemistry*. 33: 239-244.

# SILVICULTURAL ALTERNATIVES IN A LONGLEAF PINE/WIREGRASS WOODLAND IN SOUTHWEST GEORGIA: UNDERSTORY HARDWOOD RESPONSE TO HARVEST-CREATED GAPS

Steven B. Jack, Robert J. Mitchell, and Stephen D. Pecot<sup>1</sup>

**Abstract**—Management of longleaf pine woodlands and savannas in areas that have multiple objectives including conservation of biodiversity is increasingly common on public and private lands, and various silvicultural approaches have been proposed to meet the diverse objectives. While considerable work has investigated how alternative silvicultural systems influence longleaf pine regeneration patterns, few studies document how competing understory hardwoods respond to the proposed silvicultural alternatives. We examined pine regeneration and understory hardwood response as part of a larger study in a mature longleaf pine forest with replicated blocks randomly assigned one of four silvicultural treatments: control (no cutting), single-tree selection, small-group selection, and large-group selection. Following harvest, understory woody (non-pine) plants increased their growth more than 3-fold due to decreased competition with the pine overstory in the gap-based approaches. This resulted in increased hardwood litter in the gaps, which subsequently resulted in fire feedbacks that increased the potential for perpetuating hardwood domination of gaps intended for pine regeneration.

## INTRODUCTION

Fire has molded forests for millennia (Bird and Cali 1998), influencing the manner in which they are structured and regulating their functions. The impact that fire has on ecosystems is perhaps nowhere more evident than in the longleaf pine (*Pinus palustris* Mill.) woodlands and associated communities in Coastal Plain landscapes of the Southeastern United States. Historically, longleaf pine dominated areas of the Coastal Plain, unbroken in its range except for moist, bottomland sites (Wahlenburg 1946). Schwarz (1907) described longleaf pine forests as having an open, park-like appearance with a monotypic pine overstory and a grass-dominated herbaceous understory. The forest was all-aged, with even-aged cohorts regenerating in small patches formed in the largest gaps. This forest structure is found in today's landscape only in the presence of frequent fire.

The species distribution, abundance, and stature of hardwoods (*Quercus* and associated species) reflect interactions between site resources and historical disturbance in longleaf pine forests. The Southeastern Coastal Plain has been described as Southern Mixed Hardwood forests (Kuchler 1964), oak-hickory association (Oosting 1956), and beech-magnolia forests (Delcourt and Delcourt 1987, Pessin 1933). All these classifications represent the potential community outcome if fire is suppressed for sufficient periods of time. However, even with frequent fire many longleaf pine forests are really mixed pine-hardwood forests (see Jacqumain and others 1999), with hardwoods at best relegated to small sprouts as advance regeneration on many sandhills and intermediate sites (flat-wood sites tend to be dominated by gallberry and saw palmetto which invade with fire suppression).

Loss of pine overstory is likely to increase the difficulty of controlling oaks with fire and competition. Open-canopy longleaf pine forests have sufficient light for vigorous hardwood development, where light rarely falls below 30 percent of full sunlight and many sites experience > 50 percent full sunlight (Battaglia and others 2002, 2003; McGuire and others 2001;

Palik and Pederson 1996). However, the degree that competition, especially below ground, from adult pines regulates oak development has been little studied.

Gap-based approaches to management of longleaf pine forests have been suggested as a way to mimic natural disturbance patterns, allowing for regeneration to develop and for the use of frequent fire (Boyer and Peterson 1983). Recommended gap sizes in these approaches are based upon the idea that longleaf pine is an intolerant species (Boyer 1990) and can only be regenerated in large openings (Brockway and Outcalt 1998). However, fire behavior in created gaps may be altered by a lack of needles and greater hardwood litter, initiating feedbacks that discourage fire and increase the dominance and growth of fire-sensitive species (Williams and Black 1981).

To better understand how silvicultural alternatives influence pine seedlings and oaks in the understory, we harvested a second-growth longleaf pine woodland using single-tree selection and two group selection approaches (Battaglia and others 2002, 2003; Jones and others 2003; Palik and others 2003; Pecot and others 2006). The objective of this work, which was part of a larger study, was to investigate the manner in which longleaf pine interacts with hardwood sprouts and longleaf pine seedlings across ranges of pine stocking and gap sizes.

## METHODS

### Study Site

The research was conducted at the Joseph W. Jones Ecological Research Center in southwest Georgia on the Coastal Plain region of the Southeastern United States. The climate is subtropical with mean daily temperature ranging from 11 °C to 27 °C. Annual precipitation averages 132 cm/year, evenly distributed throughout the year. Soils of the study site are of the Orangeburg series, a fine-loamy, siliceous, thermic typic Paleudult. The site is dominated in the overstory by 70- to

<sup>1</sup> Conservation Ecologist, Scientist, and Research Associate, respectively, Joseph W. Jones Ecological Research Center, Newton, GA 39870-9651.

90-year-old second-growth longleaf pine and in the understory by a species-rich groundcover, including wiregrass (*Aristida stricta* Michx.) (Kirkman and others 2001).

### Treatment Design

The study design was described previously (Battaglia and others 2002, 2003; Jones and others 2003; Palik and others 2003) and incorporates four overstory removal treatments assigned randomly within three 2.5-ha blocks (3 replications). The four treatments were (1) uncut control and basal area reduction through (2) single-tree selection, (3) small-group selection (approximately 0.10-ha circular gaps), and (4) large-group selection (approximately 0.20-ha circular gaps). In each cut treatment, residual overstory basal area was similar. All trees > 10 cm d.b.h. were surveyed into Universal Transverse Mercator (UTM) space. Next, we calculated an overstory abundance index (OAI) for all locations on a 1 x 1 m grid. OAI is a distance-weighted measurement of basal area within a circumscribed area (Jones and others 2003, Palik and others 2003, Stoll and others 1994). We chose 15 m as the radius for our circumscribed area (Jones and others 2003, Palik and others 2003), since most overstory effects of longleaf pine on plant responses are observed within that distance (Brockway and Outcalt 1998, McGuire and others 2001). A total of 300 plots were established that spanned the range of OAI (dataset A). Next, we established 60 additional plots to test the influence of overstory effects on hardwood populations (dataset B). In each large-group selection treatment area, we established 10 plots (4m x 2m) in a randomly selected gap. For each gap, four plots were established within the intact (uncut) savanna matrix, four at the gap edge, and two in the gap center. In each control treatment area, we also established 10 plots that had similar OAI values to those plots in the large-group selection treatment areas. We randomly chose half of the plots in each stand to receive a trenching treatment which prevented overstory roots from regrowing into the plot area over time (Pecot and others 2006). For datasets A and B, we planted 10 1-year-old containerized longleaf pine seedlings, evenly distributed in the central portion of each subplot. Finally, we examined the spatial response of hardwood biomass in 2 randomly selected gaps in each of the small- and large-group treatment areas (dataset C). We established plots in 4 cardinal directions at 0, 1, 2, 4, 6, 8, 12, and 15 m from the gap edge in the small gap with an additional location (25 m from gap edge) in each large gap, for a total of 816 plots.

### Sampling

For dataset A, seedling survival was assessed monthly throughout the duration of the study (February 1999 to December 2001). In December, 2001, we measured total (above- and below-ground) seedling biomass in 40 randomly selected plots. For each seedling, we measured root-collar diameter and height to the top of the bud to the nearest 0.1 mm. We then carefully excavated and collected each root system. Seedling components were dried at 70 °C to a constant mass and weighed. In addition, we measured diameter at 1 cm height and height to the top of the stem for all hardwoods in a 0.75-m<sup>2</sup> circular area at each of these plots and used a locally derived equation to predict biomass from d<sup>2</sup>h. For dataset B, we measured diameter at 1 cm height and height to the top of the stem for every hardwood stem in a 0.75-m<sup>2</sup> circular ring randomly placed in each of the small and large gaps and calculated biomass using the same equation as in

dataset A. For dataset C, we measured the aboveground portion of all understory hardwoods 2 years after trenching installation. These plants were clipped at ground level, dried at 70 °C to a constant mass, and weighed. Mean plot biomass (datasets A and B) and mean biomass of the four cardinal directions at each gap location (dataset C) were calculated.

### Data Analysis

Prior to stand-level analyses, we weighted each plot measurement to reflect the importance of that particular plot in the treatment area to improve the estimate of stand means. The weights were the proportions of grid points falling in each of five OAI classes, calculated separately for each treatment area. Prior to all analyses, we determined if each variable met the assumption of a normally distributed variable and transformed them as necessary. Statistical differences for all tests were accepted as significant at  $\alpha < 0.05$  (SAS for Windows v. 9.1, SAS Institute, Inc., Cary, NC, USA). Regression analysis was used to test for effects of overstory abundance on seedling and hardwood biomass (dataset A). We used a randomized-block, mixed-models analysis of variance (Littell and others 1996) to test for treatment effects (weighted to stand level) on seedling biomass and survival and hardwood biomass. For dataset B, we used nonlinear regression to predict the relationship between seedling and hardwood biomass. For dataset C, we tested for differences in understory hardwood biomass (expressed as percent of maximum biomass observed across all savanna locations) with the main effects of trenching and location. When interactions of the main effects were present, a set of simple effects tests were performed.

## RESULTS AND DISCUSSION

As overstory abundance increased, the biomass of planted pine seedlings declined (fig. 1a). The relationship is an exponentially decreasing form and the asymptote at an overstory abundance correlating with approximately 60 percent canopy closure. In contrast, above-ground biomass of hardwoods is much more variable over the range of overstory abundance, and no significant statistical relationship could be determined (fig. 1b). Instead, the relationship appears to be more of an upper boundary or threshold, where hardwood biomass cannot be greater than the threshold at a particular overstory abundance. This high degree of variability is likely due to the wide range of starting conditions in gaps, including the initial number of hardwood stems.

The relative location of pine seedlings or hardwood stems within a gap also affected growth responses (fig. 2). The relationship is significant for pines and hardwoods, but the pine response is less variable and does not separate by gap size (fig. 2a). In contrast, the hardwood response was more variable and differed with gap size (fig. 2b). There is a rapid biomass response as distance from gap edge increases with an asymptote reached at 15 and 10 m from gap edge for seedlings and hardwoods, respectively.

The different harvest treatments resulted in similar growth responses for the pine seedlings and hardwood stems (table 1). Compared to the seedling response, the response was much stronger for the hardwood stems, with clear statistically significant differences between the harvest treatments.

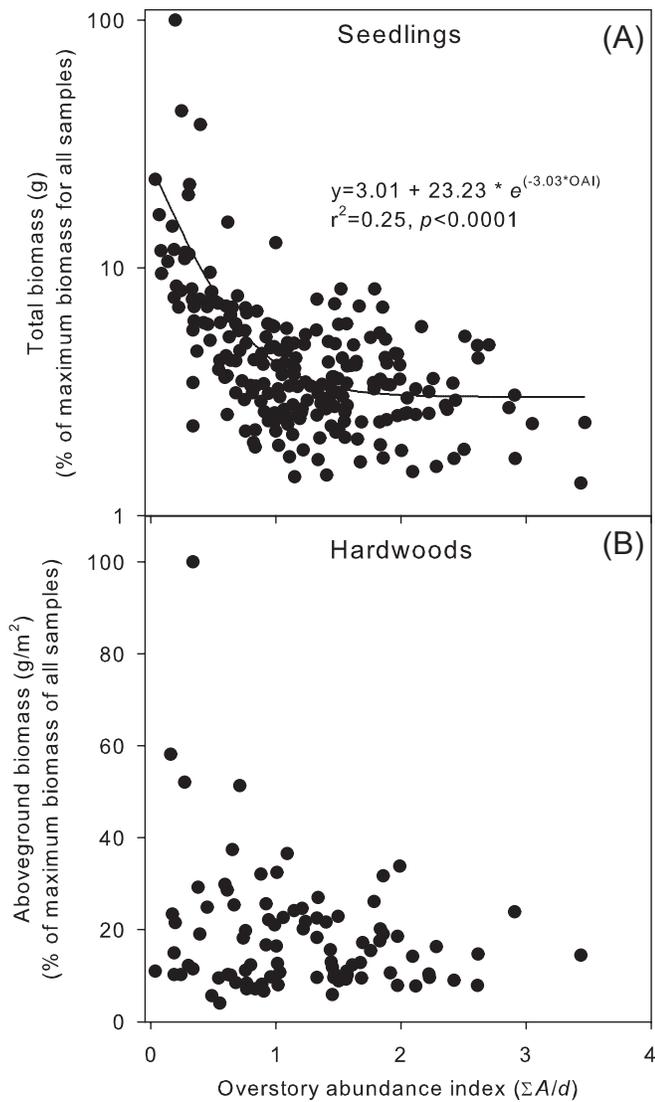


Figure 1—Total biomass (expressed as percent of maximum biomass observed in this study) of planted longleaf pine seedlings increased with decreasing longleaf pine overstory stocking (OAI) ( $r^2=0.25$ ,  $p<0.0001$ ) (A), but understory hardwoods were more variable and not related to OAI ( $p>0.05$ ) (B). For clarity, figure 1a is presented using the log scale.

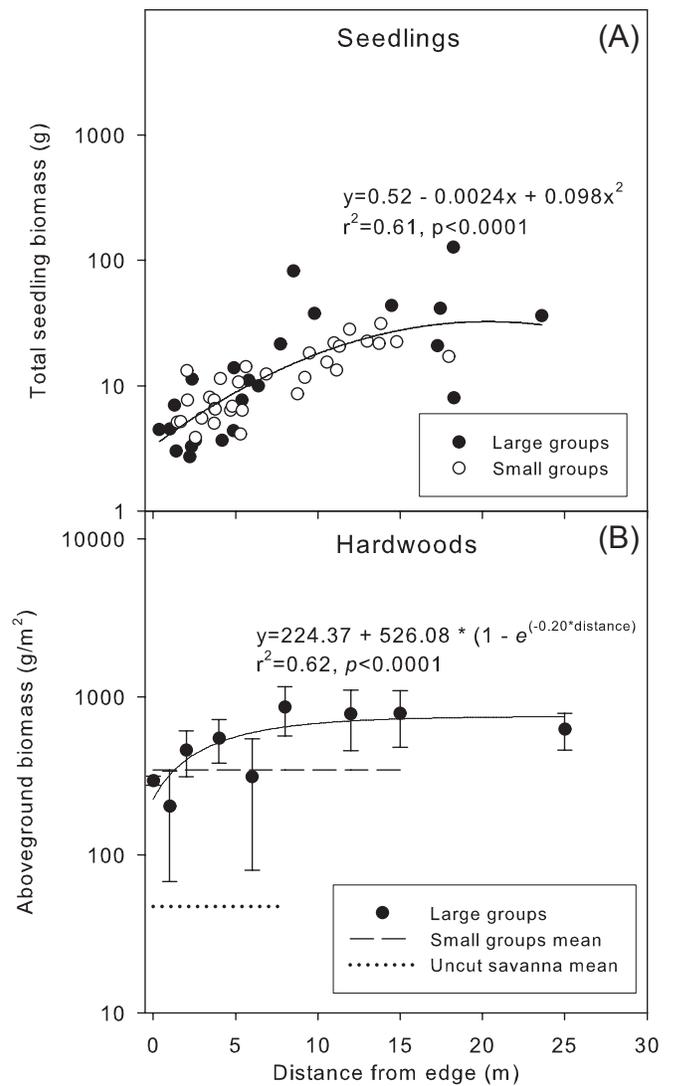


Figure 2—Biomass of planted longleaf pine seedlings increased with distance from gap edge ( $r^2=0.61$ ,  $p<0.0001$ ), but this response did not differ with gap size (A). Mean biomass of understory hardwoods increased with gap size, and in large gaps hardwood biomass increased to an asymptote at approximately 10 m from the gap edge ( $r^2=0.62$ ,  $p<0.0001$ ) (B).

**Table 1—Total seedling biomass, understory hardwood biomass, and seedling survival from treatment plots on a 70- to 90-year-old longleaf pine forest, Baker County, GA. Letters following values indicate significant differences ( $p < 0.001$ ) for each variable among overstory treatment levels**

Treatment	Seedling biomass	Hardwood biomass	Seedling survival
	<i>g</i>	<i>g/m<sup>2</sup></i>	<i>percent</i>
----- Mean ± 1 SE -----			
Uncut control	6.61 ± 0.51 <sup>a</sup>	46.98 ± 6.45 <sup>a</sup>	80.15 ± 1.16 <sup>a</sup>
Single-tree	9.05 ± 1.25 <sup>a</sup>	68.17 ± 5.98 <sup>ab</sup>	76.82 ± 0.99 <sup>ab</sup>
Small groups	9.74 ± 0.55 <sup>a</sup>	96.72 ± 5.16 <sup>bc</sup>	72.77 ± 1.98 <sup>b</sup>
Large groups	21.38 ± 5.39 <sup>b</sup>	185.23 ± 29.17 <sup>c</sup>	75.07 ± 0.30 <sup>c</sup>

Furthermore, an interesting tradeoff between pine seedling growth and survival was apparent. In general, greater overstory canopy abundance led to higher survival for the pine seedlings (table 1). This response may be in part due to the long-term drought conditions during the study and a “nurse crop” effect from the overstory canopy. Still, in an operational sense, a balance between seedling growth and survival must be achieved to meet particular objectives. This balance must also take into account the retention of enough overstory to provide fuels to permit the use of prescribed fire.

We were also interested in how changes in overstory abundance influence seedling and hardwood responses through altered resource availability. Table 2 shows that canopy manipulations greatly affected both above- and below-ground resource availability. When plots were trenched to remove below-ground competition, understory hardwood biomass increased significantly in the intact savanna and at the gap edge with trenching, but no trench effect was observed in the center of the gaps. Thus, an intact canopy retards hardwood stem growth by restricting the availability of both above- and below-ground resources, with below-ground competition perhaps exerting the strongest control.

Several factors likely affected seedling and hardwood responses observed in this study. Obviously, gap size and distance from the gap edge had an influence (fig. 2, table 1); however, it is important to note that the gap sizes in this study were smaller than are often prescribed in gap-based silvicultural approaches for longleaf pine. Because the seedling growth response levels off beyond 15 m from the gap edge, and the lack of overstory in the center of gaps results in a lower distribution of fine fuels to carry prescribed fire, it appears that smaller gap sizes can be recommended.

The harvest process itself has an effect on the structure of fine fuels in the forest. The heavy equipment and skidding of trees can severely disturb the groundcover and make burning more difficult. The presence of well-established hardwood stems decreases the ability to use fire following harvest, which can lead to shifts in mid- and overstory dominance. A related factor is historical fire management in harvested areas. If past fire management has allowed the development of a heavy under- or mid-story of hardwood stems (either through infrequent fire or poor burning conditions), it is more difficult to establish pine regeneration and to have fire alone adequately control the hardwood competition.

**Table 2—Effects of removal of below ground competition through trenching location on understory hardwood biomass (g/m<sup>2</sup>) in a 70- to 90-year-old longleaf pine forest, on understory hardwood biomass (g/m<sup>2</sup>) Baker County, GA. Letters following values indicate significant differences (p < 0.0001) among trench treatments at each savanna**

Treatment	Untrenched	Trenched
	----- Mean ± 1 SE -----	
Intact savanna	20.38 ± 6.03 <sup>a</sup>	83.10 ± 18.45 <sup>b</sup>
Gap edge	8.09 ± 2.93 <sup>a</sup>	100.00 ± 21.13 <sup>b</sup>
Gap center	54.90 ± 19.76 <sup>a</sup>	51.89 ± 26.27 <sup>a</sup>

Characteristics of advance pine regeneration can also affect the relationships observed in this study. Well-established seedlings that can rapidly respond to increased resource availability following harvests are more likely to successfully capture the harvest-created gaps and compete well with hardwoods. It has been suggested that adequate advance regeneration is important to the success of gap-based silvicultural approaches (Farrar and Boyer 1991), and the results of this study further support this conclusion. Finally, the climatic conditions during the course of this study potentially affected the observed results. The harvest operations were conducted just prior to a multi-year, region-wide drought. These conditions likely increased the observed “nurse crop” effect of seedling survival and may have influenced hardwood growth in the understory (table 1).

## CONCLUSIONS

The results of this study have some important implications for gap-based silvicultural approaches. First, the presence (or absence) of advance pine regeneration is an important consideration in choosing gaps to be created with harvests, as is the control of competing hardwoods in potential gaps. Second, gaps should be situated such that continuous fine fuels (especially pine needles) are available to carry prescribed fire. Once hardwoods are well-established in gaps, the burning conditions required to provide control are generally outside of the prescription parameters for the surrounding pine matrix. In cases where there are insufficient fuel sources, other operational treatments may be required to keep the hardwood competition under control.

The results of this study argue for the use of variable-sized openings based upon local (fine-scale) conditions rather than using a “cookie cutter” approach, where gap size and spatial distribution are fixed. Because of the threshold response of seedling growth in gaps, the response of hardwoods to overstory removal, and the need to maintain continuity of fuels, we recommend that gap size in general be smaller and dictated by the patterns of established seedlings that are to be released.

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## LITERATURE CITED

- Battaglia, M.A.; Mitchell, R.J.; Mou, P.P.; Pecot, S.D. 2003. Light transmittance estimates in a longleaf pine woodland. *Forest Science*. 49: 752-762.
- Battaglia, M.A.; Mou, P.; Palik, B.; Mitchell, R.J. 2002. The effect of spatially variable overstory on the understory light environment of an open-canopied longleaf pine forest. *Canadian Journal of Forest Research*. 32: 1984-1991.
- Bird, M.I.; Cali, J.A. 1998. A million-year record of fire in sub-Saharan Africa. *Nature*. 394: 767-769.
- Boyer, W.D. 1990. Longleaf pine. In: Burns, R.M.; Honkala, B.H., eds. *Silvics of North America: I. Conifers*. Agric. Handb. 654. Washington, D.C.: U.S. Department of Agriculture, Forest Service: 405-412.

- Boyer, W.D.; Peterson, D.W. 1983. Longleaf pine. In: Burns, R.M., ed. *Silvicultural systems for the major forest types of the United States*. Agric. Handb. 445. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Research Station: 153-156.
- Brockway, D.G.; Outcalt, K.W. 1998. Gap-phase regeneration in longleaf pine-wiregrass ecosystems. *Forest Ecology and Management*. 106: 125-139.
- Delcourt, P.A.; Delcourt, H.R. 1987. Long-term forest dynamics of the temperate zone: a case study of the late-Quaternary forests in eastern North America. New York, NY: Springer-Verlag. 439 p.
- Farrar, R.M.; Boyer, W.D. 1991. Managing longleaf pine under the selection system - promises and problems. In: Coleman, S.S.; Neary, D.G., comps. *Proceedings of the sixth biennial southern silvicultural research conference*. Gen. Tech. Rep. SE-70, vol. I. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 357-368.
- Jacqmain, E.I.; Jones, R.H.; Mitchell, R.J. 1999. Influences of frequent cool-season burning across a soil moisture gradient on oak community structure in longleaf pine ecosystems. *American Midland Naturalist*. 141: 85-100.
- Jones, R.H.; Mitchell, R.J.; Stevens, G.N.; Pecot, S.D. 2003. Controls of fine root dynamics across a gradient of gap sizes in a pine woodland. *Oecologia*. 134: 132-143.
- Kirkman, L.K.; Mitchell, R.J.; Helton, R.C.; Drew, M.B. 2001. Productivity and species richness across an environmental gradient in a fire-dependent ecosystem. *American Journal of Botany*. 88: 2119-2128.
- Kuchler, A.W. 1964. *Potential natural vegetation of the conterminous United States*. New York, NY: American Geographical Society. 156 p.
- Littell, R.C.; Milliken, G.A.; Stroup, W.W.; Wolfinger, R.D. 1996. *SAS system for mixed models*. Cary, NC: SAS Institute, Inc. 633 p.
- McGuire, J.P.; Mitchell, R.J.; Moser, E.B. [and others]. 2001. Gaps in a gappy forest: plant resources, longleaf pine regeneration, and understory response to tree removal in longleaf pine savannas. *Canadian Journal of Forest Research*. 31: 765-778.
- Oosting, H. 1956. *The study of plant communities*. San Francisco, CA: W.H. Freeman and Co. 440 p.
- Palik, B.; Mitchell, R.J.; Pecot, S. [and others]. 2003. Spatial distribution of overstory retention influences resources and growth of longleaf pine seedlings. *Ecological Applications*. 13: 674-686.
- Palik, B.J.; Pederson, N. 1996. Overstory mortality and canopy disturbances in longleaf pine ecosystems. *Canadian Journal of Forest Research*. 26: 2035-2047.
- Pecot, S.D.; Mitchell, R.J.; Palik, B.J. 2006. Competitive responses in longleaf pine savannas: above- and belowground effects on seedlings and understory plants. *Ecological Applications*. *Submitted*.
- Pessin, L.J. 1933. Forest associations in the uplands of the lower Gulf Coastal Plain (longleaf pine belt). *Ecology*. 14: 1-14.
- Schwarz, G.F. 1907. *The longleaf pine in virgin forest*. New York, NY: John Wiley and Sons. 135 p.
- Stoll, P.; Weiner, J.; Schmid, B. 1994. Growth variation in a naturally established population of *Pinus sylvestris*. *Ecology*. 75: 660-670.
- Wahlenburg, W.G. 1946. *Longleaf pine: its use, ecology, regeneration, protection, growth, and management*. 1<sup>st</sup> ed. Washington, DC: Charles Lathrop Pack Forestry Foundation. 429 p.
- Williams, G.B.; Black, E.M. 1981. High temperatures of forest fires under pines as a selective advantage over oaks. *Nature*. 293: 643-644.

# STAND DYNAMICS OF A LONGLEAF PINE RESTORATION PROJECT

John S. Kush and Ralph S. Meldahl<sup>1</sup>

**Abstract**—Ecological restoration in a longleaf pine (*Pinus palustris* Mill.) stand is being studied in the Flomaton Natural Area (FNA) in Escambia County, AL. The FNA had been protected from fire for over 45 years. The absence of fire permitted a hardwood midstory and litter layer to develop at the expense of longleaf pine regeneration and an herbaceous understory. Reintroducing fire posed a problem because of the existing fuel conditions. The stand was burned in 1995, 1996, 1997, 2001, and 2003. Longleaf pine density has decreased while basal area has remained relatively stable during the restoration efforts. The fuel loads are decreasing slowly and despite the heavy litter layer, longleaf pine regeneration has been established.

## INTRODUCTION

Prior to European settlement, forested savannas dominated by longleaf pine and the most diverse herbaceous layer in temperate North America blanketed an estimated 90 million acres in the Southeastern United States. These forests were swept by fire every 1 to 10 years, resulting in an open, park-like nature (Chapman 1932). Due to fire suppression, agriculture, and site conversion, longleaf forests now exist on < 3 percent of their former range. A 1995 U.S. Biological Survey Report listed the longleaf pine forest as the third most endangered ecosystem in the United States (Noss and others 1995). Old-growth longleaf pine forests exist in an even more imperiled state, covering less than 9,900 acres, or 0.01 percent of their former extent (Varner and Kush 2004).

Private, state, and federal land managers have recently undertaken ecological restoration of the longleaf pine forests in the Southeastern United States. Restoration to this point has lacked information on reducing litter accumulations, herbaceous species establishment, changes in overstory structure, and the fate of longleaf pine regeneration during the restoration process.

The Flomaton Natural Area (FNA) is a 60-acre virgin stand of old-growth longleaf pine, currently owned by International Paper, which underwent more than 45 years of fire suppression. The Society of American Foresters (SAF) recognized the importance of this stand in 1963 when they designated the area as the E.A. Hauss Old-Growth Longleaf Natural Area (Walker 1963). The SAF's definition of a natural area is a tract of land set aside to preserve permanently in unmodified condition a representative unit of virgin growth of a major forest type with the preservation primarily for scientific and educational purposes. In 1995, we began a major restoration project with the re-introduction of fire into this fire-suppressed ecosystem (Varner and others 2000). Since then, we have been monitoring and managing the FNA as an old-growth longleaf pine habitat.

## METHODS

### Study Area

The FNA is located within the city limits of the southern Alabama city of Flomaton, in Escambia County. The climate

is humid and mild with a mean annual precipitation of 61 inches well distributed throughout the year. The predominant soil series is the Orangeburg. Formed in marine sediments of sandy loams and sandy clay loams, these soils are low in natural fertility and organic matter.

Prior to the onset of reintroducing fire, 30 permanent 1/5-acre plots were established on a 3 by 4 chain grid to monitor restoration efforts. Within these, four 1-m square quadrats per plot have been surveyed annually for longleaf pine seedlings and herbaceous vegetation.

Fire was reintroduced in 1995. One-half of the FNA was burned in the winter and the other half in the spring. The stand was prescribed burned in 1996, 1997, 2001, and 2003. Due to relatively dry winters and springs and/or lack of help, the stand was not burned between 1997 and 2001. In 2000, the stand was bush-hogged because of the vines and blackberries that were taking over the understory. The bush-hog operation was carried out in such a way to minimize the impact to the longleaf pine regeneration, and there was no noticeable loss in seedling density.

We realized that fire alone would never remove all of the hardwoods. Once hardwoods reach 3 to 4 inches d.b.h. they are little affected by the cooler burns that should be used for the first few fires in old-growth stands. In 1997, a fuelwood operation was conducted in the stand to remove all hardwoods. The operation was conducted carefully, and there was very little damage to the longleaf pine.

## RESULTS AND DISCUSSION

### Longleaf Pine Overstory

Prior to restoration efforts, longleaf pine accounted for 40 percent of the density, 70 percent of the basal area, and there were no longleaf pine saplings < 1-inch d.b.h. (Kush and Meldahl 2000). The plots have been re-measured three times since 1993. The initial longleaf pine density and basal area were 256 trees acre<sup>-1</sup> and 78.8 feet<sup>2</sup> acre<sup>-1</sup>. By 1996, the density dropped to 124 trees acre<sup>-1</sup>, but the basal area only dropped to 77.6 feet<sup>2</sup> acre<sup>-1</sup>. The loss in density occurred in the smaller d.b.h. classes as no longleaf < 3 inches d.b.h. remained. In 2000, the density fell to 100 trees acre<sup>-1</sup> and

<sup>1</sup> Research Associate and Associate Professor, respectively, Auburn University, School of Forestry and Wildlife Sciences, 108 M. White Smith Hall, Auburn, AL 36849.

basal area to 76.0 feet<sup>2</sup> acre<sup>-1</sup>. By 2004, there were 91 trees acre<sup>-1</sup> and a basal area of 74.9 feet<sup>2</sup> acre<sup>-1</sup>.

The mortality of longleaf pine between 1993 and 2001 was primarily due to suppression. Between 2000 and 2004, much of the mortality was due to lightning, 48.1 percent, and associated insect attack, 23.6 percent. It appeared that the restoration efforts with the use of fire were responsible for 10.2 percent of the mortality.

### Litter Layer

The major problem with the re-introduction and use of fire in the restoration process has been the accumulated fuel loads. The lethal nature of fire occurs when it kills a large portion of the feeder roots which developed over the decades or when the litter around the base of the tree burns, girdling the tree. One of the major concerns with any restoration effort is avoiding a rapid reduction of the accumulated litter layer. Prior to the reintroduction of fire, there were an average of 2.92, 4.79, and 8.03 tons acre<sup>-1</sup> of litter, partially decomposed litter, and humus in the stand, respectively. By 1997, there were 2.04, 5.02, and 6.54 tons acre<sup>-1</sup> of litter, partially decomposed litter, and humus, and by 2003, measurements were 1.37, 5.15, and 5.67 tons acre<sup>-1</sup>, respectively. While progress has been made in reducing the fuel load, a tremendous amount remains. It will take several more years of careful burning to eliminate the partially decomposed litter and humus layer.

### Herbaceous Layer

Prior to restoration efforts, there were a number of shrubs and woody vines and only one herbaceous species (Varner and others 2000). After the 1997 fire, there were 23 herbaceous species. There are now 25 genera and more than 40 herbaceous plants and grasses that have appeared within the stand. Most of these species are native plants whose seeds have been stored in the seed bank.

### Longleaf Pine Regeneration

H.H. Chapman (1909) wrote "Longleaf pine is found in pure stands but seldom even-aged. Although an extremely intolerant tree, which will thrive best in even-aged stands, the natural form of this forest constantly trends toward small, even-aged groups of a few hundred square feet. Being naturally resistant to fire, large clearings never occur from this cause. In regions of severe winds, or tornadoes, larger even-aged patches and strips are found, sometimes one-quarter to one-half mile in width, which have come in after blowdown. These are pretty well interspersed with patches or single survivors of the old forest, which have acted as seed trees."

Several decades later Wahlenberg (1946) wrote: "The original longleaf pine forests were made up mainly of pure, even-aged irregularly open stands. The even-aged character was the result of relatively infrequent but heavy seed falls and the ability to reproduction to survive only in openings free of an overstory."

During the early hours of September 16, 2004, the eye of Hurricane Ivan passed somewhere to the west of the Flomaton, AL. Winds in the Flomaton, AL area were estimated to be 120 miles per hour. Within a matter of moments, nearly one-third of the eastern side of the stand was on the ground; trees were uprooted or snapped off at various heights along the bole. Those words of Chapman and Wahlenberg describe what is happening in the FNA today. Work by Kush and others (2004) discussed the status of longleaf pine regeneration within the FNA. In 2002, they found 3,100 seedlings acre<sup>-1</sup> across the entire stand and an average of 8,800 seedlings acre<sup>-1</sup> across 5 randomly measured gaps. Despite the litter depth, seedlings are becoming established at the FNA. The reason for this apparent success may be due to the low intensity fires and extensive mop-up efforts after burning that have been used to avoid the entire consumption of the litter layer.

### ACKNOWLEDGMENTS

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### LITERATURE CITED

- Chapman, H.H. 1909. An experiment in logging longleaf pine. *Forest Quarterly*. 7: 385-395.
- Chapman, H.H. 1932. Is the longleaf type a climax? *Ecology*. 13: 328-334.
- Kush, J.S.; Meldahl, R.S. 2000. Composition of a virgin stand of longleaf pine in south Alabama. *Castanea*. 65(1): 56-63.
- Kush, J.S.; Meldahl, R.S.; Avery, C. 2004. A restoration success: longleaf pine seedlings established in a fire-suppressed, old-growth stand. *Ecological Restoration*. 22(1): 6-10.
- Noss, R.F.; LaRoe, E.T.; Scott, J.M. 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. Biological Report 28. Washington, DC: U.S. Department of Interior, National Biological Service. 58 p.
- Varner, J.M., III; Kush, J.S. 2004. Remnant old-growth longleaf pine (*Pinus palustris* Mill.) savannas and forests of the Southeastern USA: importance, status, and threats. *Natural Areas Journal*. 24(2): 141-149.
- Varner, J.M., III; Kush, J.S.; Meldahl, R.S. 2000. Ecological restoration of an old-growth longleaf pine stand utilizing prescribed fire. *Tall Timbers Fire Ecology Conference Proceedings*. 21: 216-219.
- Wahlenberg, W.G. 1946. Longleaf pine: its use, ecology, regeneration, protection, and management. Washington, DC: Charles Lathrop Pack Forestry Foundation. 429 p.
- Walker, L.C. 1963. Natural areas of the Southeast. *Journal of Forestry*. 61(9): 670-673.

# ANALYSIS OF SEASONAL, DIURNAL, AND NOCTURNAL GROWTH PATTERNS OF YOUNG LONGLEAF PINE

John C. Gilbert, Ralph S. Meldahl, John S. Kush, and William D. Boyer<sup>1</sup>

**Abstract**—Forty longleaf pine (*Pinus palustris* Mill.) trees initially ranging from 1 to 1.5 m in height were measured on the Escambia Experimental Forest from 1969 through 1980. The trees were evenly divided between two soil types. From 1969 through 1970, height and diameter measurements were recorded one to four times weekly during the growing seasons and once a month during the dormant seasons. Daily height growth measurements were recorded in the morning and again in the evening during the peaks of these two growing seasons to determine diurnal and nocturnal growth. Follow-up height and diameter measurements were recorded periodically from 1971 through 1980. To test the effects shading had on growth patterns, cheesecloth was suspended over 10 randomly selected trees from each soil type during the first growing season. Analyses of variance were used to identify potentially significant differences in growth between shade treatments and soil types.

## INTRODUCTION

There are still many unanswered questions concerning the growth of young longleaf pine. Tree growth is affected by a multitude of abiotic and biotic stresses on a continuous basis, such as light intensity, moisture, temperature, wind, insects, pathogens, and plant competition (Kozlowski and Pallardy 1997). Research efforts have not clearly explained the growth patterns of young longleaf pine or how the environmental stresses are directly or indirectly affecting growth. To determine growth patterns of young longleaf pine, it is necessary to directly observe the height and diameter growth over time and record pertinent environmental factors at the site level. A data set of this size has the potential to answer questions about patterns of young longleaf pine growth on different scales.

## Project Background

A study was designed to determine how environmental conditions affect the height and diameter growth of young longleaf pines. The study was initiated in 1969, and data were collected until 1980. However, due to a lack of time and funding, the project was not completed. The data analyses were resumed in 2003.

## PROCEDURES

### Plot Layout

The site for this study was the Escambia Experimental Forest (EEF) near Brewton, AL. The EEF is a 3,000-acre forest that was established in 1947 when T.R. Miller Mill Company leased the land to the U.S. Department of Agriculture, Forest Service, for 99 years at no cost (Boyer and others 1997). The EEF has been used extensively for longleaf pine research (Boyer and others 1997). Forty longleaf pine trees were selected for the study. The study site was a naturally regenerated longleaf pine stand that was the product of the 1955 seed crop. All the selected trees were between 1 and 1.5 m tall. Twenty longleaf pine trees were selected on each of the two soil types that were present in the stand. One soil type was a Lucy loamy sand, and the other was a Wagram loamy sand. The taxonomic class for both soils is loamy, kaolinitic,

thermic Arenic Kandiodults (Soil Survey Division, Natural Resources Conservation Service 2003). Both soils have an average site index of 20.4 m, and the depth of the A horizon of both soils is very similar. However, the Lucy loamy sands can have a slightly thinner A horizon and a B horizon with a higher clay content at shallower depths than the Wagram loamy sands (Mattox and others 1975). The trees on the Lucy loamy sand were located on the crest of a ridge, and the trees on the Wagram loamy sand were located on a slope at the base of the ridge.

Ten of the trees on each of the two soil types were randomly selected for artificial shading. The randomly-selected trees were shaded with cheesecloth during the first year of the study. The cheesecloth was stretched across a square meter frame that was structured to keep the cheesecloth at least 1 m above the growing tip of the tree. The structures were periodically checked and adjusted. The growing tips of the shaded trees received a reduction of about 30 percent of the full sunlight they would normally receive at the peak of the diurnal cycle. The cheesecloth was installed on March 28, 1969, and removed September 24, 1969.

### Growth Measurements

The data for this study were collected from 1969 through 1980. Intensive growth and environmental measurements were taken from 1969 through 1970. Heights were measured one to four times weekly. During the month of April, leaders were measured in the morning and again in the evening to determine diurnal and nocturnal growth differences. Nineteen diurnal and nocturnal height growth measurements were taken in 1969, and 16 were taken in 1970. Heights were measured monthly during the dormant season. Separate records were kept for each new leader.

Since at the initiation of the study the trees had not reached breast height (1.37 m), diameters were measured at 10 cm above the soil surface. Diameters were measured weekly during the growing season and monthly during the dormant season. Follow-up height and diameter measurements were taken periodically from 1971 through 1980.

<sup>1</sup> Graduate Student, Associate Professor, and Research Associate IV, respectively, Auburn University, School of Forestry and Wildlife Sciences, Auburn, AL 36849; and Research Forester Emeritus, USDA Forest Service, Southern Research Station, Auburn, AL 36849.

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## Environmental Measurements

An on-site weather station recorded air temperature and precipitation measurements daily during the entire study. Soil moisture was recorded on a weekly basis from March, 1969, until December, 1970. Environmental variables collected during April of each growing season were relative humidity, wind speed, and solar radiation.

## RESULTS AND DISCUSSION

### 1969 through 1980

From 1969 through 1980, the average maximum yearly temperature was 26 °C, and the average minimum temperature was 12 °C. Average yearly precipitation was 157 cm. The driest year was 1971 with 112 cm of precipitation, while 1975 was the wettest year, with 230 cm of precipitation.

On average, the trees grew 12.8 m over the 12 growing seasons from 1969 to 1980. There were no statistically significant differences between average height growth on the two soil types or between the shading treatments over this period. All statistical tests were performed at the 0.05 level of significance. Average diameter growth was 7.20 cm. There were significant statistical differences between the two soil types with respect to average diameter growth over this period. Diameter growth for trees on the Lucy loamy sands was greater than diameter growth for trees on the Wagram loamy sands. However, there were no significant effects of the shading treatment on diameter growth.

### 1969 and 1970 Growing Seasons

Figure 1 shows the percent of average height and diameter growth by month from the initiation of the study in March, 1969, to the end of the intensive measurements in December, 1970. The main portion of the growing season began in March and

ended in October. April was the peak of the growing season for height growth, representing over 30 percent of the growth each year. Diameter growth had similar patterns to height growth, but diameter growth seemed to persist into the winter months. However, this was a small percentage when compared to the most active portion of the growing season. Average daily temperature during the 1969 growing season was 28 °C. The total amount of precipitation during this time was 131 cm. During the 1970 growing season, there was a total of 155 cm of precipitation with an average daily temperature of 29 °C.

Table 1 shows average height and diameter growth for the 1969 and 1970 growing seasons. Cumulative average height

**Table 1—Mean height and diameter growth by shade treatment and soil type for the 1969 and 1970 growing seasons. Trees were located on the EEF near Brewton, AL**

Year	Site condition	Height growth	Diameter growth
		<i>m</i>	<i>cm</i>
1969	Not shaded	0.99	1.26
	Shaded	1.00	1.13
	Lucy	1.02	1.37
	Wagram	0.97	1.03
	Overall	0.99	1.20
1970	Not shaded	1.09	1.42
	Shaded	1.03	1.50
	Lucy	1.06	1.63
	Wagram	1.05	1.29
	Overall	1.06	1.46

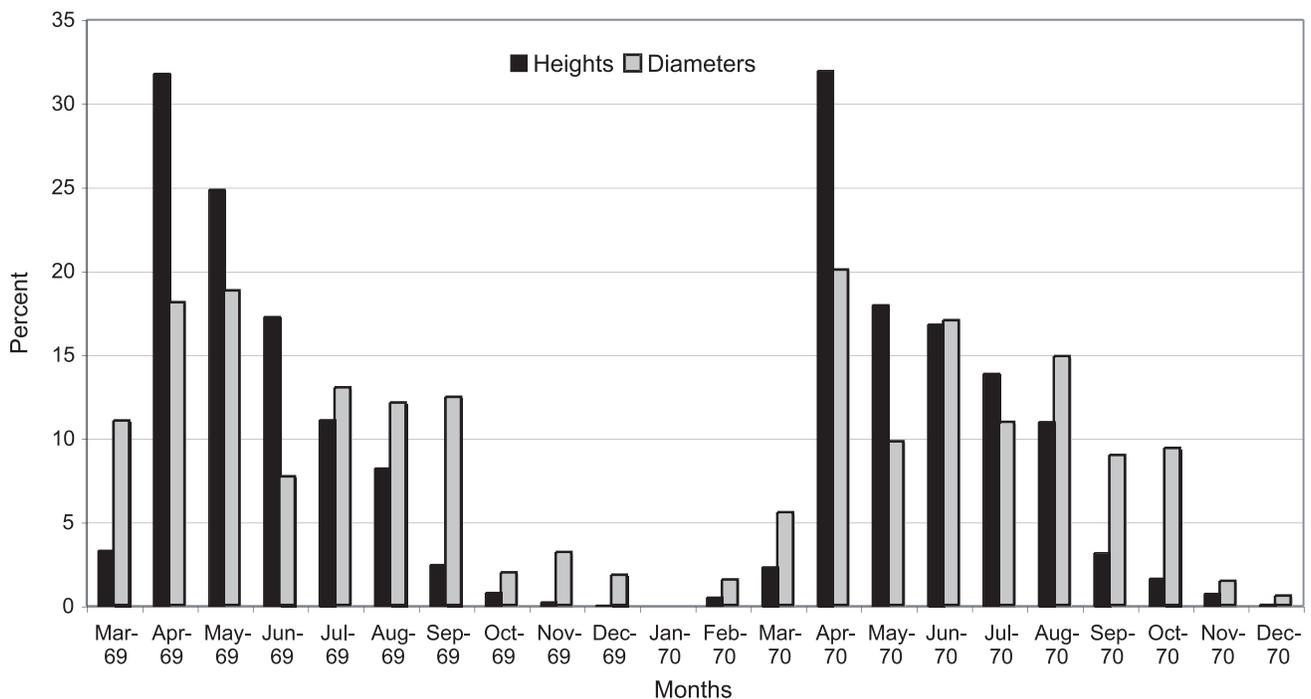


Figure 1—Percent of average monthly height and diameter growth plotted by month. Data were collected in 1969 and 1970 on the EEF near Brewton, AL.

growth over the two growing seasons was 2.1 m. There was not a significant statistical difference in height growth with respect to the shading treatments or between the two soil types during each growing season or over the 2-year period. Cumulative average diameter growth during the two growing seasons was 2.66 cm. In contrast to height growth, there were significant differences in diameter growth between the two soil types during each growing season and over the 2-year period. Diameter growth for trees on the Lucy loamy sands was greater than diameter growth for trees on the Wagram loamy sands. However, there were no significant differences in diameter growth between the shade treatments on the intervals tested.

### **Diurnal and Nocturnal Growth**

The diurnal period between the morning and evening measurements was about 8 hours, and the nocturnal period between evening measurements and the following morning measurements was about 16 hours. During the 19 days the trees were measured in 1969, the average daily temperature was 26 °C. The average temperature during the night was 12 °C. During the 16 days the trees were measured in 1970, the average daily temperature was 28 °C, while the average nightly temperature was 14 °C. The total amounts of precipitation during these measurement periods in 1969 and 1970 were 10.16 cm and 14 cm, respectively. Average height growth over the 19 days was 21.64 cm. About 35 percent of the growth occurred during the diurnal period, while about 65 percent occurred during the nocturnal period. During the 16 days the trees were measured in 1970, average height growth was 20.44 cm. About 25 percent of the growth occurred during the diurnal period, and about 75 percent of the growth occurred during the nocturnal period. The large percentage of growth occurring during the nocturnal periods is possibly due to the time in which the trees were measured. The evening measurements occurred between 4:00 p.m. and 6:00 p.m. The trees continued to receive a few more hours of sunlight until nightfall. There was not a statistically significant difference between the soil types or the shade treatments for average diurnal or nocturnal growth during the measurement periods in April of 1969 or 1970.

### **CONCLUSIONS**

The shading treatment resulted in a reduction in direct solar radiation of about 30 percent, which seemed to have no significant effect on either height or diameter growth of the young longleaf pines. Soil type did not appear to affect height growth, but there were differences in diameter growth. Diameter growth for trees on the Lucy loamy sands was better than diameter growth for trees on the Wagram loamy sands. This could possibly be due to a moisture gradient caused by the higher clay content in the Lucy loamy sands. To understand more about why height and diameter growth patterns behave as they do, the relationships between growth and the environment will need to be further explored. Future examinations between the different intervals of growth measurements and the environmental variables recorded have the potential to answer more questions about how height and diameter growth were being affected by the environment.

### **ACKNOWLEDGMENTS**

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### **LITERATURE CITED**

- Boyer, W.D.; Ward, G.A.; Kush, J.S. 1997. The Escambia experimental forest marks fifty years of research on the ecology and management of longleaf pine. *Southern Journal of Applied Forestry*. 21(1): 47.
- Mattox, M.G.; Duncan, L.A.; Neal, H.B. [and others]. 1975. Soil survey of Escambia County, Alabama. United States Department of Agriculture, Soil Conservation Service and Forest Service, in cooperation with the Alabama Department of Agriculture and Industries, and the Alabama Agricultural Experiment Station. 98 p.
- Kozlowski, T.T.; Pallardy, S.G. 1997. *Physiology of woody plants*, second ed. San Diego, CA: Academic Press, Inc. 411 p.
- Soil Survey Division, Natural Resources Conservation Service. 2003. United States Department of Agriculture. Official Soil Series. Descriptions [Online WWW]. Available URL: <http://ortho.ftw.nrcs.usda.gov/osd/> [Accessed 27 Oct 2003].

# EARLY LONGLEAF PINE SEEDLING SURVIVORSHIP ON HYDRIC SOILS

Susan Cohen and Joan Walker<sup>1</sup>

**Abstract**—We established a study to evaluate site preparation in restoring longleaf pine on poorly drained sites. Most existing longleaf pine stands occur on drier sites, and traditional approaches to restoring longleaf pine on wetter sites may rely on intensive practices that compromise the integrity of the ground layer vegetation. We applied silvicultural treatments to improve soil conditions that impede longleaf survival and growth on poorly drained soils. The study design is a split-plot with eight treatments replicated on six blocks. Treatments were an herbicide application or a single-pass chop prior to burning, followed by flat planting, mounding and planting, or bedding and planting. Flat planting had the highest survivorship, and we detected significant differences ( $p \leq 0.05$ ) among treatments on seedling survival at 6 months but none after 1 year.

## INTRODUCTION

Longleaf pine (*Pinus palustris* Mill.) has often been replaced by other southern pine species due its long-standing reputation of being difficult to regenerate (Boyer 1988). In artificially regenerated longleaf stands, poor survival is attributed to the quality of nursery stock, quality of planting, or unsatisfactory field conditions during planting and through the first year (Boyer 1988, Larson 2002). Longleaf seedlings are sensitive to competing vegetation, so controlling the vegetation in the first growing season supports early emergence from the grass stage (Larson 2002). Additionally, site preparation prior to planting can improve difficult field conditions such as poor drainage (Boyer 1988).

Larson (2002) defined quality longleaf seedlings as those with needle length  $\geq 15$  cm, a firm and moist plug with an air-pruned taproot, and a root-collar diameter (RCD) of approximately 0.65 cm with a dormant visible bud. Lauer (1987) determined no relationship between RCD and survival rates, but RCD did hinder growth and height initiation out of the grass stage. Ramsey and others (2003) also found no relationship between survival and RCD, and found that competition may be just as important as RCD for emergence from the grass stage.

One key to maximizing seedling survival is proper planting depth (Boyer 1988, Burns 1974, Larson 2002). Soil should cover the top of the plug to prevent moisture loss from the nursery media but not the seedling bud. Erosion should not uncover the plug, and air pockets from poorly packed soil can damage or kill containerized seedlings (Larson 2002). On well-drained Lakeland sand, Burns (1974) found a corresponding increase in longleaf mortality with each increase in planting depth, and deep planting negatively affected growth. Not until age 3 years, however, did the deepest plantings show the highest mortality. Deep planting may have protected the seedling from desiccation by the wind and sun, delaying the mortality associated with deep planting that other researchers reported.

Routine mechanical site preparation can improve microsites for seedlings (Burger and Pritchett 1988). While mounding and bedding improve drainage and aeration, treatments (like chopping and herbicides) that reduce competition increase moisture available to seedlings (Spittlehouse and Childs 1990). Bedding has become commonplace (Thomas and others 2004), but mounding is not used extensively in the Southeast.

Mounding as a site preparation technique has been used for centuries and currently is used in the uplands of Scandinavia and Canada; it is becoming more prevalent in the Upper Great Lake States (Londo 2001, Sutton 1993). Mounding involves scooping up soil and inverting it on the forest floor to create a double organic layer to provide nutrients and water for seedlings. Mounding can increase the volume of aerated soil on wet sites, reduce excessive soil moisture, increase the rooting zone (Londo 2001, Sutton 1993), and control competition. Runoff water flows into the pits by each mound. By increasing decomposition, mounds increase nutrient availability (Londo 2001).

Many species of northern conifers planted on mounds show mixed results for both survival and growth rates (Londo 2001); however, long-term evaluation is lacking. In the Southeast, only slash pine (*P. elliotii* Englem.) has been studied and reported on in the literature (Sutton 1993). Studying slash pine on silt-loam soils in Louisiana, Haywood (1987) found greater survival and accelerated growth due to mounding. The discontinued nature of mounds permitted natural surface drainage, and during the winter when the water table was highest, mounding provided additional rooting. Rates of settling, erosion, and regrowth of competing vegetation in mounding have received little to no attention (Sutton 1993).

Chemical treatments can also help establish longleaf pine. Ramsey and others (2003) examined longleaf survival from a well-drained old field where they applied herbicides and fertilizers at different times postplanting. The herbicide treatment plots had the greatest survival after 1 year, but in the second year, the control and herbicide-only treatment plots had similar survivorship. They attributed the additional 4 to 6 percent second-year mortality to natural causes and not to treatment effects. Additionally, the second-year leveling off of mortality indicated the seedlings had well-established root systems. The fertilizer treatment was detrimental to seedling survival by accelerating the growth of competing understory vegetation (Ramsey and others 2003).

The majority of seedling mortality occurs primarily in the first growing season (Boyer 1988, Ramsey and others 2003), and our objective was to determine if applied treatments affected seedling survivorship. This research reports longleaf pine seedling survival 1 year after planting. This research is part

<sup>1</sup> Biologist, USDA Forest Service, Southern Research Station, 3041 Cornwallis Road, Research Triangle Park, NC 27709; and Research Plant Ecologist, USDA Forest Service, Southern Research Station, Department of Forest Resources, Clemson University, SC 29634, respectively.

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of an ongoing project designed to evaluate site preparation methods for optimal tree survival and growth and for effects on the understory community.

## MATERIALS AND METHODS

The project is based at Marine Corps Base, Camp Lejeune, in Onslow County, NC. Camp Lejeune is in the Atlantic Coastal Flatlands section of the Outer Coastal Plains Mixed Forest Province (Bailey 1995). Study sites have Leon soils (sandy, siliceous, thermic Aeric Alaquod), a poorly drained fine sand with a cemented spodic horizon. Despite their poor drainage, spodosols have a low water-holding capacity due to a sandy nature, low organic matter content, and macroporosity of surface horizons (Barnhill 1992). The previous stands of slash and loblolly pines (*Pinus taeda* L.), ranging in age from 10 to 40 years, were sheared 6 months to 2 years prior to treatment installation.

The research design was a split-plot with eight treatments replicated on six blocks. Each 0.6-ha treatment plot had a 0.4-ha measurement plot and a 15-m buffer. The treatments began in different stages from August to December, 2003. A single-pass chop or herbicide application preceded burning, followed by either flat planting, mounding and planting, or bedding and planting. Each block had a control treatment (burned and flat planted) and a combination treatment (herbicide and chop prior to bedding).

The chop treatment was done with a 2.4-m Lucas drum chopper pulled by a TD15 dresser crawler tractor. The herbicide treatment, a combination of Chopper® (2.8 liter ha<sup>-1</sup>) and Garlon 4® (1.4 liter ha<sup>-1</sup>), was broadcast-applied prior to burning as an alternative to chopping. A Rome six-disc bedding harrow (three on each side), pulled with a TD15 dresser crawler tractor, created 2.1- to 2.4-m beds. Mounding was done with a New Forest Technology™ custom mounding bucket mounted on a Caterpillar 320BL excavator. Mounds (1.2 m wide) were installed in rows as opposed to an irregular pattern that is usually employed.

In December 2003, we hand-planted container-grown longleaf pine seedlings on 4.5- by 2-m spacing. The seeds were sown in Rotak multipots (6-45), in a vermiculite-peat moss-perlite (2:2:1) planting medium and fertilized with Osmocote control-release fertilizer (3.5 kg Osmocote/m<sup>3</sup> of planting medium). Seedlings were kept on outdoor benches and watered with an automatic sprinkler. The minimum requirement for culls was > 0.5-cm RCD and abundant secondary needles > 10 cm in length.

We surveyed measurement plots for seedling survival 6 months and 1 year after planting. In flat-planted plots, seedlings were located and marked with pin flags. The pin flags were counted prior to marking the seedlings. Flags marking dead seedlings were pulled, counted, and subtracted from the live total. In bedded and mounded plots, we established the boundaries of measurement plots and counted the number of rows. We walked rows to tally the number of live seedlings; seedlings were marked as alive if any portion of the foliage was green. To detect significant differences for survival among treatments, we performed analysis of variance with a split-plot design (Proc GLM; SAS Institute 2002). The effects on seedling survival due to chopping vs. herbicides and mounding and planting vs. bedding and planting vs. flat planting, as well as any interaction, were tested as a 2 x 3 factorial. Since the

control and chop-herbicide-bed do not fit into a factorial, we omitted them from this portion of the analysis. We considered differences significant at  $p \leq 0.05$ .

## RESULTS AND CONCLUSIONS

Six months after planting, all treatments had > 85 percent seedling survival with the control being the highest (95 percent) and the chop-mound being the lowest (85 percent; table 1). The treatments chop-bed ( $p = 0.02$ ), chop-mound (0.008), and herbicide-mound (0.015) differed significantly from the control. Factorial results detected no significant difference on seedling survival from a chop or an herbicide application ( $p = 0.52$ ). However, there was a significant difference ( $p = 0.007$ ) for survival between flat planting and mounding (table 2). We detected no significant interaction between herbicide or chop and mounding, bedding, or flat planting.

**Table 1—Mean seedling survival percentage at 6 months and 1 year after planting (standard deviation given in parenthesis)**

Treatment	Mean survival	
	6 months	1 year
	<i>percent</i>	
CB	88.4 <sup>a</sup> (± 7.4)	66.5 (± 15.9)
CF	93.4 <sup>ab</sup> (± 2.6)	71.5 (± 13.4)
CHB	91.3 <sup>ab</sup> (± 4.7)	66.0 (± 9.8)
CM	85.0 <sup>a</sup> (± 7.9)	70.9 (± 13.6)
HB	89.6 <sup>ab</sup> (± 6.4)	68.8 (± 16.7)
HF	92.3 <sup>ab</sup> (± 4.3)	70.8 (± 16.6)
HM	87.1 <sup>a</sup> (± 3.8)	66.3 (± 9.4)
CTL	95.4 <sup>b</sup> (± 1.8)	74.0 (± 17.7)

C = chop; B = bed; F = flat planted; H = herbicide; M = mound; CTL = control.

Within a column, values not sharing a letter are significantly different ( $p \geq 0.05$ ).

**Table 2—Mean seedling survival percentage from the 3 x 2 factorial at 6 months and 1 year after planting**

Treatment	Mean survival	
	6 months	1 year
	<i>percent</i>	
Planting method		
Bed	88.5 <sup>ab</sup>	67.8
Mound	86.5 <sup>b</sup>	69.5
Flat	92.5 <sup>a</sup>	70.8
Pr > F	0.008	0.8
Site preparation		
Herbicide	89.6	68.7
Chop	88.7	70.1
Pr > F	0.5	0.7

Within a column, treatments followed by letters are significantly different ( $p \geq 0.05$ ).

After 1 year, no significant differences appeared among treatments for survival ( $p = 0.7$ ). The control had the highest percentage survival (74 percent), and the chop-herbicide-bed treatment had the lowest survival (65 percent). First-year survival had greater variation within treatments relative to 6-month survival as indicated by the standard deviations (table 1, fig. 1). Seedling survival showed no significant differences between herbicides and chopping, or among bedding, mounding, and flat planting (table 2).

Treatment differences at 6 months were no longer evident at 1 year; however, the control treatment continued to have the highest survival. Because the majority of seedlings die in the first growing season (Boyer 1988, Ramsey and others 2003), we expect that differences in mortality will not re-emerge over time. Poor survival is attributed to the quality of nursery stock, quality of planting, or unsatisfactory field conditions during planting and through the first year (Boyer 1988, Larson 2002). Assuming equal seedling quality, planting quality and field conditions remain as reasons for the early 6-month differences; however, even these differences do not remain significant after 1 year.

The variation within treatment plots increased dramatically from 6 months to 1 year. Within individual treatment plots, we frequently observed that the majority of seedlings in a row were dead or chlorotic, while the majority in the adjacent row exhibited vigor, suggesting that planting quality varied with individual planters. The individual planters moved down rows as a group, and the same planter almost never planted adjacent rows. The planters' varying skill probably yielded the high variation in seedling survival. Because the same crew planted the entire research area, quality was equal among beds, mounds, and flat areas. Mechanical treatments had no effect on survivorship, and no differences emerged between methods of competition control (chopping and herbicides) or planting

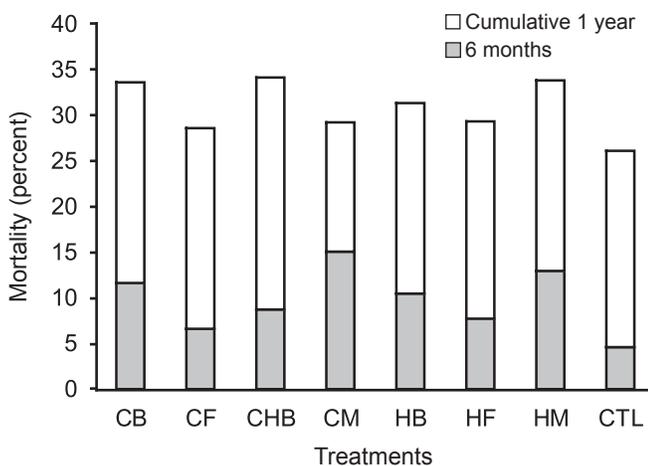


Figure 1—Cumulative mean seedling mortality over 1 year by treatment. CTL = control, C = chop, H = herbicide, M = mound, B = bed, and F = flat planted.

area (bed, mound, or flat). While survivorship continues to be monitored, treatments will be evaluated for effect on emergence from the grass stage and growth.

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## LITERATURE CITED

- Bailey, R.G. 1995. Description of the ecoregions of the United States, 2<sup>d</sup> ed. Misc. Pub. No. 1391. Washington, DC: U.S. Department of Agriculture, Forest Service. 108 p.
- Barnhill, W.L. 1992. Soil survey of Onslow County, North Carolina. National cooperative soil survey. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 139 p.
- Boyer, W.D. 1988. Effects of site preparation and release on the survival and growth of planted bare-root and container grown longleaf pine. Georgia Forest Research Paper 76. [Place of publication unknown]: Georgia Forestry Commission, Research Division: 1-7.
- Burger, J.A.; Pritchett, W.L. 1988. Site preparation effects on soil moisture and available nutrients in a pine plantation in the Florida flatwoods. *Forest Science*. 34: 77-87.
- Burns, R.M. 1974. Deep planting detrimental to longleaf pines on droughty acid sands. *Tree Planter's Notes*. 25(4): 28-29.
- Haywood, J.D. 1987. Response of slash pine planted on mounds in central and southwestern Louisiana. *New Forests*. 4: 291-300.
- Larson, D.R. 2002. Field planting containerized longleaf pine seedlings. In: Barnett, J.P.; Dumroese, R.K.; Moorhead, D.J., eds. Proceedings of workshops on growing longleaf pine in containers: 1999 and 2001. Gen. Tech. Rep. SRS-56. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 62-63.
- Lauer, D.K. 1987. Seedling size influences early growth of longleaf pine. *Tree Planter's Notes*. 38 (3): 16-17.
- Londo, A.J. 2001. Bucket mounding as a mechanical site preparation technique in wetlands. *Northern Journal of Applied Forestry*. 18 (1): 7-13.
- Ramsey, C.L.; Jose, S.; Brecke, B.J.; Merritt, S. 2003. Growth response of longleaf pine (*Pinus palustris* Mill.) seedlings to fertilization and herbaceous weed control in an old field in southern USA. *Forest Ecology and Management*. 172: 281-289.
- SAS Institute. 2002. Release 9.1. Cary, NC: SAS Institute. [Not paged].
- Spittlehouse, D.L.; Childs, S.W. 1990. Evaluating the seedling moisture environment after site preparation. In: Gessel, S.P.; Lacate, D.S.; Weetman, G.F.; Powers, R.F., eds. Sustained productivity of forest soils. Proceedings of the seventh North American forest soils conference. Vancouver, BC: University of British Columbia, Faculty of Forestry Publication: 432-450.
- Sutton, R.F. 1993. Mounding site preparation: a review of European and North American experience. *New Forests*. 7: 151-192.
- Thomas, R.F.; Jokela, E.J.; Allen, H.L. 2004. The evolution of pine plantation silviculture in the southern United States. In: Rauscher, H.M.; Johnsen, K., eds. Southern forest science: past, present, and future. Gen. Tech. Rep. SRS-75. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 63-82.

# HOW DOES FIRE AFFECT LONGLEAF PINE ROOT CARBOHYDRATES, FOLIAR NUTRIENTS, AND SAPLING GROWTH?

Eric A. Kuehler, Mary Anne Sword Sayer, and C. Dan Andries<sup>1</sup>

**Abstract**—In central Louisiana, we conducted a prescribed-fire study in a 5-year-old longleaf pine (*Pinus palustris* P. Mill.) stand to evaluate the effects of fire on fine-root (2- to 5-mm diameter) carbohydrates, dormant season foliar nutrients, and sapling growth. Control, burn, and nonburned vegetation control treatments were studied using a randomized complete block design with five blocks. Prescribed fire was applied in May 2003. Root starch concentration was significantly lower and root glucose concentration significantly greater in the burned plots than in control and nonburned plots 1 month after treatment. Foliar potassium concentration was significantly greater after treatment in the burned plots compared to control and nonburned plots. Annual groundline diameter growth was also significantly greater in the burned plots than in the control plots. Our data suggest that fire shifts root carbohydrate and foliar potassium concentrations of longleaf pine saplings to restore leaf area and/or strengthen the tree stem.

## INTRODUCTION

In the Southeastern United States, prescribed fire is commonly used to control brown-spot needle blight (caused by *Mycosphaerella dearnessii* M.E. Barr.) and competing vegetation, and to alter the structure of young longleaf pine (*Pinus palustris* P. Mill.) stands. Plant growth is influenced, in part, by nutrition-dependent foliar physiology and carbohydrate translocation from the foliage to other plant components. Because fire can cause early foliage senescence by scorching the crown (Haywood and others 2004), the production and supply of energy needed for forest productivity may be adversely affected by repeated use of prescribed fire. Our research evaluated the effects of prescribed fire on three factors that are important to longleaf pine production: root carbohydrate concentration, foliar nutrition, and stemwood growth. We hypothesize that prescribed fire affects root carbohydrate dynamics and foliar nutrition and that these responses are linked to sapling growth.

## METHODS

### Study Site

The study was in the west gulf region of the Southeastern United States on two sites in Rapides Parish in central Louisiana. The climate is humid and subtropical with mean January and July temperatures of 8 and 28 °C, respectively. Mean annual precipitation is 1525 mm with > 965 mm occurring between March and November. Soils range from very fine sandy to silt loam and are classified as Beauregard silt loam (fine-silty, siliceous, thermic Plinthic Paleudult), Malbis fine sandy loam (fine-loamy, siliceous, thermic Plinthic Paleudult), Ruston fine sandy loam (fine-loamy, siliceous, thermic Typic Paleudult), and Gore very fine sandy loam (fine, mixed, thermic Vertic Paleudult). The two sites are generally flat to gently sloping with < 10 percent slope.

Container-grown longleaf pine seedlings from seed sources in Mississippi (3 blocks) and Louisiana (2 blocks) were planted at 1.83 by 1.83 m in 1997. Treatment plots measure 22 by 22 m and contain 12 rows of 12 seedlings each.

Measurement plots are the interior 10 rows of 10 trees each; the outer 2 rows of trees serve as a buffer.

### Treatments

We studied three silvicultural treatments. Control plots (C) had no silvicultural activities. In the burn-only plots (B), prescribed burns were conducted in May 1998, June 2000, and most recently, on May 21, 2003, using the striphead fire method. In the nonburned, vegetation-control plots (N), herbicides were applied after planting to control herbaceous and woody plants, and undesirable woody regrowth was hand felled.

### Measured Variables

We quantified nonstructural carbohydrate concentrations of longleaf pine roots that were 2 to 5 mm in diameter. One root sample was collected from each of three randomly selected buffer trees per plot by following roots from the base of the tree until root diameter was between 2 and 5 mm, then excising a 5- to 10-cm length of root. Because this sampling method was destructive to roots, we selected a different set of three trees on each collection date. Sampled roots were excised with shears, placed on dry ice within 10 minutes of collection, and freeze-dried. Root samples were collected the day before, 1 month after, and again 7 months after the May 2003 prescribed fire. Freeze-dried roots were ground to pass through a #30 mesh screen and analyzed using an enzymatic assay modified for pine (Jones and others 1977, Kuehler and others 1999). Root starch, glucose, and sucrose concentrations were quantified as mg g<sup>-1</sup> tissue dry weight.

Foliage was collected for nutrient analyses from the upper one-third of the south-facing crown of three trees per measurement plot on March 3, 2003, and January 23, 2004. We collected foliage during the dormant season, when nutrient reallocation fluxes are at a minimum (Dickson 1989). Sample trees were of mean height ( $\pm$  10 percent) per plot. Ten fascicles from the last fully expanded flush of the previous year were collected from each tree, dried at 70 °C, and ground to pass through a #30 mesh screen. Nitrogen (N) concentration was determined using a C, N, S elemental analyzer (LECO

<sup>1</sup> Plant Physiologist, Research Plant Physiologist, and Biological Science Technician, respectively, USDA Forest Service, Southern Research Station, Pineville, LA 71360.

Corporation, St. Joseph, MI) and expressed as percentage of dry weight. Phosphorus (P) was determined colorimetrically and expressed as  $\text{mg g}^{-1}$  tissue dry weight (John 1970). Foliar concentrations of potassium (K), calcium (Ca), and magnesium (Mg) were determined by atomic absorption spectrophotometry and expressed as  $\text{mg g}^{-1}$  tissue dry weight (Isaac and Kerber 1971).

In January 2003 and February 2004, we quantified total tree height in meters and groundline diameter in centimeters of all longleaf pine trees in each measurement plot. We determined annual growth increments by subtracting tree height and diameter in 2003 from those in 2004.

### Experimental Design

Our study used a randomized complete block design with five blocks and three silvicultural treatments. Treatment differences regarding fine-root carbohydrate concentration and annual growth increment were statistically tested by analysis of variance procedures using the statistical analysis software, SAS (SAS Institute, Cary, NC). Where treatment differences were statistically significant, we used Tukey's Studentized Range Test as a means separation procedure. Analysis of covariance was applied to foliar nutrient concentrations using the nutrient concentrations in 2003 as the covariate; comparison using Bonferroni's pairwise comparison test was made on adjusted treatment means. Statistical significance was determined at  $P \leq 0.05$ .

### RESULTS AND DISCUSSION

One month after burning, root starch concentration was significantly affected by treatment ( $P = 0.0036$ ), with lower values on the B plots than on the C and N plots (fig. 1A). At this time, root starch concentration on the B plots was 35 percent lower than before the burn, while values on the C and N plots were unchanged. Root glucose concentration increased in all treatments 1 month after the burn. At this time, root glucose concentration was significantly affected by treatment ( $P = 0.0066$ ), with 50 percent more root glucose on the B plots than on the C and N plots (fig. 1B). Root sucrose concentration 1 month after the burn (fig. 1C) and root starch, glucose, and sucrose concentrations 7 months after the burn were not significantly affected by any of the treatments.

These data indicate that, in longleaf pine saplings, root carbohydrate reserves may be mobilized to support the restoration of leaf area after scorch and fire-induced senescence. Sword Sayer and others (2006) report that these saplings averaged > 50-percent crown scorch. Also, at peak leaf area in July, a larger percentage of total leaf area in the upper crown was second-flush foliage on the B plots than on the C and N plots. Perhaps root starch was mobilized to support the second-flush production until the foliage had matured enough to change from an energy sink to an energy source.

It is also possible that the increase in root glucose concentration induced the production of secondary metabolites for root protection through the shikimic acid pathway. Tschaplinski and Blake (1994) found an increase in root glucose, shikimic acid, and the phenolic compound salicyl alcohol 4 days after shoot decapitation of hybrid poplar (*Populus* spp.). They speculated that the increase in glucose concentration induced the production of these protective compounds.

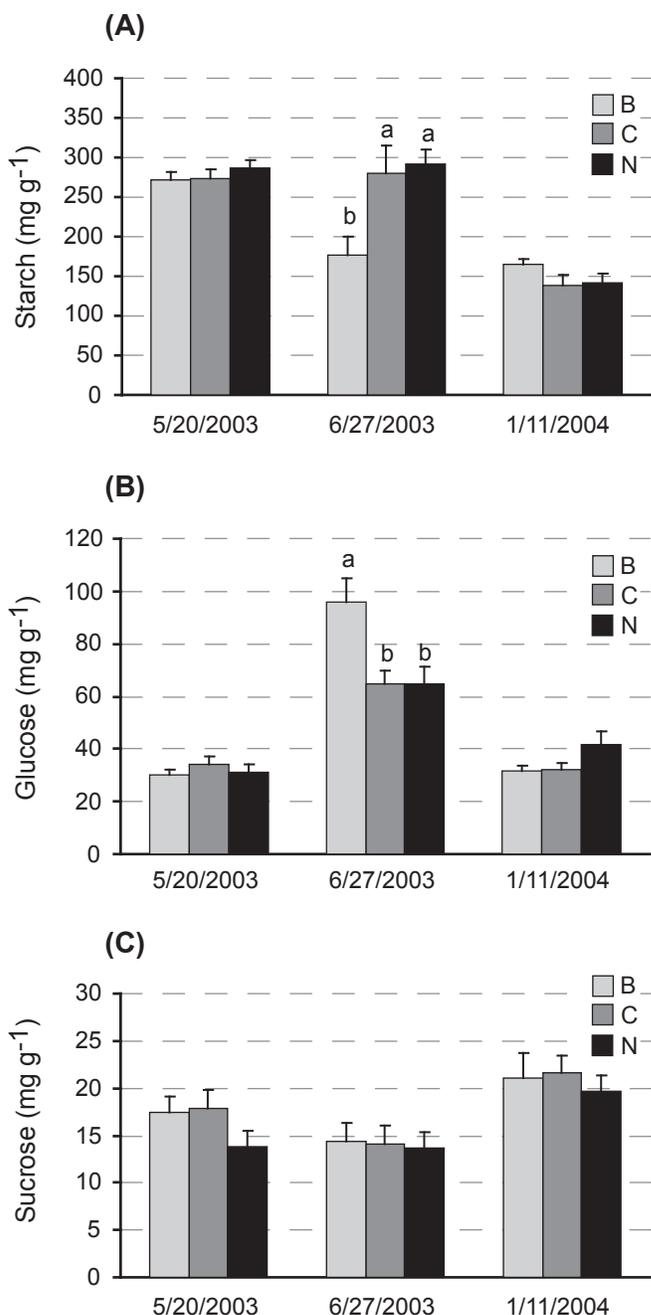


Figure 1—Mean (+1 standard error) longleaf pine root starch (A), glucose (B), and sucrose (C) concentration ( $\text{mg g}^{-1}$ ) before (5/20/2003) and after (6/27/2003 and 1/11/2004) prescribed fire for burn (B), control (C), and nonburned vegetation control (N) treatments. Letters above the bar indicate statistically significant differences at  $P \leq 0.05$  using Tukey's Studentized Range Test.

Current photosynthate translocated from foliage is the energy source for new root production and elongation (Dickson 1991, van den Driessche 1987). With the loss of foliage by scorch, we expected to see a postburn decline in root sucrose concentration. It appears, however, that prescribed fire on our study site did not disrupt carbohydrate allocation to the roots of saplings.

Foliar N and P concentrations in 2003 and 2004 were deficient (Blevins and others 1996) regardless of treatment (table 1).

**Table 1—Mean ( $\pm 1$  standard deviation) dormant season longleaf pine foliar nutrient concentrations in response to silvicultural treatment before (2003) and after (2004) prescribed fire**

Nutrient	Critical level <sup>a</sup>	n	Silvicultural treatment by year					
			2003			2004		
			B	C	N	B	C	N
N (%)	0.95	5	0.87(0.05)	0.94(0.06)	0.92(0.13)	0.85(0.08)	0.91(0.06)	0.92(0.14)
P (g/kg)	0.80	5	0.59(0.06)	0.49(0.18)	0.58(0.06)	0.66(0.06)	0.63(0.07)	0.64(0.08)
K (g/kg)	3.00	5	4.11(0.91)	3.87(1.24)	3.90(0.91)	4.93(0.79) <sup>a</sup>	3.85(0.78) <sup>b</sup>	4.08(0.45) <sup>b</sup>
Ca (g/kg)	1.00	5	1.44(0.24)	1.40(0.26)	1.94(0.53)	1.82(0.16)	1.65(0.27)	1.56(0.14)
Mg (g/kg)	0.60	5	1.06(0.17)	1.03(0.16)	0.89(0.11)	0.98(0.14)	1.18(0.29)	0.90(0.19)

Treatment B = burn; treatment C = control; treatment N = non-burned vegetation control; N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium.

Means followed by different letters are significantly different using Bonferroni's pairwise comparison test with an overall  $P \leq 0.05$ .

<sup>a</sup> Concentration below which the nutrient is considered deficient (Blevens and others 1996).

Although foliar N, P, Ca, and Mg concentrations were not, foliar K concentration was significantly affected by treatment ( $P = 0.0010$ ). Foliar K concentration was greater on the B plots than on the C and N plots by 28 and 21 percent, respectively. These findings disagree with those of Boyer and Miller (1994), who found that repeated prescribed fire had no effect on the foliar K concentration of 30-year-old longleaf pine. A similar response to the B treatment was also not observed in available soil K (Personal communication. 2005. James D. Haywood. Research Forester, USDA Forest Service, Southern Research Station, 2500 Shreveport Highway, Pineville, LA 71360). Continued measurement of foliar nutrition at our study site will determine whether the effect of burning on foliar K concentration is temporary or long-term.

Annual height increment was significantly affected by treatment ( $P = 0.0048$ ); greater growth occurred on the N plots than on the C plots (fig. 2). Between January 2003 and February 2004, longleaf pine on the N plots grew 28 percent taller than on the C plots. At the same time, those on the N plots grew 13 percent taller than on the B plots, although the difference was not statistically significant. Groundline diameter growth between January 2003 and February 2004 was also significantly affected by treatment ( $P = 0.0445$ ); there was 32 percent more growth on the B plots than on the C plots (fig. 2). During this 1-year period, trees on the B plots had 14 percent

greater diameter growth than trees on the N plots, although the difference was not statistically significant.

Boyer (2000) reported that biennial prescribed fire in southwest Alabama reduced longleaf pine height and diameter at breast height over the first 24 years of stand development. Our data do not reflect those findings. Greater annual increment of groundline diameter on the B plots relative to the diameter on C plots, as well as a trend of less annual height but more annual groundline diameter growth on the B plots relative to the growth on N plots, may be a morphological response to instability. Telewski (1995) explains that trees develop shorter stems and/or greater radial growth in response to flexure stress in order to reduce wind-drag on the crown. At our study site, repeated burning removed much of the taller competing vegetation, leaving an open, parklike stand of saplings. To prevent windthrow, trees on the B plots may have allocated carbon to increase stem taper.

These data suggest that repeated prescribed fire affects the pattern of carbon allocation in young longleaf pine trees. For example, stem form may indirectly respond to fire with an increase in taper. Also, fire-induced changes in the seasonal dynamics of root carbohydrates may represent a shift in carbon allocation to restore leaf area after scorch and/or produce protective secondary metabolites such as phenolics. Research will continue in an effort to understand how carbohydrate dynamics, foliage production, and stemwood growth of longleaf pine respond to repeated use of prescribed fire. With this information, the time and intensity of prescribed fire that maximize stand growth can be defined.

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#### LITERATURE CITED

- Blevens, D.; Allen, H.L.; Colbert, S.; Gardner, W. 1996. Nutrition management for longleaf pinestraw. Woodland owner notes, Raleigh, NC: NC State University, North Carolina Cooperative Extension Service. 8 p.
- Boyer, W.D. 2000. Long-term effects of biennial prescribed fires on the growth of longleaf pine. In: Moser, W.K.; Moser, C.F., eds. Fire and forest ecology: innovative silviculture and vegetation management. Tall Timbers fire ecology conference proceedings, number 21. Tallahassee, FL: Tall Timbers Research Station: 18-21.

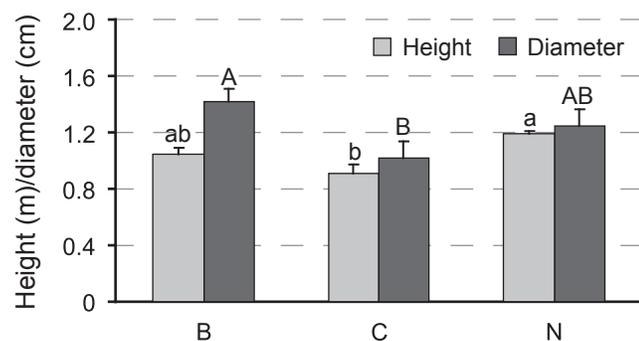


Figure 2—Annual growth increment of height (m) and groundline diameter (cm) ( $+1$  standard error) for burn (B), control (C), and nonburned vegetation control (N) treatments. Letters above the bar indicate statistically significant differences at  $P \leq 0.05$  using Tukey's Studentized Range Test.

- Boyer, W.D.; Miller, J.H. 1994. Effect of burning and brush treatments on nutrient and soil physical properties in young longleaf pine stands. *Forest Ecology and Management*. 70: 311-318.
- Dickson, R.E. 1989. Carbon and nitrogen allocation in trees. In: Dreyer, E.; Aussenac, G.; Bonnett-Masimbert, M. [and others], eds. *Forest tree physiology*. Paris: Elsevier/INRA: 631s-647s. *Annales des Sciences Forestieres*. 46 supplement.
- Dickson, R.E. 1991. Assimilate distribution and storage. In: Raghavendra, A.S., ed. *Physiology of trees*. New York: John Wiley: 51-85.
- Haywood, J.D.; Sword, M.A.; Harris, F.L. 2004. Fire monitoring: effects of scorch in Louisiana's pine forests. In: Connor, K.F., ed. *Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 65-67.
- Isaac, R.A.; Kerber, J.D. 1971. Atomic absorption and flame photometry techniques and uses in soil, plant, and water analysis. In: Walsh, L.M., ed. *Instrumental methods for analysis of soils and plant tissue*. Madison, WI: Soil Science Society of America: 17-37.
- John, M.K. 1970. Colorimetric determination of phosphorus in soil and plant materials with absorbic acid. *Soil Science*. 109: 214-220.
- Jones, M.G.K.; Outlaw, W.H.; Lowry, O.L. 1977. Enzymatic assay of  $10^{-7}$  to  $10^{-14}$  moles of sucrose in plant tissues. *Plant Physiology*. 60: 379-383.
- Kuehler, E.A.; Sword, M.A.; Andries, C.D. 1999. Seasonal fine-root carbohydrate and growth relations of plantation loblolly pine after thinning and fertilization. In: Haywood, J.D., ed., *Proceedings of the 10<sup>th</sup> biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 420-425.
- Sword Sayer, M.A.; Goelz, J.C.G.; Haywood, J.D. 2006. Effects of prescribed fire on production of foliage by sapling longleaf pine. In: Connor, K.F., ed. *Proceedings of the 13<sup>th</sup> biennial southern silvicultural research conference*; Gen. Tech. Rep. SRS-92, Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 478-485.
- Telewski, F.W. 1995. Wind-induced physiological and developmental responses in trees. In: Coutts, M.P.; Grace, J., eds. *Wind and trees*. Cambridge, UK: Cambridge University Press: 237-263.
- Tschaplinski, T.J.; Blake, T.J. 1994. Carbohydrate mobilization following shoot defoliation and decapitation in hybrid poplar. *Tree Physiology*. 14: 141-151.
- van den Driessche, R. 1987. Importance of current photosynthate to new root growth in planted conifer seedlings. *Canadian Journal of Forest Research*. 17: 776-782.

# CONTAINER-GROWN LONGLEAF PINE SEEDLING QUALITY

Mark J. Hains and James P. Barnett<sup>1</sup>

**Abstract**—The Longleaf Alliance, in cooperation with the USDA Forest Service, the Georgia Forestry Commission, and the Clemson Extension Service, has installed numerous longleaf pine (*Pinus palustris* Mill.) seedling quality studies across the Southeastern United States. This paper reviews survival and growth for different classes of container-grown longleaf pine including: target seedlings, floppies, doubles, and sonderegggers (hybrids) two to three growing seasons post-outplanting.

## INTRODUCTION

Longleaf seedlings are usually sold on a per thousand basis (The Longleaf Nursery List 2004), and an average lot of 1000 seedlings will contain several classes or categories of seedlings. These studies were initiated to determine the feasibility of increasing longleaf pine planting success by visually sorting through given lots of container-grown longleaf pine seedlings and removing non-target seedlings. Container-grown longleaf seedling quality may vary dramatically from nursery to nursery. If seedlings are judged by the Interim Guidelines for Growing Longleaf Seedlings in Containers (Barnett and others, n.d.; Barnett and others 2002), some nurseries ship batches of seedlings from which the vast majority are good quality/target seedlings, while other nurseries ship lots from which the majority should be culled. Some nurseries pack boxes with a given number of good/target seedlings and include cull/floppy seedlings as extras to be planted or discarded at the purchaser's discretion.

When first conceived, the goal of these seedling quality studies was to determine if seedlings could be visually sorted into various classifications, which would then be tracked to determine the relative survivability and vigor of the classifications. By collecting this data, it could be determined how much a landowner, forester, or tree planter could gain from the removal of culls, hybrids, or doubles.

Initially, survival and growth were tracked based solely upon visual classifications. Upon further review, we determined that it would be beneficial to track how visually grading seedlings affected average measurements, such as root collar diameter (RCD). With the benefit of simple RCD measurements, a forester or tree planter could compare their longleaf seedling classification or categories to those utilized in this study. More recently, Dr. David South (Auburn University, School of Forestry and Wildlife Sciences) suggested additional studies to track RCD and other measurements by individual seedlings and their location within a study site.

## METHODS

### Study Design

Seedlings were selected from one nursery and one seed source for each site. Seedlings were out-planted by hand in randomized complete blocks. Seedlings were planted so that the plug was level with or protruding above the soil surface, depending on the site preparation for a given study site.

There were 3 or 4 replications per site, 3 to 7 treatments (seedlings classes or categories), and 14 to 20 seedlings per treatment. Data reported are from studies installed in 2001, 2002, and 2003 in Georgia, Alabama, and South Carolina.

### Seedling Categories/Classes

**Target/good**—Longleaf seedlings are grown in small ribbed containers with individual container cavities having a volume of about 6 cubic inches, a minimum depth of 4.5 inches, and a seedling density of < 50 per square foot (Barnett and McGilvray 1997). Typical seedlings are sown in the spring and form a well-rooted "plug" by late fall or early winter. Target seedlings met seedling quality standards as defined by the Interim Standards for Longleaf Pine Container Seedlings Stock (Barnett and others n.d.; Barnett and others 2002).

**Doubles**—Some nurseries double-seed containers to insure an optimum percentage of cells are filled with viable seed, often resulting in two live seedlings per plug. Some nurseries remove one of the seedlings by clipping the smaller seedling at the top of the plug, approximately where one would measure RCD. In these studies, only those plugs with two intact seedlings were included as doubles.

**Floppies**—Suppressed seedlings usually do not develop sufficient root collars or fine root systems to form a good plug and are typically referred to as "culls" or in this study as "floppies". Seedlings that did not meet the Interim standards because of inadequate plugs were selected as floppies. In subsequent studies, floppies were further subdivided into those greater or lesser than 4.75 mm in RCD.

**Sonderegggers**—Hybrids between longleaf and loblolly are historically referred to as "sonderegggers" (Walker and Wiant 1966). Sonderegger seedlings typically exhibit height growth while still in the container. Initial attempts to include sonderegggers in seedling quality studies were largely inconclusive due to difficulty in identification of hybrid seedlings. At first, any seedling exhibiting stem growth was assumed to be a hybrid. In later studies, only seedlings with exaggerated stem growth of  $\geq 4$  inches were included as hybrid seedlings.

**Extra large**—Visually, extra large seedlings would automatically go into the "target/good" seedling pile. However, there is some concern that extra-large seedlings may become root-bound. Seedlings > 9.0 mm were selected as extra-large on two sites. In the most recent seedling quality study seedlings > 10.0 mm (1 cm) in RCD were selected.

<sup>1</sup> Research Coordinator, The Longleaf Alliance, Solon Dixon Forestry Education Center, Andalusia, AL 36420; and Project Leader, USDA Forest Service, Southern Research Station, Alexandria Forestry Center, Pineville, LA 71360.

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**Buds on stem**—Some longleaf seedlings exhibit multiple bud formation approximately where the tap-root meets the first needle growth, at or around where one would measure RCD. It is currently unknown if adventitious bud formation is an early indication of potential problems with the seedling or if these buds are of no importance to seedling quality. Seedlings exhibiting bud growth separate from the terminal bud were first selected for study inclusion and out-planted on February 8, 2005.

**Weeds in plug**—It is common to find other plant species occupying the same plug as a longleaf pine seedling. The Interim Standards call for plugs with weeds to be rejected as cull seedlings. In January, 2005, longleaf plugs with willows in the same plug were acquired from a nursery in Georgia. These plugs were selected for study inclusion and out-planted in Virginia on January 21, 2005, and in Alabama on two sites on February 8, 2005, and February 11, 2005.

### Study Sites

**Alabama, Samson Site**—This site was an old field utilized for cotton and peanut production until 3 years prior to study installation. A scalping site preparation was utilized. Seedlings were grown by Meek’s Farms of Kite, GA, and hand planted on December 14, 2001. Seedlings were released with 2 ounces of Oust® per broadcast acre in April, 2002.

**Alabama, Monroe Site**—This site is part of an Auburn University Agriculture Experiment Station and was in cotton production the year prior to study installation. The site was scalped prior to planting. Seedlings grown by Simmons Tree Farm of Denton, GA, were hand-planted on February 21, 2002, with dibble bars and plug tools. Seedlings were released with 2 ounces of Oust® per broadcast acre in April 2002.

**Alabama, Davis Ridge Site**—This is a cutover, mixed-pine hardwood stand with a chemical site preparation following harvest. Seedlings provided by Meeks Tree Farm of Kite, GA, were planted with OST “dibble” bars on December 19, 2002. Seedlings were released the spring following planting.

**Georgia, Milledgeville Site**—This is an old agricultural field that has been fallow for several years. The site was scalped and then hand-planted to container-grown seedlings from Meeks Tree Farm of Kite, GA, on January 15, 2003. Seedlings were released the spring following planting.

**Georgia, Denton Site**—This site was a cotton field the year prior to study installation. No site preparation was applied. Seedlings provided by Simmons Tree Farm of Denton, GA, were hand-planted using a plug tool on February 6, 2003.

**South Carolina, Pelion Site**—This site was a cutover sand ridge. Hardwoods were sprayed with 16 ounces of Arsenal® per broadcast acre in 2001. Remaining live hardwoods and longleaf were cut down at the time of planting on February 4, 2003.

## RESULTS AND DISCUSSION

Floppies and sonderegger seedlings yielded the lowest survival rates of the various seedling categories/classes (table 1). Seedlings classified as “floppies” but with RCDs > 4.75 mm exhibited comparable survival rates but grew slower in comparison with target seedlings. Small floppies (RCDs < 4.75 mm)

**Table 1—Percent difference for survival and height of selected seedling categories compared to good/target seedlings. Values for good/target seedlings are in parentheses**

Percent difference	2 year survival	2 year height	Number of seedlings planted & number of sites
----- feet -----			
Good/target (all RCDs)	90.5% (0.0%)	0.56' (0.0%)	546
XL only	94.8% (-0.6%)	0.62' (+12.8%)	172
Floppy (all RCDs)	71.8% (-18.7%)	0.26' (-53.3%)	532
Floppy –large (>4.5 mm RCD)	89.2% (-3.8%)	0.26' (-55.8%)	158
Floppy – small (<4.5 mm RCD)	76.6% (-16.5%)	0.19' (-67.3%)	158
Doubles	95.3% (+1.4%)	0.36' (-21.1%)	256
Seedlings w/ stem growth (in plug)	68.1% (-18.3%)	1.12' (+28.7%)	216

exhibited lower survival and growth rates than target seedlings (table 1).

Doubles exhibited slightly higher survival rates than target/good quality seedlings (table 1, fig. 1), but many doubles persisted with resultant decreases in height growth (fig. 2).

True sonderegger seedlings may suffer high mortality rates when compared to target seedlings. On the Monroe Site and the Samson Site, nearly 100 percent of the sonderegger seedlings died in the first growing season. Almost all seedlings with < 4 inches of stem growth that were initially selected as hybrids now appear to be true longleaf seedlings. If visual parameters are utilized to select hybrids, most seedlings exhibiting stem elongation > 4 inches in the container are hybrids, while seedlings with < 4 inches are often true longleaf seedlings.

Extra-large seedlings did not exhibit significant differences in survival but did add more height in the first two growing seasons when compared to smaller, good-quality seedlings.

### Additional Studies

(1) Seedlings in recently planted studies will be tracked by individual RCD. (2) Seedlings with willows have been out-planted on two dry sites and one wet site. (3) Seedlings with other weed species will be examined as feasible. (4) Seedlings with buds on the taproot have been out-planted and will be examined based upon the number of visible buds and RCD. (5) Further examination of root morphology is required to determine if certain containers lend themselves to spiraled roots or other problems with longleaf seedlings.

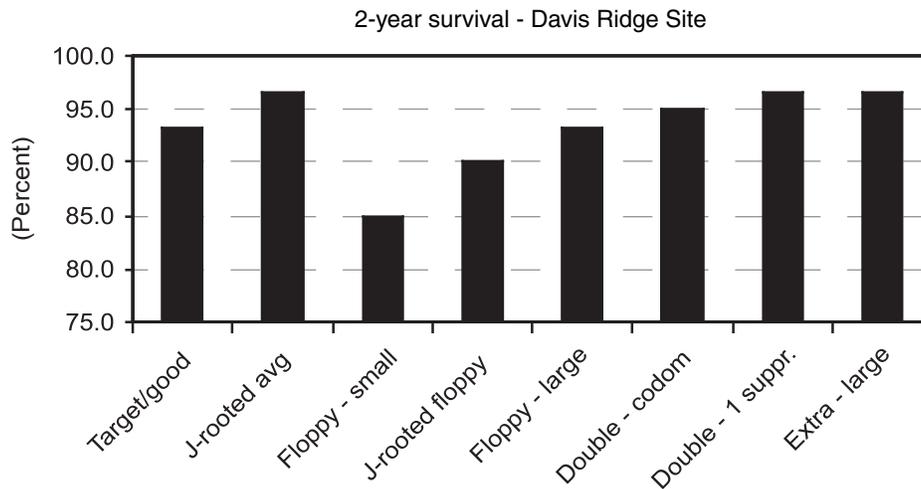


Figure 1—Two year seedling survival at the Davis Ridge Site.

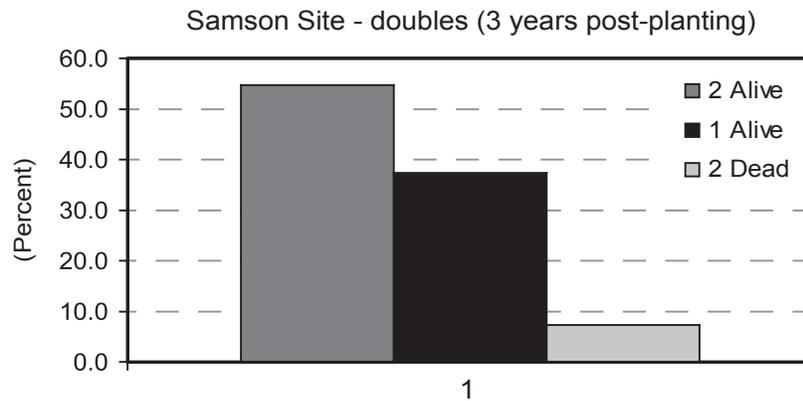


Figure 2—Height growth of doubles 3 years post-planting at the Samson Site.

## SUMMARY

Visually sorting container-grown longleaf pine seedlings may result in the removal of numerous floppy, hybrid, and double seedlings. Removing small RCD floppies and true sondereggers will likely result in an increased overall survival rate, especially when adverse environmental factors stress newly planted seedlings. Clipping doubles and discarding the smallest (< 4.75 mm RCD) floppies should yield increases in the average height of surviving seedlings at 2 years post-planting.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Barnett, J.P.; Hains, M.J.; Hernandez, G.A. [N.d.] Interim guidelines for growing longleaf seedlings in containers. Gen. Tech. Rep. SRS-60. Asheville, NC: U.S. Dept. of Agriculture, Forest Service, Southern Research Station. [Not paged].
- Barnett, J.P.; Hains, M.J.; Hernandez, G.A. 2002. Interim guidelines for longleaf pine seedlings grown in containers. In: Barnett, J.P.; Dumroese, R.K.; Moorhead, D.J., eds. Proceedings of workshops on growing longleaf pine in containers—1999 and 2001. Gen. Tech. Rep. SRS-56. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 27-29.
- Barnett, J.P.; McGilvray, J.M. 1997. Practical guidelines for producing longleaf pine seedlings in containers. Gen. Tech. Rep. SRS-14. Asheville, NC: U.S. Dept. of Agriculture, Forest Service, Southern Research Station. 28 p.
- The Longleaf Nursery List. 2004/05. The Longleaf Alliance. 7 p.
- Walker, L.C.; Wiant, H.V., Jr. 1966. Silviculture of longleaf pine. Nacogdoches, TX: Stephen F. Austin State University, School of Forestry. 105 p.

# EARLY GROWTH OF PLANTED LONGLEAF PINE SEEDLINGS IN RELATION TO LIGHT, SOIL MOISTURE, AND SOIL TEMPERATURE

Benjamin O. Knapp, G. Geoff Wang, and Joan L. Walker<sup>1</sup>

## Poster Summary

Drastic reductions in longleaf pine (*Pinus palustris* Mill.) acreage have led to an increased focus on regeneration of the longleaf pine ecosystem. Many areas require artificial regeneration for establishment, and site preparation techniques may be implemented to increase regeneration success. The objectives of this study were to determine differences in growth of first-year longleaf pine seedlings based on various site preparation treatments and to determine differences in microsite conditions (available light, soil moisture, soil temperature, competition) due to site preparation treatments.

### METHODS

The study was conducted on Marine Corps Base, Camp Lejeune, in Onslow County, NC. The study area was on a poorly drained, Leon fine sand soil. A randomized complete block design consisting of five blocks and eight treatments was implemented in the summer of 2003. The eight site preparation treatments used were flat/chop (FC), flat (F), flat/herbicide (FH), bed/chop (BC), bed/herbicide (BH), bed/chop/herbicide (BCH), mound/chop (MC), and mound/herbicide (MH). Containerized longleaf pine seedlings were planted in December 2003, and growth and microsite measurements were taken during August 2004. Growth was monitored by measuring the root collar diameter of selected seedlings on each plot. Microsite measurements included soil moisture, soil temperature, percent full sunlight reaching each seedling, and amount of competing vegetation. Differences in treatment results were analyzed using SAS software.

### RESULTS AND DISCUSSION

The growth measurements resulted in differences in root collar diameter among the treatments ( $p < 0.0001$ ), with FC (11.7 mm) and F (12.1 mm) having the smallest diameters. There were no statistical differences between BC, BCH, BH, FH, MC, or MH. The soil moisture results showed significantly more moisture on F (38.1 percent), FH (38.3 percent), and FC (35.1 percent) treatments than any other treatments, except no difference between FC and MC (26.2 percent). There were

no differences in soil temperature. The percent of full sunlight reaching the seedlings was least on F (73.1 percent), FC (86.8 percent), and FH (89.4 percent), although only F was statistically different from any other treatment. Finally, the height of competing vegetation was greatest on F (25.8 cm), FC (17.8 cm), FH (11.7 cm), and BC (10.4 cm). The results of the growth and micro-environment measurements display a trend in the impact of site preparation on seedling growth. The treatments that had the least amount of growth (F and FC) are also among the treatments with the most soil moisture, least sunlight reaching the seedlings, and most competing vegetation. How these factors specifically affect the seedlings is not yet understood; however, competition for light, moisture, and nutrients may all contribute in varying degrees depending on site and year. Bedding and mounding increase drainage on these poorly drained sites, altering moisture levels within the root zone. These treatments also control competing vegetation, a necessity for longleaf pine seedling success. The competition for light is not considered an important factor at this stage of seedling growth, as the treatment with the lowest light levels reaching the seedling (F with 73.1 percent) still has adequate light for photosynthesis.

### CONCLUSION

Site preparation treatments impacted the growing conditions of longleaf pine seedlings, resulting in growth differences by treatment. Continued research will clarify the effect of site preparation treatments on the growth of longleaf pine seedlings.

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<sup>1</sup> Graduate Student and Assistant Professor, respectively, Clemson University, Department of Forestry and Natural Resources, 261 Lehotsky Hall, Clemson, SC 29634-0317; and Research Ecologist, USDA Forest Service, Southern Research Station, Clemson University, 261 Lehotsky Hall, Clemson, SC 29634-0317.

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# HERBACEOUS WEED CONTROL IN AN OLD-FIELD PLANTED LONGLEAF PINE STAND

Bryan C. McElvany, E. David Dickens, and Philip R. Torrance<sup>1</sup>

**Abstract**—Over 110,000 acres of longleaf pine (*Pinus palustris* Mill.) have been planted on old fields in Georgia since 1998 in the Conservation Reserve Program (CRP). Part of the CRP guidelines mandate that no more than 500 trees acre<sup>-1</sup> are planted. This relatively low planting density, coupled with shade intolerance and high cost of containerized longleaf pine seedlings, make optimizing early survival a high priority. A study area in Emanuel County, GA, was installed (spring 2000) to discern the effectiveness of various herbicides banded over newly planted longleaf seedlings in a former cotton field. Survival and height growth data after herbicide treatment indicate that the early (April 7, 2000) Oust+Velpar L herbicide treatment gave greater initial survival and height growth than nine later herbicide treatments (May 9, 2000) or an untreated control. First-year survival ranged between 90 percent with the April 7 Oust+Velpar L treatment and 40 to 65 percent with the May 9 herbicide treatments. After 3 years, the number of trees out of the grass stage and mean heights of the trees were significantly greater with the April 7 herbicide application. During the spring of 2000, rainfall patterns were 5 percent of normal in this region. It appears that the April 7 herbicide treatment allowed the seedlings to survive this critical dry spell. These results indicate that substantial establishment costs can be saved with an earlier herbicide application under severe spring drought conditions.

## INTRODUCTION

Herbaceous weed control has been identified as one of the most important factors in successfully converting old fields to longleaf pine (*Pinus palustris* Mill.) plantations. This is due in part to the fact that longleaf pine remains in a grass stage for 1 to 7 years after planting. During this period, competition with herbaceous weeds for light, nutrients, and water can significantly reduce the survival and growth of longleaf pine seedlings.

Many sites in the Coastal Plain of Georgia are being converted from row crops to pine plantations. Since 1998, these old-field sites are commonly converted to longleaf pine plantations. Over 110,000 acres have been converted to longleaf pine plantations in Georgia, including sites located in Emanuel County. This study addressed the efficacy of several herbicide mixtures, dosages, and timing in controlling herbaceous weeds on an old field during the establishment of longleaf pine in the middle coastal plain of Georgia.

## MATERIALS AND METHODS

Longleaf pine containerized seedlings were planted on an old-field site (previous crop cotton) in December, 1999. The study area is located on the Tifton soil series (Plinthic Kandudults). Experimental design was randomized block with four replications per treatment (table 1). Individual plots consisted of four treated rows of trees with each row containing 10 surviving seedlings as of May 8, 2000. An additional row of trees was treated adjacent to the measurement rows. On April 8, 2000, an over-the-top banded (4 feet) application of Oust + Velpar L was applied to the majority of the planted area as an operational treatment. On May 9, 2000, the balance of this study area's treatments were applied. Seedlings that died during the first growing season were replaced in December, 2000. Data were subjected to a one-way analysis of variance. Least squares means were calculated and compared using Duncan's Multiple Range test ( $\alpha = 0.05$ ). Parameters tested

were seedling survival, percentage of seedlings out of the grass stage, and the height of those seedlings out of the grass stage.

## RESULTS

First-year survival was the most dramatic result found in this study. The Oust Velpar treatment applied in April had significantly greater survival (90 percent) over all treatments applied in May (40 to 64 percent) (fig. 1). This treatment timing effect continued through year 3 (fig. 2). The percentage of trees that had extended out of the grass stage (fig. 3) was significantly

**Table 1—Treatments applied in 2002 to an old field longleaf pine stand located in Emanuel County, GA**

Code <sup>a</sup>	Treatment	Application date
C	Control, no treatment	May 9
A4	Arsenal 4 oz ac <sup>-1</sup>	May 9
A6	Arsenal 6 oz ac <sup>-1</sup>	May 9
A8	Arsenal 8 oz ac <sup>-1</sup>	May 9
A4P1.2	Arsenal 4 oz ac <sup>-1</sup> and Pendulum 1.2 qt ac <sup>-1</sup>	May 9
A6P1.2	Arsenal 6 oz ac <sup>-1</sup> and Pendulum 1.2 qt ac <sup>-1</sup>	May 9
A4O2	Arsenal 4 oz ac <sup>-1</sup> and Oust 2 oz ac <sup>-1</sup>	May 9
A4V24	Arsenal 4 oz ac <sup>-1</sup> and Velpar L 24 oz ac <sup>-1</sup>	May 9
A4OS6.5	Arsenal 4 oz ac <sup>-1</sup> and Oustar 6.5 oz ac <sup>-1</sup>	May 9
OS13	Oustar 13 oz ac <sup>-1</sup>	May 9
O2V32	Oust 2 oz ac <sup>-1</sup> and Velpar L 32 oz ac <sup>-1</sup>	April 7

<sup>a</sup> Treatment codes will be used throughout this paper.

<sup>1</sup> Research Coordinator I and Associate Professor, respectively, University of Georgia, Warnell School of Forest Resources, Statesboro, GA 30460; and County Extension Agent, Cooperative Extension Service, University of Georgia, Swainsboro, GA 30401.

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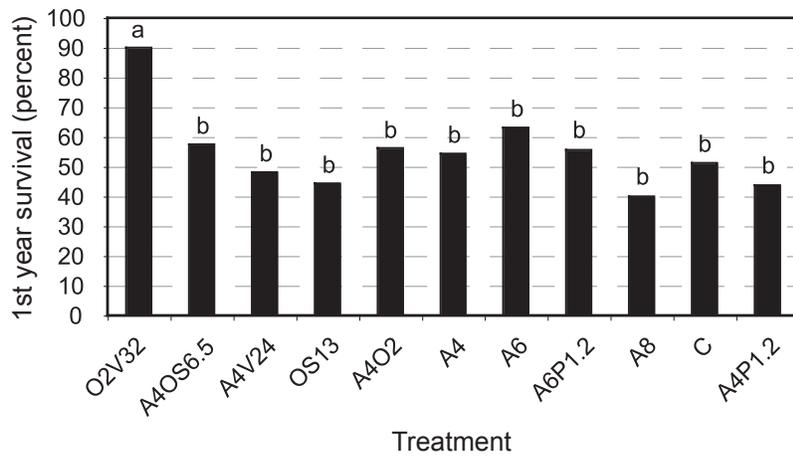


Figure 1—First-year survival on an old field planted longleaf pine stand in Emanuel County, GA, treated with Oust+Velpar L on April 7, 2000, and remaining treatments on May 9, 2000.

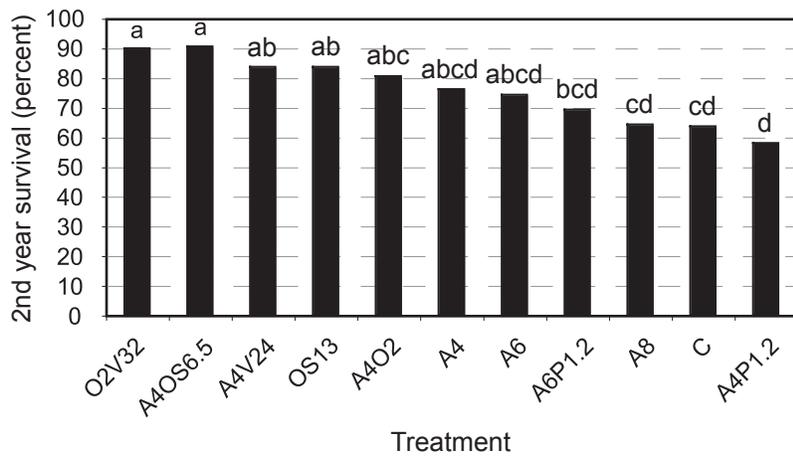


Figure 2—Second-year survival, including replanting, on an old field planted longleaf pine stand in Emanuel County, GA, treated with Oust+Velpar L on April 7, 2000, and remaining treatments on May 9, 2000.

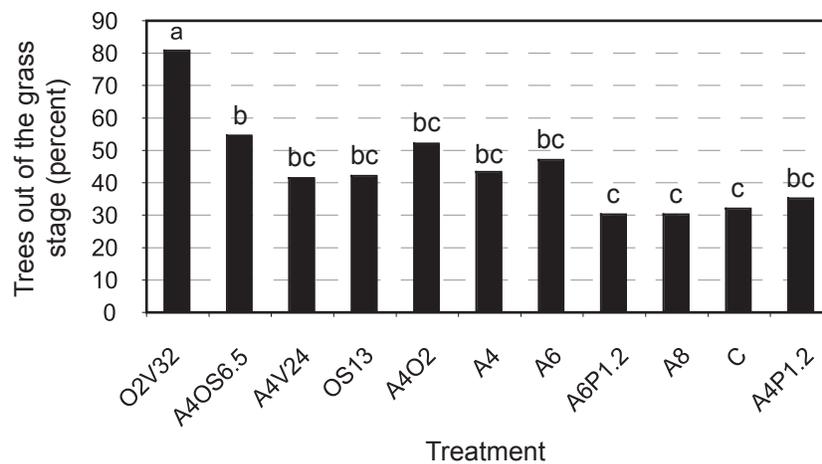


Figure 3—Percentage of longleaf pine trees out of the grass stage three growing seasons after treatment on an old-field planted site in Emanuel County, GA, treated with Oust+Velpar L on April 7, 2000, and remaining treatments on May 9, 2000.

higher in the Oust + Velpar L treatment applied in April (80 percent) over all treatments applied in May (30 to 55 percent). The mean total height (fig. 4) of all trees that had extended out of the grass stage was also significantly higher for the April Oust + Velpar L treatment (3.95 feet) compared to the majority of the herbicide treatments applied in May (2.04 to 3.50 feet).

### CONCLUSIONS

These results indicate that timing may prove to be important in the application of herbicides for longleaf pine establishment on old fields. In May, 2000, rainfall was only 5 percent (0.21 inches) of the 50 year average for that month (fig. 5). The application of Oust and Velpar that was applied in early April of 2000 appears to have allowed more competition control during

that critical dry spell. Earlier competition control, prior to the onset of droughty conditions, may have enabled those trees to obtain enough soil moisture to survive during the extended droughty conditions.

### DISCUSSION

Successful longleaf pine establishment can be much more difficult and generally more costly on old fields and pastures than loblolly or slash pine. This study, using various herbicides individually and in tank mixes, indicates that for longleaf pine, post-planting herbaceous weed control prior to mid-April may be critical to optimize early survival and growth on moderately well to well-drained soils. Early herbaceous weed control appears to be especially critical when droughty conditions occur in late April, May, and into mid-June.

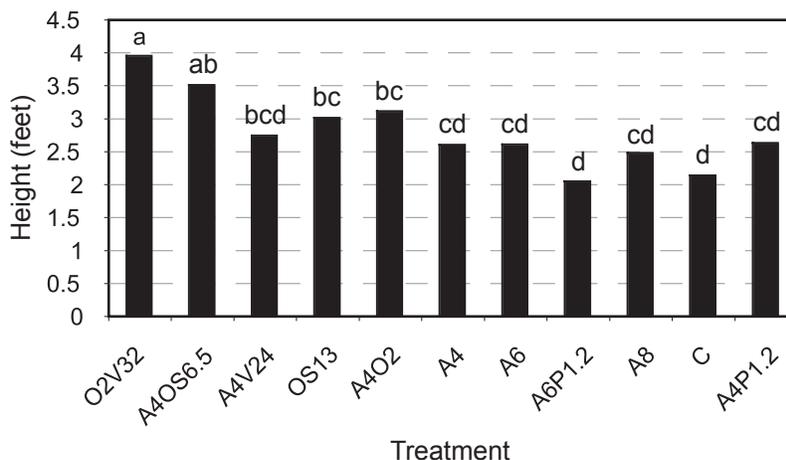


Figure 4—Mean total height of trees that have extended out of the grass stage three growing seasons after treatment in an old-field planted longleaf pine stand in Emanuel County, GA, treated with Oust+Velpar L on April 7, 2000, and remaining treatments on May 9, 2000.

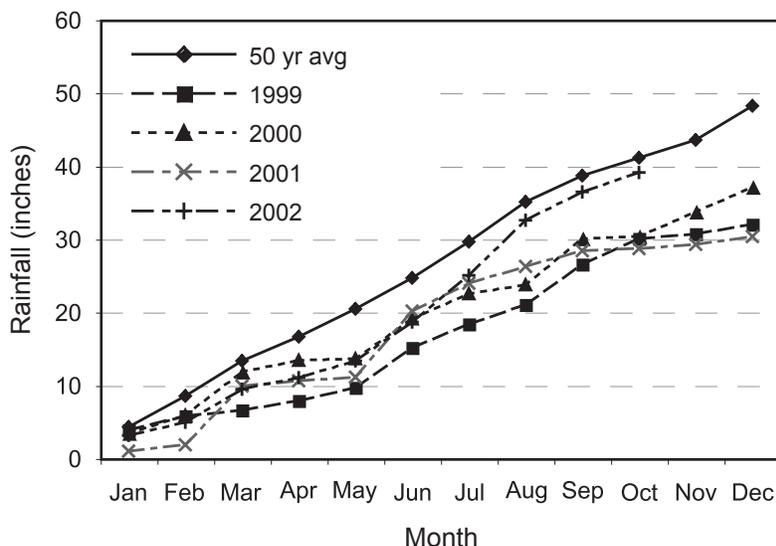


Figure 5—Monthly rainfall patterns from 1999 to 2002 as compared to the 50 year average rainfall as reported by the Georgia Automated Environmental Monitoring Network station in Vidalia, GA.

# CARBON SEQUESTRATION AND NATURAL LONGLEAF PINE ECOSYSTEMS

Ralph S. Meldahl and John S. Kush<sup>1</sup>

**Abstract**—A fire-maintained longleaf pine (*Pinus palustris* Mill.) ecosystem may offer the best option for carbon (C) sequestration among the southern pines. Longleaf is the longest living of the southern pines, and products from longleaf pine will sequester C longer than most since they are likely to be solid wood products such as structural lumber and poles. In addition, a fire-maintained longleaf pine ecosystem supports a productive understory of grasses and herbaceous plants. A study initiated in 1973 to determine the effects of using prescribed fire for hardwood control is being used to assess the amount of C in the overstory, understory vegetation, litter layer, and soils.

## INTRODUCTION

Forested ecosystems have a significant potential for sequestering large amounts of carbon (C) through land management. To fully realize the potential C sequestration capabilities of these ecosystems, there is a need to develop strategies and methods for increasing C sequestration. A fire-maintained longleaf pine-dominated (*Pinus palustris* Mill.) ecosystem may offer one of the best options for C sequestration among the forested ecosystems of the Southeastern United States. Longleaf pine is the longest living of the southern pines, capable of reaching 500 years of age (Platt and others 1988). It will continue to put on growth, even at older ages (West and others 1993). Products from longleaf pine will sequester C longer than most since they are likely to be solid wood products such as structural lumber and poles. In addition to the tree itself, a fire-maintained longleaf pine ecosystem supports a productive understory of grasses and herbaceous plants, which themselves may offer more C storage than the trees. This ecosystem provides habitat for a number of threatened and endangered plant and wildlife species, including red-cockaded woodpeckers, gopher tortoises, and indigo snakes (Hardin and White 1989, Landers and others 1995).

## Native Species/Ecosystem Benefits

In addition to wood production, another reason for growing longleaf pine would be the potential ecological benefits derived from the important plant and animal communities associated with longleaf pine ecosystems. A fire-maintained longleaf pine ecosystem is among the most species-rich outside of the tropics. A mesic longleaf woodland may contain 140 vascular species per 1,000 m<sup>2</sup>, the largest values reported for the temperate Western Hemisphere (Peet and Allard 1993).

As part of the U.S. Forest Service Northern Global Change Program, a project was conducted to estimate current C storage on selected Department of Defense installations and to evaluate the future C sequestration potential of these lands under different forest management scenarios (Hoover 2000). Multiple stand growth simulations were run on a 40-ha stand with a rotation age of 40 years. The parameters tested were site index, initial stocking level, and survivorship at 10 years. In nearly all cases, the simulations indicated that longleaf pine would store more C than the other three major southern pine species, given the same starting conditions. Results from the

old-field longleaf pine plantation simulator indicated there would be C gains due to increased stocking toward the end of the simulation period, when the trees were putting on volume rapidly and continued to do so beyond the 40-year rotation. Holding stocking levels constant and varying site index, a rotation of longleaf pine on a high-quality site stored more C than any other species investigated.

## OBJECTIVE

A study was initiated in 1973 to determine the effects of hardwood control treatments on understory plant succession and overstory growth in naturally regenerated stands of longleaf pine (Boyer 1983, 1987, 1991, 1993, 1994). These treatments were combinations of mechanical, chemical, and fire (seasonal and no-burn). Boyer (1995) reported on responses of understory vegetation before, and 7 and 9 years after, treatments. Kush and others (1999, 2000) examined effects of 23 years of different seasonal biennial burns (or no burn) plus supplemental hardwood control treatments on the long-term response of understory vegetation in naturally regenerated longleaf pine forests. Using the study initiated by Boyer, the relationships between prescribed burn treatment and above/below ground biomass and C sequestration are being examined.

## METHODS

### Study Area

The study was conducted at the Escambia Experimental Forest in south central Escambia County, AL. The forest is maintained by the U.S. Department of Agriculture, Forest Service, Southern Research Station, in cooperation with T.R. Miller Mill Company of Brewton, AL.

### Plot Sampling

In early September, 2003, the longleaf pine overstory was re-measured for diameter, and crown and total height. All hardwood trees with a d.b.h. > 0.5 inches were identified, and their d.b.h. and total height were recorded. In late September/early October, 2003, living material with a d.b.h. < 0.5-inches was destructively sampled from nine 9.0-square-foot sample plots per treatment plot. The vegetation was sorted by vegetation classes; i.e., grasses, vines, woody, and herbaceous. The litter layer was sampled from one 1.0-square foot per

<sup>1</sup> Associate Professor and Research Associate, respectively, 108 M. White Smith Hall, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL 36849.

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sample plot. The vegetation and litter was oven-dried at 70 °C for 72 hours and weighed. A sub-sample of the dried material was ground with a Wiley Mill and sieved to be used for percent C determination.

### Carbon Analyses Protocol

Samples were run on a Thermo Finnigan Flash 1112 N/C (CE Elantech Inc., Italy) according to the machine's standard operating instructions. Twenty percent of all the samples were duplicated to check the instrument's repeatability. One NBS standard and one CE Elantech Inc. certified standard were used in each sample set to check the accuracy of the sample values. A sample set consisted of 31 samples, 2 certified standards, a blank (empty tin capsule), and 6 random duplicate samples. After the samples had been run, SAS (SAS Institute 1999) was used to generate coefficients of variation for each duplicate sample. If the coefficient of variation was higher than 5 percent, the sample was rerun. This continued until the coefficient of variation was lower than 5 percent. Entire sample sets were reweighed and rerun if standards were not within 10 percent of certified standard values.

### RESULTS AND DISCUSSION

The no-burn treatment had the highest basal area when compared with the burning treatments. Among the burn treatments, the winter burn plots had a higher basal area with 118.16 square feet acre<sup>-1</sup>. Among the treatments, the basal area on the winter burn plots was the highest with 116.01 square feet acre<sup>-1</sup>. The spring burn plots had 114.00 square feet acre<sup>-1</sup>, and the summer had 112.24 square feet acre<sup>-1</sup>.

### Carbon Sequestration

Table 1 presents the weight of C that was present in the non-longleaf pine vegetation by burning treatment. It must be kept in mind that the last winter season burn before sampling was in February 2003, the spring in May 2002, and the summer in July 2002. There were no statistically significant differences in percent C among the different treatments and vegetation components. Dry weight was multiplied by percent C to get total C for the treatment.

The no-burn treatment had the highest amount of C stored, because there was no fire to reduce the aboveground biomass. Among the burning treatments, the winter had the most C, which is related to the woody vegetation present. Efforts are underway to sample the soils for the amount of C being stored there.

**Table 1—The amount of carbon (pounds acre<sup>-1</sup>) stored in the non-longleaf pine vegetation, by burning treatment, on the Escambia Experimental Forest in Brewton, AL**

Season of burn	Layer				Total
	Woody	Herb	Grass	Vine	
Spring	125.89	36.94	32.23	16.07	211.13
Summer	101.38	30.96	25.72	2.77	160.83
Winter	231.91	16.17	48.81	45.43	342.32
No burn	509.13	1.85	0.82	167.06	678.86

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### LITERATURE CITED

- Boyer, W.D. 1983. Growth of young longleaf pine as affected by biennial burns plus chemical or mechanical treatments for competition control. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 62-65.
- Boyer, W.D. 1987. Volume growth loss: a hidden of periodic burning in longleaf pine? Southern Journal of Applied Forestry. 11: 154-157.
- Boyer, W.D. 1991. Effects of a single treatment on long-term hardwood development in a young pine stand. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 599-606.
- Boyer, W.D. 1993. Season of burn and hardwood development in young longleaf pine stands. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 511-515.
- Boyer, W.D. 1994. Eighteen years of seasonal burning in longleaf pine effects on overstory growth. In: Fire, meteorology and the Landscape: Proceedings of the 12<sup>th</sup> international conference on fire and forest meteorology. Society of American Foresters: 602-610.
- Boyer, W.D. 1995. Responses of groundcover under longleaf pine to biennial seasonal burning and hardwood control. In: Edwards, M.B., comp. Proceedings of the eighth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 512-516.
- Hardin, E.D.; White, D.L. 1989. Rare vascular plant taxa associated with wiregrass (*Aristida stricta*) in the Southeastern United States. Natural Areas Journal. 9: 234-245.
- Hoover, C.M. 2000. Carbon sequestration on Department of Defense lands: executive summary. Defense environmental network and information exchange website: <https://www.denix.osd.mil/denix/Public/ES-Programs/Conservation/CarbonReport/carbonreport.html>. [Date accessed: October 9, 2000].
- Kush, J.S.; Meldahl, R.S.; Boyer, W.D. 1999. Understory plant community response after 23 years of hardwood control treatments in natural longleaf pine (*Pinus palustris*) forests. Canadian Journal of Forest Research. 29: 1047-1054.
- Kush, J.S.; Meldahl, R.S.; Boyer, W.D. 2000. Understory plant community response to season of burn in natural longleaf pine forests. In: Moser, W.K.; Moser, C.F., eds. Fire and forest ecology: innovative silviculture and vegetation management. Tallahassee, FL: Tall Timbers Research Station. Tall Timbers Fire Ecology Conference Proceedings. 21: 32-39.
- Landers, J.L.; Van Lear, D.H.; Boyer, W.D. 1995. The longleaf pine forests of the Southeast: requiem or renaissance? Journal of Forestry. 93(11): 39-44.
- Peet, R.K.; Allard, D.J. 1993. Longleaf pine vegetation of the southern Atlantic and eastern Gulf Coast regions: a preliminary classification. In: Hermann, S.M., ed. Proceedings of the Tall Timbers fire ecology conference. The longleaf pine ecosystem: ecology, restoration and management. Tallahassee, FL: Tall Timbers Research Station. Timbers Fire Ecology Conference Proceedings. 18: 45-81.
- Platt, W.J.; Evans, G.W.; Rathbun, S.L. 1988. The population dynamics of a long-lived conifer (*Pinus palustris*). The American Naturalist. 131(4): 491-525.
- SAS Institute Inc. 1999. SAS/STAT user's guide, version 8. Cary, NC: SAS Institute Inc. 3848 p.
- West, D.C.; Doyle, T.W.; Tharp, M.L. [and others]. 1993. Recent growth increases in old-growth longleaf pine. Canadian Journal of Forest Research. 23(5): 846-853.

## **Nutritional Amendments**

*Moderator:*

**TOM FOX**

Virginia Polytechnic Institute  
and State University



# THE SHORT-TERM EFFECTS OF FERTILIZATION ON LOBLOLLY PINE PHOTOSYNTHESIS AND BIOMASS

Nathan King, John Seiler, Thomas R. Fox, and Kurt Johnsen<sup>1</sup>

**Abstract**—The physiological processes in loblolly pine leading to enhanced growth in response to fertilization have not been clearly established. We tracked net photosynthesis ( $P_n$ ), height, basal diameter, and volume changes in loblolly pine seedlings in response to fertilization during the entire 2004 growing season.  $P_n$  measurements were conducted prior to fertilization and after fertilization in early May. The seedlings that received fertilization showed an increase in  $P_n$  rates above the controls for most of the growing season. Also, the fertilized seedlings had height, basal diameter, and volume increases of 10, 13, and 34 percent over the unfertilized seedlings. We conclude that fertilization led to an initial increase in  $P_n$  rates, which helped create extra photoassimilate to be used in building larger leaf areas, which in turn led to more above ground biomass.

## INTRODUCTION

One common silvicultural management tool used to increase tree growth is forest fertilization. Nitrogen (N) and phosphorus (P) are typically considered particularly crucial elements in determining the productivity of forest species (Helms 1976). Fertilization is a practical method of enhancing the nutrient content of infertile soil types, such as sandy coastal plain soils. Loblolly pine stands in the South are often fertilized due to their positive biological and economic responses to nutrient applications (Colbert and Allen 1996, Jokela and Stearns-Smith 1993). The North Carolina State Forest Nutrition Cooperative (2000) noted that 75 percent of the planted lands in the region were planted in pine and almost 1.6 million acres of planted pine were fertilized in 1999.

Although fertilization often results in increased pine tree biomass, the physiological reasons for this rise in productivity are still unclear. Teskey and others (1987) state that specific leaf photosynthesis rate, respiration rate of foliage tissue, leaf area, and surface area of a tree are responsible for governing net carbon gains. Several studies have focused on gas exchange and leaf area in fertilized forests, but the results have been contradictory. Literature surveyed generally show that net photosynthesis favorably responds to N fertilization or increased foliar N concentrations over the long term. This is a logical relationship since N is a vital component in Rubisco and chlorophyll. Eight out of 12 journal articles surveyed reported an increase in net photosynthesis either all or partially due to the effects of N fertilization (Chandler and Dale 1995, Kellomaki and Wang 1997, Lavigne and others 2001, Murthy and others 1996, Murthy and others 1997, Roberntz and Stockfors 1998, Schoettle and Smith 1999, Strand 1997). The other four articles reported no significant difference or varying differences in net photosynthesis due to N fertilization (Gough and others 2004a, Schaberg and others 1997, Teskey and others 1994, Zhang and others 1997). For example, Murthy and others (1996) noted a significant difference in net photosynthesis ( $P_n$ ) of young loblolly pine foliage due to fertilization. However, no increase in  $P_n$  was found in loblolly pines that had increased leaf N content and chlorophyll content in a study by Zhang and others (1997). Some studies have suggested that the primary reason productivity increases is due to increased

leaf areas and stem wood in fertilized loblolly pine stands (Teskey and others 1987, Vose and Allen 1988).

Gough (2003) initially studied this topic on loblolly pine seedlings in a greenhouse environment. Gough planted these seedlings in a relatively infertile soil type from the North Carolina Sandhills region [sandy, siliceous, thermic Psammentric Hapludult (Wakulla series), USDA Forest Service, unpublished data]. He reported that following N fertilization, foliar N concentrations increased above the controls and remained elevated for approximately 50 days. Gough found that the N levels returned to control levels around 146 days after fertilization. Also, Gough reported light saturated photosynthesis ( $A_{sat}$ ) levels that were statistically greater in the N fertilized loblolly pines than in the controls 6 days after the treatment application.  $A_{sat}$  levels remained high throughout most of the study but began to decrease towards control levels over the last 100 days. Furthermore, Gough noted that, 4 weeks after the initial increase in photosynthetic capacity, aboveground biomass in the seedlings was statistically higher in the fertilized loblolly pines. More specifically, the fertilized seedlings' ground diameters and heights were greater. Also, projected leaf areas at the end of the study were 36.5 percent greater in the fertilized seedlings. Hence, Gough hypothesized that increased N uptake into foliage led to an initial increase in photosynthetic capacity, which helped create extra photoassimilate to be used in creating larger leaf areas. Afterwards, the seedling would have higher overall photosynthesis due to larger amounts of photosynthetic tissue and this would lead to increased above ground biomass. However, Gough (2003) noted that his findings in the greenhouse might not translate to a field setting. Hence, the objective of this study will be to clarify the physiological mechanisms involved in increasing loblolly pine biomass with an emphasis on leaf specific photosynthesis.

## METHODS AND MATERIALS

### Study Site

The study site was located in Patrick County, VA (36° 40' N, 80° 10' W) at the Reynolds Homestead Forestry Research Center. The site was in the upper Piedmont province, where

<sup>1</sup> Graduate Student, The Honorable and Mrs. Shelton Short Professor, and Associate Professor, respectively, Virginia Polytechnic Institute and State University, Blacksburg, VA 24060; and Project Leader, USDA Forest Service, Southern Research Station, Research Triangle Park, NC 27709.

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the topography consists of gently rolling hills. The elevation varies between 300 and 350 m above sea level. The site was located in the temperate climate zone with warm, humid summers and cool, moist winters. The average minimum temperature is -1.4°C, and the average maximum is 29.2°C. Precipitation is evenly distributed throughout the seasons and averages 1.3 m/year.

The soils consist of the Lloyd clay loam, Louisa loam, and Hiwassee loam series and are well-drained, deep Ultisols originating from granite, schist, and gneiss parent material. The site has been heavily farmed for two centuries, which has resulted in a loss of essentially all of the old A horizon. Instead there is a reduced profile, with a surface Ap horizon and clayey B horizons mixed in below.

The study site consisted of 8 square plots of 25 different loblolly pine clones that were planted May 19, 2003. The site preparations included a treatment of Roundup®, ripping, and shallow cultivation in the planting rows. The clones were evenly spaced 2.4 m apart in rows consisting of five clones that were randomly selected. All rows were evenly spaced 3.0 m apart, and the clones were numbered in a serpentine pattern from 1 to 25 starting in the lower left hand corner of the plot. There was also a row of buffer seedlings surrounding and separating the eight study plots. Thus, the total size of each plot was approximately 338.2 m<sup>2</sup>. The clones were provided by the Forest Biology Research Cooperative (FBRC) (University of Florida, Gainesville, FL). The parents were selected from the Atlantic Coast and Florida provenances that are bred by the Loblolly Pine Lower Gulf Elite Population. The study plots were mowed and weeded periodically during the growing seasons in order to reduce competition and confounding factors. Oust® (Dupont Corp.) and Roundup® (Monsanto Co.) herbicides were also used to clear out competition from the seedling rows. No other environmental variables were controlled during the experiment in order to allow the seedlings to experience typical field grown conditions.

### Pre-fertilization Measurements

Prior to application of the fertilizer treatment, growth measurements including height and basal diameter were collected on all 200 seedlings. Seedling growth was monitored periodically during the growing season by tracking the changes in the variables above. Also, any dead or dying seedlings were noted and excluded from the study. Out of the 25 loblolly pine clones, 8 were chosen for intensive physiological and growth measurements.

In order to establish the short-term effects of fertilization on loblolly pine physiology, measurements were taken twice, one in late April and one in early May, to establish a base of comparison for subsequent measurements after treatment application in May. Net photosynthesis and a foliar C and N analysis were conducted on one new, fully expanded needle fascicle per clone. The data collected the previous time governed how often each measurement was taken. On days when all measurements were taken, a total of 192 samples were recorded.

Net photosynthesis measurements under saturating light conditions ( $A_{\text{sat}}$ ) were conducted using a LiCor 6400 Portable Photosynthesis System (LiCor Inc., Lincoln, Nebraska).  $A_{\text{sat}}$  was measured on a fascicle of needles immediately after

detachment from the seedling. Photosynthesis was recorded 3 times per fascicle over a period of 10 seconds, and the mean of the three samples was used for subsequent data analysis. Thus, 64 mean  $A_{\text{sat}}$  values were used for data analysis. All chamber conditions remained at ambient for this study with the exception of photosynthetically active radiation (PAR; 1,600  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) and  $[\text{CO}_2]$  (360  $\mu\text{mol mol}^{-1}$ ). Hence, the data collected was reflective of the environmental conditions experienced by the field-grown seedlings. After  $A_{\text{sat}}$  measurements, each removed fascicle diameter was measured using digital calipers, and then the fascicles were enclosed in an envelope. The following equation was used to calculate  $A_{\text{sat}}$  on a per leaf area basis given the information collected (Ginn and others 1991):

$$LA_i = (n \cdot l \cdot d) + (\pi \cdot d \cdot l) \quad (1)$$

where

$n$  = number of needles per fascicle,

$d$  = fascicle diameter, and

$l$  = needle length.

The  $A_{\text{sat}}$  fascicles were stored and used to obtain foliar C and N concentrations. All needles were oven-dried and ground up prior to C and N analysis.

### Nutrient Addition and Post-fertilization Measurements

Within each of the 4 blocks, 1 plot was randomly chosen for fertilization. The other half of the block were the unfertilized control plots. Two types of fertilizer were applied to achieve a fertilization level of 112 kg of elemental N/ha (100 pounds per acre N). The fertilizer application consisted of 224 kg/ha (200 pounds per acre) of diammonium phosphate (DAP) and 184 kg/ha (164.5 pounds per acre) of ammonium nitrate. Hence, the DAP supplied 47.5 kg/ha (42.4 pounds per acre) N and 23.2 kg/ha (20.7 pounds per acre) P while the ammonium nitrate supplied the other 64.5 kg/ha (57.6 pounds per acre) N. The fertilizer was spread by hand using a banded application technique, over the 4 randomly selected fertilization treatment plots on May 6, 2004.

Post-fertilization measurements were conducted immediately following a soaking rain within a week after application. Measurements were conducted in the exact same fashion as the pre-fertilization measurements. Initially, measurements were conducted twice a week so that the short term physiological changes in foliar C and N concentrations and  $A_{\text{sat}}$  were not missed. However, measurements were taken at less frequent intervals later in the growing season as measurements began to stabilize.

### Statistical Analysis

The study was conducted using a completely randomized block design with a split plot. A fertilized plot and a control plot made up each of 4 main blocks. The split plot consisted of the 8 different loblolly pine clones. The analysis was conducted using the PROC GLM procedure in SAS (SAS Institute, Cary, NC). Individual ANOVAs by date were used to determine significance between the fertilized and unfertilized clones at  $\alpha = 0.05$ . Multiple linear regression analysis in SAS was used to determine any significant environmental effects on  $A_{\text{sat}}$ .

## RESULTS AND DISCUSSION

Although not always statistically significant, fertilization increased leaf specific photosynthesis on most dates sampled (fig. 1). Shortly after fertilization, there was some variation in  $P_n$  rates, but the fertilized seedlings had significantly higher rates ( $p < 0.05$ ) on the May 25 and June 16 sampling dates. Subsequent measurements in late July showed the fertilized seedling  $P_n$  rates rose above the unfertilized rates and remained there through the final December sampling date. Net photosynthesis rates between the fertilized and unfertilized clones differed significantly ( $p \leq 0.1$ ) on three other sampling dates (fig. 1).

These findings are in agreement with a greenhouse study of loblolly pine seedlings conducted by Gough and others (2004b). He reported statistically greater light saturated photosynthesis ( $A_{sat}$ ) rates in the N-fertilized loblolly pines 6 days after the treatment application.  $A_{sat}$  levels in controls ranged from 1.5  $\mu\text{mol}/\text{m}^2/\text{s}$  to 4  $\mu\text{mol}/\text{m}^2/\text{s}$ , while fertilized foliage levels ranged from 1.5  $\mu\text{mol}/\text{m}^2/\text{s}$  to 6  $\mu\text{mol}/\text{m}^2/\text{s}$  and were almost always higher than the control levels.  $A_{sat}$  levels remained high throughout most of the study but began to decrease towards control levels over the last 100 days. Despite these similarities, our study showed trends that were slightly muted in comparison to Gough's findings. One possible explanation for less-pronounced differences in  $P_n$  after fertilization could be due to the soil base fertility. Our study was in the Piedmont of Virginia on an old field site with a heavy clay subsoil that may have had a higher base soil fertility. Hence, the addition of N fertilizer may not have dramatically increased the N content of the soil as it would have in Gough's very sandy, infertile, Wakulla series soil type.

Fertilization also increased all of the biomass characteristics sampled during the study. The fertilized seedlings' mean height and basal diameter growth were 10 and 13 percent > the unfertilized seedlings by December (figs. 2 and 3). Mean volume growth was 34 percent greater in the fertilized seedlings by the last sampling date as well (fig. 4). Hence, the biomass differences between treatments support claims that an increase in  $P_n$  lead to a larger C pool to be used in creating larger leaf areas (Gough and others 2004b). Then these larger leaf areas contribute to improved growth and productivity due to increases in stemwood (Teskey and others 1987, Vose and Allen 1988).

Gough and others (2004b) found similar increases in basal diameters and heights about 4 weeks after the initial increase in  $A_{sat}$ . He found significant differences in his biomass characteristics whereas our values were only approaching significance ( $p = 0.118$  basal diameter,  $p = 0.286$  height, and  $p = 0.145$  volume) by the end of December when growth ceased. Also, projected leaf areas at the end of Gough's study were 36.5 percent greater in the fertilized seedlings. Albaugh and others (1998) recorded height, volume, and diameter changes between loblolly pines during a fertilization study at the Southeast Tree Research and Education Site (SETRES) in the North Carolina sandhills region. The results showed the fertilized pines had increases in diameter (30 percent), height (23 percent), volume (81 percent), and basal area (68 percent) over the controls (Albaugh and others 1998).

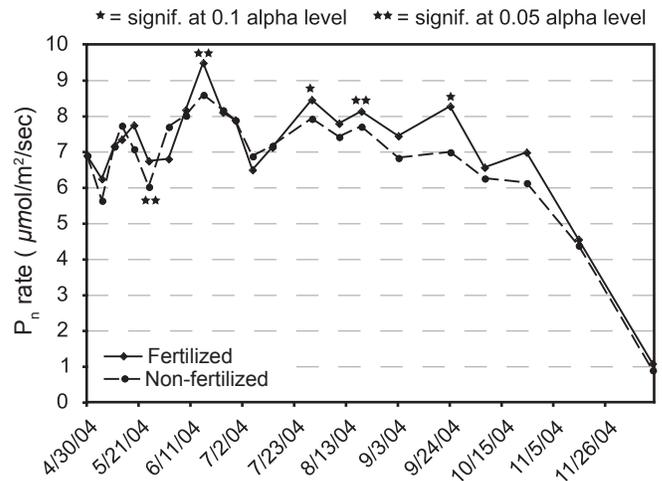


Figure 1—Loblolly pine mean net photosynthesis rates by treatment in a 2-year-old plantation located on the Virginia Piedmont (Patrick Co., VA).

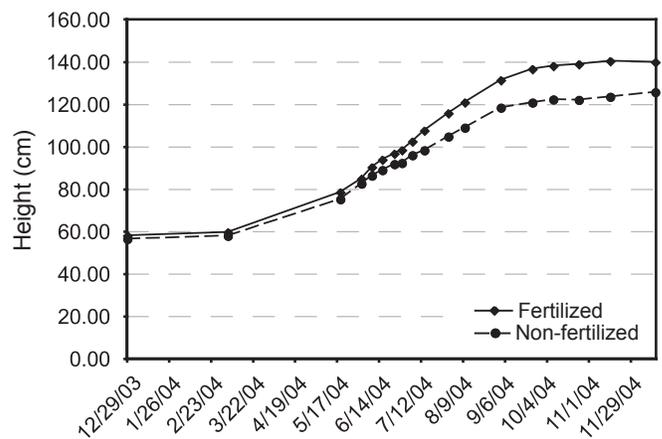


Figure 2—Loblolly pine mean height growth by treatment in a 2-year-old plantation located on the Virginia Piedmont (Patrick Co., VA).

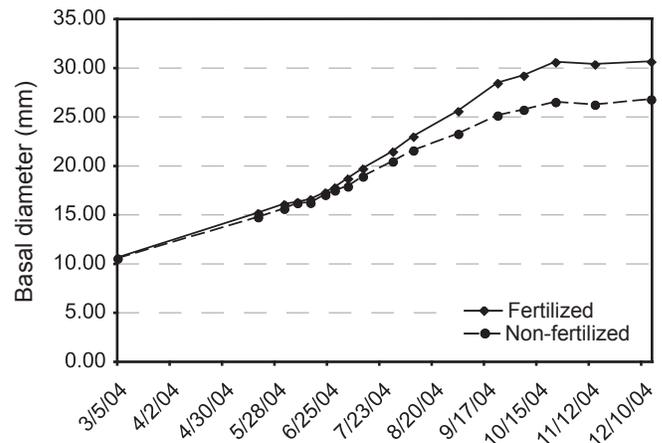


Figure 3—Loblolly pine mean basal diameter growth by treatment in a 2-year-old plantation located on the Virginia Piedmont (Patrick Co., VA).

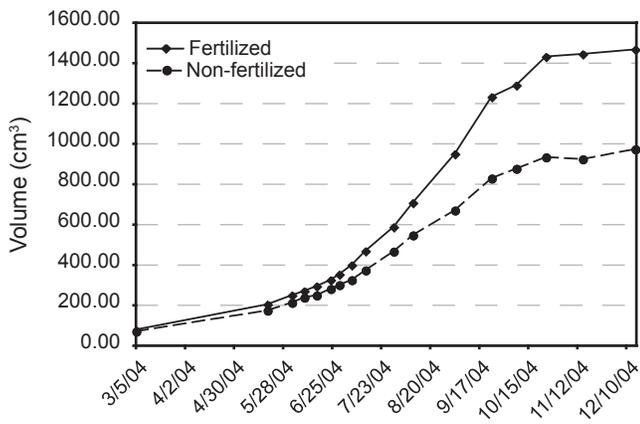


Figure 4—Loblolly pine mean volume growth by treatment (calculated from height and basal diameter data) in a 2-year-old plantation located on the Virginia Piedmont (Patrick Co., VA).

## CONCLUSIONS

Our data support Gough's (2003) hypothesis as it relates to fertilized field grown loblolly pines although the effects were not as pronounced. The short term response of the loblolly pines to fertilization involved increasing  $P_n$ . This increase caused a larger build up of photoassimilates, which could be used in constructing larger leaf areas. Hence, the fertilized seedlings were able to build larger leaf areas making more tissue available to capture PAR. Due to these differences, the fertilized seedlings were able to increase basal diameter, height, and volume growth over the course of the growing season.

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## LITERATURE CITED

Albaugh, T.J.; Allen, H.L.; Dougherty, P.M. [and others]. 1998. Leaf area and above and belowground growth responses of loblolly pine to nutrient and water additions. *Society of American Foresters*. 44(2): 317-328.

Chandler J.W.; Dale, J.E. 1995. Nitrogen deficiency and fertilization effects on needle growth and photosynthesis in Sitka spruce (*Picea sitchensis*). *Tree Physiology*. 15: 813-817.

Colbert, S.R.; Allen, H.L. 1996. Factors contributing to variability in loblolly pine foliar nutrient concentrations. *Southern Journal of Applied Forestry*. 20(1): 45-52.

Ginn, S.E.; Seiler, J.R.; Cazell, B.H.; Kreh, R.E. 1991. Physiological and growth responses of eight-year-old loblolly pine stands to thinning. *Forest Science*. 37: 1030-1040.

Gough, C.M. 2003. Quantification and physiology of carbon dynamics in intensively managed loblolly pine (*Pinus taeda* L.). Blacksburg, VA: Virginia Polytechnic Institute and State University. 144 p. Ph.D. dissertation.

Gough C.M.; Seiler J.S.; Johnsen K.H.; Sampson D.A. 2004a. Seasonal photosynthesis in fertilized and nonfertilized loblolly pine. *Forest Science*. 50: 1-9.

Gough C.M.; Seiler J.S.; Maier, C.A. 2004b. Short term effects of fertilization on loblolly pine (*Pinus taeda* L.) physiology. *Plant, Cell and Environment*. 27: 876-886.

Helms, J.A. 1976. Factors influencing net photosynthesis in trees: an ecological viewpoint. In: Cannell, M.G.R.; Last, F.T., eds. *Tree physiology and yield improvement*. London: Academic Press. 567 p.

Jokela, E.J.; Stearns-Smith, S.C. 1993. Fertilization of established southern pine stands: effects of single and split nitrogen applications. *Southern Journal of Applied Forestry*. 17: 135-138.

Kellomaki, S.; Wang, K.Y. 1997. Photosynthetic responses of Scots pine to elevated CO<sub>2</sub> and nitrogen supply: results of a branch-in-bag experiment. *Tree Physiology*. 17: 231-240.

Lavigne, M.B.; Little, C.H.A.; Major, J.E. 2001. Increasing the sink: source balance enhances photosynthetic rate of 1-year-old balsam fir foliage by increasing allocation of mineral nutrients. *Tree Physiology*. 21: 417-426.

Murthy, R.; Dougherty, P.M.; Zarnoch, S.J.; Allen, H.L. 1996. Effects of carbon dioxide, fertilization, and irrigation on the photosynthetic capacity of loblolly pine trees. *Tree Physiology*. 16: 537-546.

Murthy, R.; Dougherty, P.M.; Zarnoch, S.J.; Allen, H.L. 1997. Seasonal trends of light-saturated net photosynthesis and stomatal conductance of loblolly pine trees grown in contrasting environments of nutrition, water and carbon dioxide. *Plant, Cell and Environment*. 20: 558-568.

North Carolina State Forest Nutrition Cooperative. 2000. Twenty-ninth annual report. Raleigh, NC: North Carolina State University. 20 p.

Roberntz, P.; Stockfors, J. 1998. Effects of elevated CO<sub>2</sub> concentration and nutrition on net photosynthesis, stomatal conductance and needle respiration of field-grown Norway spruce trees. *Tree Physiology*. 18: 233-241.

Schaberg, P.G.; Perkins, T.D.; McNulty, S.G. 1997. Effects of chronic low-level N additions on foliar elemental concentrations, morphology, and gas exchange of mature montane red spruce. *Canadian Journal of Forest Research*. 27: 1622-1629.

Schoettle, A.W.; Smith, W.K. 1999. Interrelationships among light, photosynthesis and nitrogen in the crown of mature *Pinus contorta* ssp. *latifolia*. *Tree Physiology*. 19: 13-22.

Strand, M. 1997. Effect of mineral nutrient content on oxygen exchange and chlorophyll a fluorescence in needles of Norway spruce. *Tree Physiology*. 17: 221-230.

Teskey, R.O.; Bongarten, B.C.; Cregg, B.M. [and others]. 1987. Physiology and genetics of tree growth response to moisture and temperature stress: an examination of the characteristics of loblolly pine (*Pinus taeda* L.). *Tree Physiology*. 3: 41-61.

Teskey, R.O.; Gholz, H.L.; Cropper, W.P., Jr. 1994. Influence of climate and fertilization on net photosynthesis of mature slash pine. *Tree Physiology*. 14: 1215-1227.

Vose, J.M.; Allen, H.L. 1988. Leaf area, stemwood growth, and nutrition relationships in loblolly pine. *Forest Science*. 34: 547-563.

Waring, R.H.; Schlesinger, W.H. 1985. *Forest ecosystems: concepts and management*. Orlando, FL: Academic Press Inc. 396 p.

Zhang, S.; Hennessey, T.C.; Heinemann, R.A. 1997. Acclimation of loblolly pine (*Pinus taeda*) foliage to light intensity as related to leaf nitrogen availability. *Canadian Journal of Forest Research*. 27: 1032-1042.

# EFFECTS OF FERTILIZATION ON CO<sub>2</sub> EFFLUX IN A TWO-YEAR-OLD LOBLOLLY PINE STAND ON THE VIRGINIA PIEDMONT

Michael Tyree, John Seiler, and Thomas R. Fox<sup>1</sup>

**Abstract**—Fertilization is becoming a common, cost effective treatment within managed forests of the Southeastern United States. However, there is little known about how fertilization will affect the belowground processes that drive soil CO<sub>2</sub> efflux. A thorough understanding of belowground carbon (C) dynamics is necessary for the estimation of net ecosystem productivity and the C storage potential of these managed systems. In April 2004, we began monitoring total soil CO<sub>2</sub> efflux and heterotrophic respiration. Respiratory components were measured prior to fertilization, weekly following fertilization, and bi-weekly after respiratory components stabilized. We found that total soil CO<sub>2</sub> efflux did not differ consistently between fertilized and unfertilized plots over the 8 months. Heterotrophic respiration was significantly ( $P < 0.0001$ ) lower in fertilized plots starting from 8 days after fertilization throughout the duration of the study. We hypothesize that a corresponding increase in root respiration is offsetting any decrease due to microbial suppression.

## INTRODUCTION

Schlesinger (1997) estimates that forests account for up to 75 percent of all carbon (C) stored in terrestrial ecosystems and are responsible for about 40 percent of the C flux between the atmosphere and the biosphere. This makes CO<sub>2</sub> flux from soils the second-largest flux in the global C cycle, an order of magnitude greater than CO<sub>2</sub> emissions from fossil fuel burning (Raich and Schlesinger 1992). Forests have the capability to function as giant C sinks by removing inorganic C from the atmosphere and fixing it as biomass. The C finds its way to the forest floor as fallen plant material, where it is released back into the atmosphere by either soil microbes or fire, or it is incorporated into the soil for long-term sequestration.

Total CO<sub>2</sub> efflux at the soil surface is a combination of: (1) root (autotrophic) respiration resulting from maintenance and growth and (2) heterotrophic respiration produced during the decomposition of organic matter by soil micro and macro fauna found within the soil profile. Forests and forest soils can act as either C sinks or C sources; and only by understanding the different mechanisms that determine the shift between source and sink can forests be managed to sequester C long-term.

Delcourt and Harris (1980) reported that forests of the Southeast have acted as C sources from 1750 to 1960 due to the deforestation of virgin forests during the industrial revolution. Recently (1960 to present), reforestation of agricultural fields and the intensive management of secondary forests have made the Southeast function largely as a C sink. With 13 million ha of *Pinus taeda* L. (loblolly pine) stands intensively-managed in the Southeastern United States, there is the potential to sequester large amounts of C in both plant biomass and as organic matter in forest soils (Jokela and Long 2003, Maier and Kress 2000).

Fertilization in southeastern pine forests has increased approximately 800 percent since 1990 to just over 500,000 ha of planted pine being fertilized in 2000 and 2001 (NCSFNC 2002, Wear and Greis 2002). Wear and Greis (2002) estimated that the use of fertilizer in the United States exceeds use by the rest of the world.

The effects of above-ground responses to nutrient additions are well understood. Fertilization has been shown to increase net primary productivity (Albaugh and others 1998, Axelsson and Axelsson 1986, Gough and others 2004), but there are still questions concerning the impact of fertilization on belowground C evolution. The overall objective of this research is to examine how fertilization initially impacts belowground C fluxes in a 2-year-old clonal plantation of *P. taeda* located on the Virginia Piedmont. Specifically, we will determine the effects, over time, of fertilization with diammonium phosphate, supplemented with ammonium nitrate, on total soil CO<sub>2</sub> efflux and heterotrophic respiration.

## MATERIALS AND METHODS

### Site Description

This study was installed at Reynolds Homestead Forest Resources Research Center located in Patrick County, VA (latitude 36°40' N, longitude 80°10' W). The Reynolds plantation was intensively-farmed with row crops and tobacco from the early 1800s to the mid 1900s. In 1969, this property was donated by tobacco manufacturer R.J. Reynolds to Virginia Tech to study forest biology.

The elevation is approximately 300 to 500 m with a gently sloping topography, and soils are mapped as Lloyd clay loam, Louisa loam, and Hiwassee loam series. These are deep, well-drained Ultisols derived from granite, gneiss, and schist. Past farming practices led to erosion and the removal of most of the A horizon, resulting in a truncated soil profile with clayey B horizons incorporated into surface Ap horizons. The climate is warm and humid, receiving 1,310 mm of precipitation spread evenly throughout the year. The mean temperature is 14 °C with an average minimum of -1.4 °C, usually occurring in January, and an average maximum temperature of 29.2 °C, occurring in July.

### Experimental Design

This study was a randomized complete block design with a split plot with repeated measures, replicated four times. Four blocks, each consisting of two plots, received two levels of

<sup>1</sup> Graduate Research Assistant, Shelton H. Short Professor of Forestry, and Associate Professor of Forestry, respectively, Virginia Polytechnic Institute and State University, Department of Forestry, Blacksburg, VA 24061.

fertilizer (fertilizer and no fertilizer), with 25 unique *P. taeda* clones (SP) repeated within each plot. The clonal seedlings were donated by the Forest Biology Research Cooperative, University of Florida, Gainesville, FL, for use in this project. The site was prepared by spraying the planting rows with glyphosphate (Round Up, Monsanto Co., St. Louis, MO) followed by a shallow tillage of the rows. The seedlings were planted May 19, 2003, at 3.2-m (row) x 2.6-m (seedling) spacing with 25 clones per plot and a buffer strip of stock seedlings surrounding each plot. In spring of 2004 (prior to fertilization), all vegetation was removed (chemically and mechanically), and plots remained free of all vegetation except for desired *P. taeda* clones. After each sampling date, any emerging vegetation was removed mechanically to insure a clean surface for the following sampling date.

May 6, 2004, one randomly-chosen plot within each of the four blocks received a single application of fertilizer in the form of diammonium phosphate  $[(\text{NH}_4)_2\text{PO}_4]$  supplemented with ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ), which was banded at a rate of 225 kg ha<sup>-1</sup> and 186.5 kg ha<sup>-1</sup>, respectively. This rate is equivalent to 112 kg nitrogen (N) ha<sup>-1</sup> and 23 kg phosphorous ha<sup>-1</sup>.

Total soil and heterotrophic respiration of six selected clones were measured per plot, prior to fertilization, to determine a baseline respiration rate. After fertilization, measurements were repeated weekly until response to fertilization leveled off, then every other week or monthly for the duration of the experiment (approximately 1 year).

### Total Soil Respiration Measurements

Total soil CO<sub>2</sub> efflux was measured at the soil surface using the LiCor 6200 infrared gas analyzer (IRGA) (LiCor Inc., Lincoln, NE) with a dynamic closed cuvette chamber constructed from a PVC pipe for walls, a plexi glass top (25.5 cm internal diameter, height at center 13.5 cm) with a total system volume of 67,044 cm<sup>3</sup> (Janssens and others 2001, Selig 2003). The bottom of the chamber was fitted with a stainless steel edge to create a seal with the ground.

The LiCor 6200 was recalibrated before each sampling date and the system zeroed between every block. Respiration measurements were made in the same sequential blocking order at approximately the same time of day for each sampling date. The chamber was placed at the soil surface, next to the seedling stem ( $\leq 0.25$  m), where no living, photosynthesizing, plant material was present. CO<sub>2</sub> evolution was measured over a 30-second period and respiration rate ( $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) calculated on a per unit land area with the following equation:

$$\text{Soil CO}_2 \text{ efflux} = \left[ \left( \frac{\Delta C}{\Delta t} \right) \left( \frac{PV_t}{RT} \right) \right] \div \text{surface area of soil} \quad (1)$$

where

C=[CO<sub>2</sub>],

t=time,

P=atmospheric pressure,

V<sub>t</sub>=system volume,

R=universal gas constant, and

T=temperature (°C).

### Heterotrophic Respiration

Following total soil respiration measurements, heterotrophic respiration was measured using the LiCor 6200 with a 0.25-L cuvette chamber, with a total system volume of 429 cm<sup>3</sup>. Soil was extracted to 10 cm in depth with a 2.5-cm diameter push tube at the base of each seedling sampled. Roots were carefully removed from the soil sample and the soil placed into an aluminum weight boat (10 cm x 2 cm), which was immediately placed into the 0.25-L cuvette chamber. Heterotrophic respiration was measured over a 30-second sampling period. Following respiration measurements, soil was sealed into a labeled envelope and brought back to the lab for drying. Soil was oven-dried for 48 hours at 105 °C and weighed to the nearest 0.01 g. Microbial respiration was calculated and expressed on a per soil mass basis ( $\mu\text{mol g}^{-1} \text{s}^{-1}$ ).

### Soil Temperature and Moisture Measurements

Soil temperature and volumetric water content were taken, concurrently with respiration measurements, at the base of each clone, to be used as covariates to normalize respiration rates to a common temperature and moisture. Soil temperature was measured to the nearest 0.1 °C at 7 cm using a Digi-sense temperature gauge (model no. 8528-20, Cole-Parmer Instrument Co., Niles, IL). Soil moisture was measured at a depth of 15 cm using a time domain reflectometer (Soil Moisture Equipment Co., 6050X1, Golena, CA). Soil moisture content was expressed as a volume percent and determined to the nearest 1 percent.

### Analysis

The effect of fertilization on total soil and microbial respiration was analyzed using ANOVA to detect significant differences between treatments using the GLM procedure in SAS version 9 (SAS Institute, Cary, NC). Efflux rates were normalized to a common temperature and volumetric water content by ANACOVA when within block variation of temperature or moisture was significant. A time series analysis was performed to test for treatment effects over time using PROC MIXED in SAS. Clonal differences were not evaluated as part of this analysis.

## RESULTS AND DISCUSSION

### Heterotrophic (Microbial) Respiration

Heterotrophic respiration rates in the fertilized plots were significantly ( $P < 0.0001$ ) lower relative to plots that did not receive fertilizer when measured over time. Microbial respiration rates in fertilized plots decreased below control levels starting 8 days following fertilization, and remained depressed throughout the duration of the study (fig. 1a). Microbial respiration showed a positive relationship to volumetric water content of soil and, to a lesser extent, soil temperature (fig. 1c).

It has been well-documented early on in the literature (Bååth and others 1981, Kowalenko and others 1978, Nohrstedt and others 1989, Roberge 1976, Smolander and others 1994, Söderström and others 1983), and more recently (Gough and Seiler 2004, Lee and Jose 2003, Thirukkumaran and Parkinson 2000), that the addition of N to the soil affects heterotrophic respiration. N fertilization may have a direct affect on respiration rates by a change in soil pH. Ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ), and other ammonium salts, have been shown to lower soil pH, accompanied by a decrease in microbial activity (Kowalenko and others 1978, Söderström

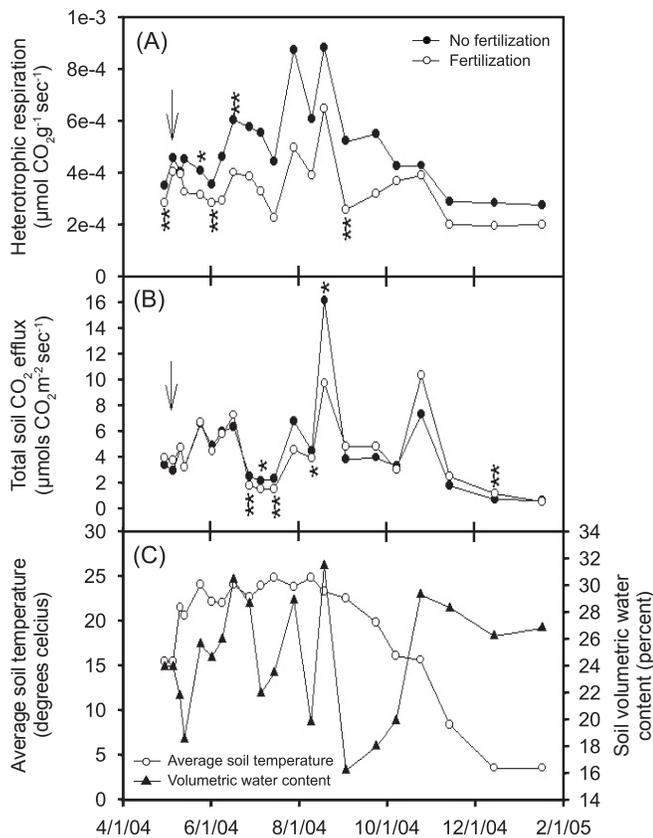


Figure 1—(A) Heterotrophic respiration in a two-year *Pinus taeda* plantation located on the Virginia Piedmont; (B) total soil CO<sub>2</sub> efflux at the soil surface; and (C) average temperature and volumetric water content of the soil. The arrows indicate time of fertilization, single asterisk (\*) represents significance at  $\alpha=0.10$ , and double asterisk (\*\*) represents significance at  $\alpha=0.05$  ( $n=24$ ). Fertilized plots received 112 kg N ha<sup>-1</sup> and 23 kg P ha<sup>-1</sup> in the form of diammonium phosphate and ammonium nitrate (225 kg ha<sup>-1</sup> and 186.5 kg ha<sup>-1</sup>, respectively).

and others 1983, Thirukkumaran and others 2000). A study by Leckie and others (2004) suggests that microbial composition and activity in the long term may be influenced by fertilization to a greater extent by indirect effects on plant growth and litter input as opposed to direct effects on microbial populations. Another possibility is a shift in population dominance within the soil community after the addition of N, and changes in C allocation to the roots. However, it is unlikely that either of these long-term effects explain our rapid decrease after just 8 days.

Gough and Seiler (2004) found that microbial respiration was significantly ( $P<0.05$ ) depressed throughout the entire 197 days in potted *P. taeda* seedlings grown in a greenhouse. The authors found that microbial activity per gram of soil was only 44 and 66 percent of that measured in control pots at 49 and 197 days following fertilization, respectively. In contrast, Haynes and Gower (1995) found no difference in heterotrophic respiration between fertilized and control trenched plots in a 31-year-old *P. resinosa* plantation in northern Wisconsin.

### Total CO<sub>2</sub> Efflux at the Soil Surface

There was no significant ( $P=0.3263$ ) difference between fertilized and control plots in total CO<sub>2</sub> efflux when analyzed over the duration of the study, but the treatment date interaction was significant ( $P<0.0001$ ). There was no consistent trend in total CO<sub>2</sub> efflux over the 8 months measured. However, on two dates, total CO<sub>2</sub> efflux was significantly ( $P<0.05$ ) lower in fertilized plots and on one date significantly ( $P<0.05$ ) greater in fertilized plots relative to controls (fig. 1b).

A review of the current literature has shown mixed responses of CO<sub>2</sub> efflux to N fertilization. Pangle and Seiler (2002) found that fertilization did not have a significant ( $P<0.05$ ) effect on soil CO<sub>2</sub> efflux in a 2-year-old *P. taeda* stand located on the Virginia Piedmont. Lee and Jose (2003) also found no significant effect of fertilization in *P. taeda*. Gough and Seiler (2004) found a significant ( $P<0.05$ ) increase in soil respiration compared to control 4 days after applying fertilizer (rate 50 kg N ha<sup>-1</sup> and 106 kg P ha<sup>-1</sup>; in the form of DAP) in 1-year-old loblolly pine seedlings grown in a greenhouse. Four to 13 days from fertilization, the authors found a significant ( $P<0.05$ ) increase in soil respiration in fertilized treatments compared to control treatments. From day 13 to 47 (post-treatment), soil respiration rates reversed and were significantly ( $P<0.05$ ) lower in fertilized pots compared to controls; and after day 47, fertilized pots were, again, significantly ( $P<0.05$ ) higher than controls. Mattson (1995) measured three forested stands that had received three different N fertilization treatments (control, single, and double fertilized sites). The author measured CO<sub>2</sub> efflux as 29 percent lower in the 2x fertilized site when compared to the control. Similarly, Maier and Kress (2000) found a decrease in CO<sub>2</sub> efflux following N fertilization in an 11-year-old *P. taeda* stand.

This difference in responses could be due to a number of things. One proposed by Gough and Seiler (2004), and by Lee and Jose (2003), is that a decrease in heterotrophic respiration combined with an increase in total autotrophic respiration may have a cancellation effect on total C evolution at the soil surface. Other possible reasons are the rate of N fertilization and the time from initial fertilization that measurements were taken (Gough and Seiler 2004).

### CONCLUSIONS

Shortly after fertilization, heterotrophic respiration decreased relative to plots that received no fertilization and remained depressed throughout the 8 months measured. We were unable to find a consistent trend in CO<sub>2</sub> efflux between treatments. Fertilized plots were significantly ( $P<0.05$ ) lower on a number of occasions, but later rose above control plots. Our hypothesis is that an increase in specific root respiration and/or root mass balanced the observable decrease in microbial activity leading to no significant ( $P<0.05$ ) difference in CO<sub>2</sub> efflux over the course of the study.

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## LITERATURE CITED

- Albaugh, T.J.; Allen, H.L.; Dougherty, P.M. [and others]. 1998. Leaf area and above- and belowground growth responses of loblolly pine to nutrient and water additions. *Forest Science*. 44(2): 317-328.
- Axelsson, E.; Axelsson, B. 1986. Changes in carbon allocation patterns in spruce and pine trees following irrigation and fertilization. *Tree Physiology*. 2: 189-204.
- Bååth, E.; Lundgren, B.; Söderström, B. 1981. Effects of nitrogen fertilization on the activity and biomass of fungi and bacteria in a podzolic soil. *Zentralblatt für Bakteriologie Mikrobiologie und Hygiene, Originale 1 Abt., C*. 2(1): 90-98.
- Delcourt, H.R.; Harris, W.F. 1980. Carbon budget of the Southeastern U.S. biota: analysis of historical change in trend from source to sink. *Science*. 210: 321-322.
- Gough, C.M.; Seiler, J.R. 2004. Belowground carbon dynamics in loblolly pine (*Pinus taeda*) immediately following diammonium phosphate fertilization. *Tree Physiology*. 24: 845-851.
- Gough, C.M.; Seiler, J.R.; Maier, C.A. 2004. Short-term effects of fertilization on loblolly pine (*Pinus taeda* L.) physiology. *Plant, Cell and Environment*. 27: 876-886.
- Haynes, B.E.; Gower, S.T. 1995. Belowground carbon allocation in unfertilized and fertilized red pine plantations in northern Wisconsin. *Tree Physiology*. 15: 317-325.
- Janssens, I.A.; Kowalski, A.S.; Ceulemans, R. 2001. Forest floor CO<sub>2</sub> fluxes estimated by eddy covariance and chamber-based model. *Agricultural and Forest Meteorology*. 106: 61-69.
- Jokela, E.J.; Long, A.J. 2003. Using soils to guide fertilizer recommendations for southern pines. Circular 1230. Gainesville, FL: University of Florida, Cooperative Extensions Service, Institute of Food and Agricultural Sciences. <http://edis.ifas.ufl.edu> [Date accessed: Oct. 20, 2003].
- Kowalenko, C.G.; Ivarson, K.C.; Cameron, D.R. 1978. Effect of moisture content, temperature, and nitrogen fertilization on carbon dioxide evolution from field soils. *Soil Biology and Biochemistry*. 10: 417-423.
- Leckie, S.E.; Prescott, C.E.; Grayston, S.J. 2004. Forest floor microbial community response to tree species and fertilization of regenerating coniferous forests. *Canadian Journal of Forest Research*. 34: 1426-1435.
- Lee, K.; Jose, S. 2003. Soil respiration, fine root production, and microbial biomass in cottonwood and loblolly pine plantations along a nitrogen fertilization gradient. *Forest Ecology and Management*. 185: 263-273.
- Maier, C.A.; Kress L.W. 2000. Soil CO<sub>2</sub> evolution and root respiration in 11 year-old loblolly pine (*Pinus taeda*) plantations as affected by moisture and nutrient availability. *Canadian Journal of Forest Research*. 30: 347-359.
- Mattson, K.G. 1995. CO<sub>2</sub> efflux from coniferous forest soils: comparison of measurement methods and effects of added nitrogen. In: Lal, R.; Kimble, J.; Levin, E.; Stewart, B.A., eds. *Soils and global change*. Boca Raton: Lewis Publishers: 329-341.
- NCSFNC. 2002. North Carolina State Forest Nutrition Cooperative 31<sup>st</sup> annual report. Raleigh, NC: North Carolina State University, Department of Forestry, College of Natural Resources. <http://unfccc.int/resource/docs/publications/guideprocess-p.pdf>. [Date accessed: December, 2003].
- Nohrstedt, H.-Ö.; Arnebrant, K.; Bååth, E.; Söderström, B. 1989. Changes in carbon content, respiration rate, ATP content, and microbial biomass in nitrogen-fertilized pine forest soils in Sweden. *Canadian Journal of Forest Research*. 19: 323-328.
- Pangle, R.E.; Seiler, J.R. 2002. Influence of seedling roots, environmental factors and soil characteristics on soil CO<sub>2</sub> efflux rates in a 2-year-old loblolly pine (*Pinus taeda* L.) plantation in the Virginia Piedmont. *Environmental Pollution*. 116: 85-96.
- Raich, J.W.; Schlesinger, W.H. 1992. The global carbon dioxide flux in soil respirations and its relationship to vegetation and climate. *Tellus*. 44B: 81-99.
- Roberge, M.R. 1976. Respiration rates for determining the effects of urea on the soil-surface organic horizon of a black spruce stand. *Canadian Journal of Microbiology*. 22: 1328-1335.
- Schlesinger, W.H. 1997. *Biogeochemistry: an analysis of global change*, second ed. San Diego: Academic Press. 558 p.
- Selig, M.F. 2003. Soil CO<sub>2</sub> efflux and soil carbon content as influenced by thinning in loblolly pine plantations on the piedmont of Virginia. Blacksburg, VA: Virginia Polytechnic and State University. 80 p. Masters thesis.
- Smolander, A.; Kurka, A.; Kitunen, V.; Mälkönen, E. 1994. Microbial biomass C and N, and respiratory activity in soil of repeatedly limed and N- and P-fertilized Norway spruce stands. *Soil Biology and Biochemistry*. 26(8): 957-962.
- Söderström, B.; Bååth, E.; Lundgren, B. 1983. Decrease in soil microbial activity and biomasses owing to nitrogen amendments. *Canadian Journal of Microbiology*. 29: 1500-1506.
- Thirukkumaran, C.M.; Parkinson, D. 2000. Microbial respiration, biomass, metabolic quotient and litter decomposition in a lodgepole pine forest floor amended with nitrogen and phosphorous fertilizers. *Soil Biology and Biochemistry*. 32: 59-66.
- Wear, D.N.; Greis, J.G. 2002. Southern forest resources assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 329 p.

# IMPACT OF WEED CONTROL AND FERTILIZATION ON GROWTH OF FOUR SPECIES OF PINE IN THE VIRGINIA PIEDMONT

Dzhamal Y. Amishev and Thomas R. Fox<sup>1</sup>

**Abstract**—During 1999, a mixed stand of Virginia pine and hardwoods in the Piedmont of Virginia was clearcut and site prepared by burning. Three replications, containing strips of loblolly pine, shortleaf pine, Virginia pine, and Eastern white pine, were planted at a 3 m x 1.5 m spacing during February to June, 2000. The strips were subsequently split to accommodate four different silvicultural treatments: (1) check - no treatment; (2) weed control; (3) fertilization; and (4) weed control plus fertilization. Herbicides were applied in 2000 (broadcast Oust®), 2001 (directed spray of Garlon® plus Roundup®), and 2003 (directed spray of Roundup®) to control both herbaceous and woody competition. Fertilizers containing N, P, and K were applied in 2001, N only in 2002. Crop tree survival was highest for loblolly pine, followed by Virginia pine, shortleaf pine and, lastly, Eastern white pine. There was a significant species x silvicultural treatment interaction at this site. Total height after 4 years followed the pattern loblolly pine>Virginia pine=shortleaf pine>white pine. In loblolly pine, weed control and fertilization increased growth compared to the check. In white pine, there was no significant difference between weed control and weed control plus fertilization compared to the check. However, white pines in the fertilized only plots were shortest due to increased hardwood competition that overtopped the pines.

## INTRODUCTION

A significant amount of the forest resource in Virginia is in the Piedmont Physiographic Province, which contains about 2.5 million ha of private and industrial commercial timberland (Brown 1986). Almost three-fourths of these forests are comprised of pine-hardwood forest types (Brown 1985, 1986). The timber in many of these stands is poor because of low quality stems and undesirable species (Knight and McClure 1978). Many of the lands owned by nonindustrial private landowners are producing at ≤ 50 percent of their productivity potential (Dubois and others 1990).

Many of the mixed pine-hardwood stands in the Piedmont are converted to pine plantations after clearcutting (McGee 1980, 1982). Plantations account for 17 percent of the forest land in the Southeast (Conner and Hartshell 2002, Guldin and Wigley 1998). The desire to maximize productivity from a given area of forest has necessitated the development of intensive management practices. Modern plantation management has concentrated on increasing forest productivity through tree improvement, vegetation management, and fertilization (Fox and others 2005). The goal is to develop integrated site-specific management regimes that incorporate the potential gains from genetic improvement and silvicultural practices (Stanturf and others 2003). This includes matching planting stock to sites to fully utilize the productive potential of the sites. Selecting the species best adapted to the given conditions is the first step in this process (Pait and others 1991).

The objectives of this study were to investigate the impact of weed control and fertilization on survival and growth of four pine species planted after harvesting mixed oak-pine stands in the Piedmont of Virginia. The four species were: eastern white pine (*Pinus strobus* L.), loblolly pine (*Pinus taeda* L.), shortleaf pine (*Pinus echinata* Mill.), and Virginia pine (*Pinus virginiana* Mill.).

## STUDY SITE LOCATION

This study was established at the Reynolds Homestead Forest Resources Research Center (RHFRR) in Patrick County, VA. The soil is an eroded phase of the Cecil series (fine kaolinitic, thermic Typic Kanhapludult). The soil series is characterized as deep, well-drained, and moderately permeable, formed in residuum of felsic, igneous, and high-grade metamorphic rock on Piedmont uplands (NRCS 2003). Slopes range from 6 to 10 percent. Summer temperatures range from 39 °C to 2 °C with an average of 25 °C. Winter temperatures range from 23 °C to -9 °C with an average of 10 °C. The frost-free period is between mid-April and the end of October. Yearly average rainfall is 49 inches, with a monthly average of 4 inches (Crockett 1972).

Stand quality on these sites prior to harvest was poor. Pre-harvest stand composition was a mixture of white oak (*Quercus alba* L.), red maple (*Acer rubrum* L.), yellow poplar (*Liriodendron tulipifera* L.), chestnut oak (*Q. prinus* L.), scarlet oak (*Q. coccinea* Muenchh.), sourwood [*Oxydendron arboreum* (L.) DC], and Virginia pine.

## STUDY DESIGN

This study was established as a Strip-Plot Design (SPD) with two sets of treatments randomized across each other through the whole block, with three blocks (replications). The first set of treatments was the pine species planted: (1) eastern white pine; (2) loblolly pine; (3) Virginia pine; and (4) shortleaf pine. The second set of treatments was the silvicultural treatment: (1) check -no treatment applied after planting; (2) weed control; (3) fertilization; and (4) weed control plus fertilizer combined.

The stand was clearcut in 1999, and between February, 2000, and June, 2000, the 4 pine species were planted in strips 30.4 m wide. These plots were subsequently split to accommodate the different silvicultural treatments that were applied in 15.2-m-wide strips with buffer zones between the different

<sup>1</sup> Graduate Student and Associate Professor, respectively, Department of Forestry, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

**Table 1—Timetable of silvicultural treatments applied in the corresponding plots. The plots are located at the RHFRRRC near Critz, VA**

Date	Treatment
1999	Clear cut
Feb 2000 – June 2000	Planted
2000	Herbicide (Oust®)
20-Jun-01	Fertilizer (50 lbs/plot 10-10-10 + micro)
28-Jun-01	Herbicide (3% Garlon®, 2% Roundup®, 0.5% Induce) directed spray
5-Mar-02	Fertilizer (50 lbs/plot 34-0-0)
15-Sep-03	Herbicide (2% Roundup®)

treatment plots. The trees were planted at a 3 m x 1.5 m distance. The weed control and fertilization treatments applied are summarized in table 1.

Total tree heights of the planted pines were measured at the end of the third growing season in January, 2003. Analysis of Variance and mean separation were performed using proc MIXED and LSMEANS procedures in SAS (SAS 2005) at  $\alpha=0.10$  level of significance.

## RESULTS AND DISCUSSION

### Survival

There was a significant species x treatment interaction effect ( $p=0.0306$ ) on survival of planted trees (table 2). The check treatment plots in loblolly pine and the weed control treatment in Virginia pine had significantly higher survival rates with more than 90 percent and nearly 85 percent of the trees surviving, respectively (fig. 1). Fertilizer application decreased survival in all species except loblolly pine, suggesting that loblolly pine grows fast enough to compete effectively with the vigorous hardwood competition. Controlling the hardwoods combined with nutrient additions also decreased survival rates compared to the non-fertilization plots. In Eastern white pine, fertilizer application decreased survival with just about 40 percent of the crop trees surviving, suggesting that the initially slow-growing white pine was overtopped by the hardwoods. These findings support the conclusion of Gjerstad and Barber (1987) that hardwoods must be controlled to ensure adequate survival and growth of planted pines in the Piedmont.

**Table 2—Analysis of Variance (ANOVA) table for the variable ‘survival’. The plots are located at the RHFRRRC near Critz, VA**

Source of variation	Degrees of freedom	Sums of squares (SSQ)	Mean square (MS)	F	P-value
Blocks (Bl)	2	0.01247	0.00623		
Treatment (Trt)	3	0.67016	0.22339	6.13	0.0294
Bl*Trt	6	0.21852	0.03642		
Species (Sps)	3	1.15868	0.38623	8.2	0.0152
Bl*Sps	6	0.28265	0.04711		
Trt*Sps	9	0.31699	0.03522	2.79	0.0306
Error	18	0.22732	0.01263		
Total	47	2.88679			

### Height Growth

Although weed control plot trees were taller than the rest on average (fig. 2), there was no significant difference in total tree height between the different silvicultural treatments (table 3). The combined weed control and fertilization plots had the shortest average tree height among the treatments. These findings suggest that hardwood competition control alone has less of an impact on crop tree growth than herbaceous vegetation control. Zutter and others (1994) reported that woody and herbaceous control together have an additive effect on

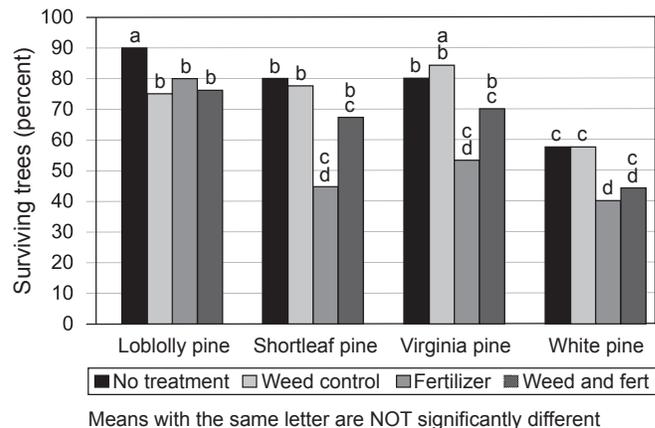


Figure 1—Species x silvicultural treatment interaction effects on crop tree survival three growing seasons after planting. The plots are located at the RHFRRRC near Critz, VA.

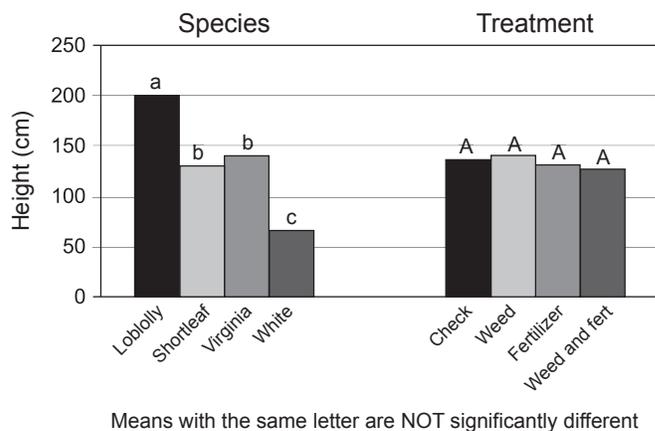


Figure 2—Main ‘species’ and ‘silvicultural treatment’ effects on total tree height three growing seasons after planting. The plots are located at the RHFRRRC near Critz, VA.

**Table 3—Analysis of Variance (ANOVA) table for the variable ‘tree height’. The plots are located at the RHFRRC near Critz, VA**

Source of variation	Degrees of freedom	Sums of squares (SSQ)	Mean square (MS)	F	P-value
Blocks (Bl)	2	195.167	97.583		
Treatment (Trt)	3	1,340.420	446.806	0.49	0.7045
Bl*Trt	6	5,518.830	919.806		
Species (Sps)	3	107,654.000	35,885.000	139.77	<0.0001
Bl*Sps	6	1,540.500	256.750		
Trt*Sps	9	1,481.250	164.583	1.04	0.4498
Error	18	2,857.500	158.750		
Total	47	120,588.000			

loblolly pine growth. Groninger and others (1994) found that relative size of pine was dependent on stand composition, density, and amount of herbaceous cover present. Also, fertilization did not enhance pine growth through age 3. This could be due to the lower nutrient requirements of the crop trees at early ages and the increased available nutrients after harvesting due to the Assart effect.

There were significant differences among the four different species of pine planted (table 3). Loblolly pine trees were significantly taller than the other species, averaging about 2 m tall (fig. 2). Eastern white pines were significantly shorter than the other species, averaging about 0.6 m in height. Total tree heights for shortleaf pine and Virginia pine did not differ significantly from each other, with an average height of about 1.3 m and 1.4 m, respectively. These differences can be explained with the species-specific ecological growth patterns, namely the slower initial growth of Eastern white pine, the faster non-determinant growth of shortleaf and Virginia pine, and the vigorous initial growth of loblolly pine.

## SUMMARY

Loblolly pine had both the greatest survival and growth through the third growing season after planting, and Eastern white pine had lowest survival and least growth. Virginia pine and shortleaf pine both had intermediate survival and growth compared to the other species with a slight dominance of Virginia pine trees. Weed control was the most beneficial treatment, increasing survival through age 3. Fertilization did not increase growth through age 3 and negatively impacted survival of the planted crop trees.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

Brown, M.J. 1985. Forest statistics for the Southern Piedmont of Virginia. Resour. Bull. SE-81. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experimental Station. 52 p.

Brown, M.J. 1986. Forest statistics for the Northern Piedmont of Virginia. Resour. Bull. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experimental Station. 67 p.

Conner, R.C.; Hartshell, A.J. 2002. Forest area and conditions. In: Weir, D.N.; Greis, J.G., eds. Gen. Tech. Rep. SRS-53. Southern Forest Resource Assessment. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 357-401.

Crockett, C.W. 1972. Climatological summaries for selected stations in Virginia. Bulletin 53. Blacksburg, VA: Water Research Center, Virginia Polytechnic Institute and State University. 164 p.

Dubois, M.R.; Straka, T.J.; Doolittle, L. 1990. Forestry in Mississippi's forestry resources, their economic importance. Bulletin 971. Mississippi State, MS: Mississippi Agricultural and Forestry Experiment Station. 41 p.

Fox, T.R.; Jokela, E.J.; Allen, H.L. 2005. The evolution of pine plantation silviculture in the Southern United States. In: Rauscher, H.M.; Johnsen, K., eds. Southern forest science: past, present, and future. Gen. Tech. Rep. SRS-75. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 63-82.

Gjerstad, D.H.; Barber, B.L. 1987. Forest vegetation problems in the south. In: Walstad, J.D.; Kuch, P.J., eds. Forest vegetation management for conifer production. New York, NY: John Wiley & Sons Inc.: 55-75.

Groninger, J.W.; Zedaker S.M.; Seiler J.R. [and others]. 1994. Growth and physiological characteristics of planted loblolly pine and red maple grown in pure and mixed stands. In: Edwards, M.B., comp. Proceedings of the eighth biennial southern silviculture research conference. Gen. Tech. Rep. SRS-001. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 299-304.

Guldin, J.M.; Wigley, T.B. 1998. Intensive management – can the South really live without it? In: Transactions of the 63rd North American wildlife and natural resource conference. Washington, DC: Wildlife Management Institute: 362-375.

Knight, H.A.; McClure, J.P. 1978. Virginia's timber. Resour. Bull. SE-44. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 53 p.

McGee, C.E. 1980. Expanding options for reforestation of the Cumberland Plateau. Southern Journal of Applied Forestry. 4: 158-162.

McGee, C.E. 1982. Low quality hardwood stands: opportunities for management in the interior uplands. Gen. Tech. Rep. SO-40. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forestry Experiment Station. 17 p.

NRCS (Natural Resources Conservation Service). 2003. Soil technical services. Helping people understand soils. <http://soils.usda.gov/>.

Pait, J.A., III.; Flinchum, D.M.; Lantz, C.W. 1991. Species variation, allocation, and tree improvement. In: Duryea, M.L.; Dougherty, P.M., eds. Forest regeneration manual. The Netherlands: Kluwer Academic Publishers: 207-231.

SAS Institute Inc. 2005. SAS user's guide. Cary, NC: SAS Institute Inc.

Stanturf, J.A.; Kellison R.C.; Broerman F.S.; Jones S.B. 2003. Productivity of southern pine plantations: where are we and how did we get here? Journal of Forestry. 101(3): 26-31.

Zutter, B.R.; Miller J.H.; Zedaker S.M. [and others]. 1994. Response of loblolly pine plantations to woody and herbaceous control: eight-year results of the region-wide study - the Comproject. In: Edwards, M.B., comp. Proceedings of eighth biennial southern silviculture research conference. Gen. Tech. Rep. SRS-001. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 75-80.

# EFFECTS OF A CONTROLLED RELEASE FERTILIZER ON THE NITROGEN DYNAMICS OF MID-ROTATION LOBLOLLY PINE PLANTATION IN THE PIEDMONT, VIRGINIA

J. Rob Elliot and Thomas R. Fox<sup>1</sup>

**Abstract**—Nitrogen deficiency is characteristic of many mid-rotation loblolly pine (*Pinus taeda* L.) plantations in the Piedmont region of the Southeast. Fertilization with urea is the most common method used to correct this deficiency. Previous studies show that urea fertilization produces a rapid pulse of available nitrogen (N) with only a portion being utilized by plantation trees. Controlled release fertilizers release available N slowly over a longer period of time and therefore may result in a greater uptake efficiency. The objective of this study was to compare a controlled-release N fertilizer (ureaform) versus urea by measuring the effects of the two fertilizer treatments on total extractable-N, mineralized-N, and ion resin exchangeable-N. Fertilization with the controlled release ureaform resulted in significantly greater and prolonged availability of total extractable-N, mineralized-N, and ion resin exchangeable-N than the fertilization with urea or the control.

## INTRODUCTION

Loblolly pine plantations are the dominant form of intensive pine silviculture in the Piedmont physiographic province of the Southeast. The soils of this region are nutrient deficient, especially with limitations in available nitrogen (N) and phosphorus (P) (Pritchett and Smith 1972). Fertilization with N + P has been shown to increase gross stand volume by 239 square feet per acre in Piedmont loblolly pine plantations (Allen and Ballard 1982). Therefore, fertilization with N and P during establishment and mid-rotation is a major practice. Recent estimates from 2003 show that 1.4 million acres are fertilized annually with N and P. However, the increased growth from fertilization has been shown to decline to pre-treatment levels over a 5 to 8 year period (Ballard 1981). From a physiological standpoint, measured N and P uptake efficiency has been shown to be very low, with recovery percentages between 13 and 21 percent (Strader 1982). The fertilizer which is not utilized by growing trees is lost through pathways of immobilization, leaching, and volatilization (Allen and Ballard 1982; Kissel and others 2004; Mattos and others 2004). Furthermore, Mudano (1986) reported that total soil available N declined to pre-fertilization levels after only 160 days.

These patterns of low N uptake and high ecosystem N loss are associated with traditional fertilizers, especially urea, which are most commonly utilized in commercial forestry because of their low cost. Controlled-release N fertilizers reportedly increase N retention in soils, N uptake in plants, and decrease N loss through leaching (Alexander and Helm 1990; Rose 2002). Though frequently used in agriculture and tree nurseries, controlled-release N fertilizers are currently not utilized in southern pine plantation forestry due to uncertainties surrounding cost effectiveness. This study investigates the ability of ureaform, a controlled-release N fertilizer, to successfully increase soil N retention in a mid-rotation loblolly pine plantation in the Piedmont of Virginia. The effects from ureaform fertilization are compared to those of a traditional water-soluble urea fertilization, as well as to a control.

## MATERIALS AND METHODS

### Site

The study site was located on the Reynold's Homestead Forest Resources Research Forest in the Piedmont physiographic province of Patrick County, VA (36° 39' N, 80° 09' W). The soils are highly weathered, kaolinitic, Typic Kanhapludults of the Cecil and Lloyd soil series. Due to soil erosion from past agricultural use, the O and A horizons are very shallow ( $\leq 5$  cm thick), with an exposed Bt clay horizon beneath. The pretreatment stand was a 9 acre, 22-year-old loblolly pine plantation, with an average basal area of 150 square feet per acre and site index (25 year) of 67 feet.

### Experimental Design and Treatments

The experimental design was a randomized complete block design with four blocks. Plot installation occurred in the summer of 2003 with 12, 0.23-acre treatment plots and 0.10-acre measurement plots centered within. The plots were blocked on pre-treatment basal area and height to account for any residual growth differences since the time of stand initiation. Continuous complete vegetation control occurred in all treatment plots beginning in the winter of 2003. Herbaceous vegetation was sprayed with a 5 percent solution of Roundup (Monsanto Corporation, St. Louis, MO). Arborescent competing vegetation was manually felled with a chainsaw. All slash from vegetation control was left on site. Due to the high stocking levels found in this stand, a mechanical thinning operation using chainsaws was implemented during the winter of 2004, reducing each treatment plot basal area to  $110 \pm 10$  square feet per acre.

Treatments were implemented in this study as three fertilization regimes: (1) no fertilization, (2) fertilization with 200 pounds N per acre as urea plus 100 pounds per acre Triple Super Phosphate (TSP), and (3) fertilization with 200 pounds N per acre as Slow-release Ureaform (Nitroform Blue-chip, Nu-Gro Corporation, Brantford, Ontario, Canada) plus 100 pounds P per acre as TSP. The fertilization was done by hand on August 1, 2004. Hereafter, the no fertilization treatment will be referred to as the control (CO), fertilization with urea + TSP

<sup>1</sup> Graduate Research Technician and Associate Professor, respectively, Virginia Polytechnic Institute and State University, Forestry Department, 218 Cheatham Hall, Blacksburg, VA, 24060.

will be referred to as (UR), and fertilization with slow-release Ureaform + TSP will be referred to as (CR).

### N-Mineralization and Extractable-N Methods

In-situ N mineralization sampling took place in all measurement plots following the Raison and others (1976) sequential coring method. Two cores made of polyvinyl chloride, 1.5 inches in diameter and 8 inches in length, were inserted into the mineral soil to a depth of 6 inches. Caps were placed on the cores to prevent precipitation from entering but loosely enough to allow for gas exchange within each core. One core was immediately removed for processing in the lab, while the second incubation core remained in place for 14 days. The incubation core was then removed for lab processing. Sequential in-situ incubations were implemented monthly at two random locations within each measurement plot, beginning July 1, 2004, and continuing through December 14, 2004. During sampling, a digital thermometer and soil moisture meter (HydroSense™, Campbell Scientific Inc., Ogden, Utah) were both inserted 8 inches into the mineral soil immediately adjacent to the incubation cores to measure soil temperature and volumetric water content. In the lab, soil from each core was sieved with a #10 mesh screen, placed in sample bags, and stored at 4 °C until extraction. At the time of extraction, 5 g of field moist soil was dried in a 105 °C oven for 24 hours to determine water content. A second 5 g of field moist soil was placed in a centrifuge tube with 50 ml of 2 M KCl and shaken on a reciprocating shaker for 1 hour. After shaking, the samples were centrifuged for 10 minutes, filtered through Whatman #42 paper, and the extracts frozen in scintillation vials. All extracts were analyzed colorometrically using a TRAACS 2000 Auto Analyzer (SEAL Analytical, Mequon, WI). N concentration data from each initial core was subtracted from its respective incubation core data to estimate N mineralization. Data from the initial cores were also used as an estimate of total KCl extractable-N as  $\text{NH}_4^+ + \text{NO}_3^-$ .

### Resin Exchangeable-N Methods

*In-situ* resin exchangeable-N sampling occurred in all measurement plots following procedures utilized by Cooperband and Logan (1994) and Huang and others (1996). Cation- and anion-exchange membrane sheets (Ionics Incorporated, Watertown, MA), 360 square inches in total area and packed in ethylene glycol, were first cut into 12.25-square-inch squares. This size is equivalent to 6.32 grams of dry resin with a capacity of 1.77  $\text{cmol}_c$  anion/cation – exchange capacity. Cation and anion membrane squares were kept separate, washed with de-ionized water, and soaked inside plastic carboys containing a 1 M NaCl solution for 24 hours before use in the field. Just before insertion into the mineral soil, membranes were removed from the solution and washed with de-ionized water. Two sets of membranes were installed at random locations within each measurement plot. Within each set, cation and anion membranes were inserted in both horizontal and vertical positions. Membranes were inserted horizontally by cutting a square of O horizon material down to the mineral soil with a serrated stainless steel spatula, carefully lifting the intact O material, and placing the membrane beneath it. Membranes were inserted vertically in the mineral soil from 4.75 inches to 1.25 inches deep by opening a vertical slit with the stainless steel spatula and placing the membrane into the mineral soil at the specified depth. The slit was firmly closed from either side with the spatula to

ensure proper contact between membrane and soil. Within each set, the cation and anion membranes were situated adjacent to one another with 3 to 5 inches between each membrane. The location of each membrane was marked with flagging and cable-ties for relocation. After a 14-day incubation period, the membranes were carefully removed from their locations, and large soil aggregates sticking to the membranes were removed. Individual membranes were then sealed in labeled plastic bags and stored at 4 °C until extraction. At the time of extraction, each membrane was placed in a 100-ml-square plastic container with 25 mL of 1 M KCl and shaken on a reciprocating shaker for 1 hour. The membranes were then removed and the extract filtered through Whatman #42 filter paper into scintillation vials. The samples were analyzed colorometrically on a TRAACS 2000 Auto Analyzer (SEAL Analytical, Mequon, WI).

### Design and Statistical Analysis

All statistical analyses were performed using SAS statistical software (SAS Institute 2002). Analyses of variance were performed using the general linear models procedure to test treatment main effects on monthly KCl extractable N, mineralized N, and resin exchangeable N. All within-plot samples were averaged by plot, and the plot was used as the experimental unit for all analyses. Means separations between treatment effects were performed for each sampling date using Fischer's least significant difference. Significance was accepted at  $\alpha \leq 0.05$  for all analyses.

## RESULTS

### Extractable-N

Pre-treatment total mineral extractable-N concentrations were extremely low in all plots, ranging from 4.30 to 7.19 mg N/kg soil. Total extractable-N was significantly affected by the fertilization treatments at each sampling date, except during October (fig. 1). CR total extractable-N ranged from 1.7 times that of CO in August to 6.6 times greater than CO in November. In comparison to UR, CO total extractable-N ranged from 1.6 times that of UR in August to 5.4 times greater than UR in November. UR treatments were not found to be significantly different than CO treatments throughout the sampling period (fig. 1). In September, 1 month after fertilization, CR total extractable-N increased by 173 percent, UR increased by 58

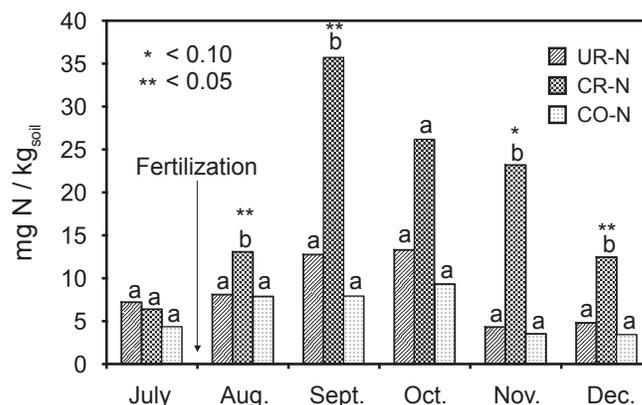


Figure 1—Monthly total extractable- $\text{NH}_4^+ + \text{NO}_3^-$  during a 6 month period in 2004. Means with same letters are not significantly different.

percent, and CO increased by 0.03 percent. From September to December, all treatments decreased in total extractable-N. However, the CR extractable-N during December was 1.9 times the pre-treatment CR extractable-N during July, whereas UR and CO extractable-N during December was, respectively, 0.34 and 0.21 times less than pre-treatment extractable-N during July.

### In Situ N-Mineralization

Pre-treatment N mineralization ranged from 0.04 mg N/kg soil to 2.25 mg N/kg soil across the three treatments. There were significant treatment effects ( $P < 0.1$ ) on N mineralization during August and November and highly significant treatment effects ( $P < 0.05$ ) on N mineralization during October (fig. 2). Net N immobilization occurred in all treatments during September; however, there were no significant differences between treatments. During October, CR net N mineralization was 5.36 mg N/kg soil, while UR and CO net N mineralization was -5.1 and -5.6 mg N/kg soil respectively (fig. 2). CR net N mineralization during November was 9.4 times UR and 23.8 times CO net N mineralization ( $P < 0.1$ ). UR and CO net N mineralization in December was, respectively, 0.99 and 1.31 mg N/kg soil < pre-treatment levels in July, while CR net N mineralization in December was 0.92 mg N/kg soil > pre-treatment levels in July.

### Resin Exchangeable-N

**O-Horizon exchangeable-NH<sub>4</sub><sup>+</sup>**—Treatment effects on O horizon resin exchangeable-NH<sub>4</sub><sup>+</sup> were highly significant ( $P < 0.05$ ) across all sampling dates, except during November when only slightly significant ( $P < 0.1$ ). During August, UR and CR exchangeable-NH<sub>4</sub><sup>+</sup> concentrations were, respectively, 15.8 and 12.8 times CO concentrations (fig. 3a). In September, CR exchangeable-NH<sub>4</sub><sup>+</sup> levels were 5.6 times > CO, while UR levels were only 3 times > CO. During October, CR exchangeable-NH<sub>4</sub><sup>+</sup> remained significantly > CO, while UR levels were 2 mg NH<sub>4</sub><sup>+</sup>/m<sup>2</sup> < CO. In November, CR levels decreased to 15 mg NH<sub>4</sub><sup>+</sup>/m<sup>2</sup> but were 3 times as great as CR pre-treatment levels in July. UR and CO during November were 2.1 mg NH<sub>4</sub><sup>+</sup>/m<sup>2</sup> and 2.3 mg NH<sub>4</sub><sup>+</sup>/m<sup>2</sup> < pre-treatment levels, respectively (fig. 3a).

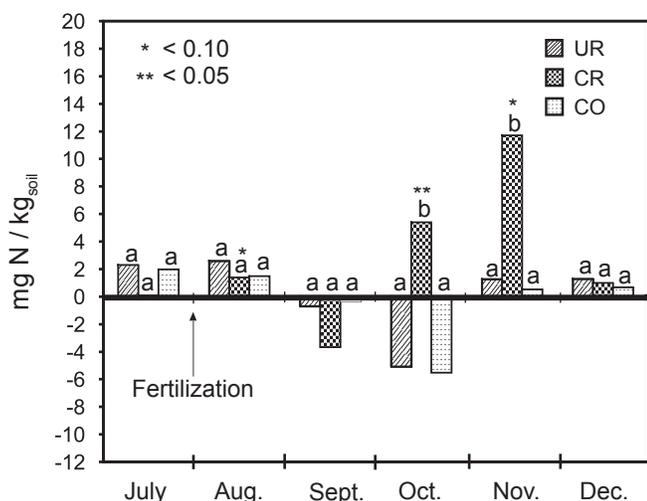


Figure 2—Average monthly N-mineralization during a 6 month period in 2004. Means with same letters are not significantly different.

**Mineral soil exchangeable-NH<sub>4</sub><sup>+</sup>**—Treatment effects on mineral soil resin exchangeable-NH<sub>4</sub><sup>+</sup> were highly significant across all sampling dates except July (fig. 3b). UR and CR concentrations were > CO across all sampling dates. From September to November, CR concentrations were 1.4 to 3.0 times > UR and 2.8 to 7.1 times > CO (fig. 3b).

**O-Horizon exchangeable-NO<sub>3</sub><sup>-</sup>**—Treatment effects on O horizon exchangeable-NO<sub>3</sub><sup>-</sup> were significant only during July and August (fig. 3c). In August, CR was 3.9 and 3.1 times > CO and UR, respectively. During November, CR NO<sub>3</sub><sup>-</sup> was 4.3 mg NO<sub>3</sub><sup>-</sup>/m<sup>2</sup> > pre-treatment levels, while UR and CR NO<sub>3</sub><sup>-</sup> levels were, respectively, 0.7 and 0.8 mg NO<sub>3</sub><sup>-</sup>/m<sup>2</sup> > pre-treatment levels.

**Mineral Soil exchangeable-NO<sub>3</sub><sup>-</sup>**—Treatment effects on mineral soil exchangeable-NO<sub>3</sub><sup>-</sup> were highly significant during July, August, and October. During July, concentrations ranged from 0.13 mg NO<sub>3</sub><sup>-</sup>/m<sup>2</sup> in CR to 2.57 mg NO<sub>3</sub><sup>-</sup>/m<sup>2</sup> in CO. In August, CR and UR increased to 1.8 mg NO<sub>3</sub><sup>-</sup>/m<sup>2</sup> and 2.9 mg NO<sub>3</sub><sup>-</sup>/m<sup>2</sup>, respectively, while CO decreased to 0.59 mg NO<sub>3</sub><sup>-</sup>/m<sup>2</sup>. In October, CR levels were 12.2 times > CO and 18.3 times > UR. In November, UR and CR were, respectively, 2.46 and 4.70 mg NO<sub>3</sub><sup>-</sup>/m<sup>2</sup> > pre-treatment levels, while CO was 2.19 mg NO<sub>3</sub><sup>-</sup>/m<sup>2</sup> < pre-treatment levels.

### DISCUSSION

Initially, it is clear that this stand was N deficient, with total extractable-N ranging between 4 and 7 mg N/kg soil in all treatment plots. The data also show that after fertilization, UR and CR both increased total extractable-N concentrations; however, CR demonstrated significantly greater concentrations of total extractable-N at each post-treatment sampling date. There was no significant difference between UR and CO total available-N throughout the sampling period. The most striking trend in this data is the prolonged availability of N after fertilization with controlled release ureaform in comparison to the rapid increase and decline in available N after fertilization with urea. This is consistent with the results of Mudano (1986), which showed a rapid pulse of soil-available N after fertilization with a water soluble N fertilizer, followed by a decline over 5 months to pre-fertilization levels.

A similar trend was seen in the N-mineralization data, with CR demonstrating significantly greater mineralized-N during October and November than both UR and CO. The most notable difference in treatment effects was during October, when UR and CO demonstrated N-immobilization while CR demonstrated N-mineralization. This is reflected in the resin exchangeable-N data for this same time period, where CR had significantly greater concentrations of mineral NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup> than UR and CO. Most likely, the retention of higher N-mineralization rates over the sampling period is due to the increased C as a microbial energy source provided by the controlled-release ureaform fertilizer.

In the resin exchangeable-N data, evidence of increased nitrification was found in CR during October. This is demonstrated by the significant 1:1 exchange in CR mineral soil NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup>, with CR mineral soil NH<sub>4</sub><sup>+</sup> decreasing by 7.2 mg N/m<sup>2</sup> and CR mineral soil NO<sub>3</sub><sup>-</sup> increasing by 6.8 mg N/m<sup>2</sup>. Only in CR was there evidence of nitrification present during the sampling period. UR demonstrated no significant increases in NO<sub>3</sub><sup>-</sup> above CO throughout the sampling period, most likely due to a depression in microbial activity.

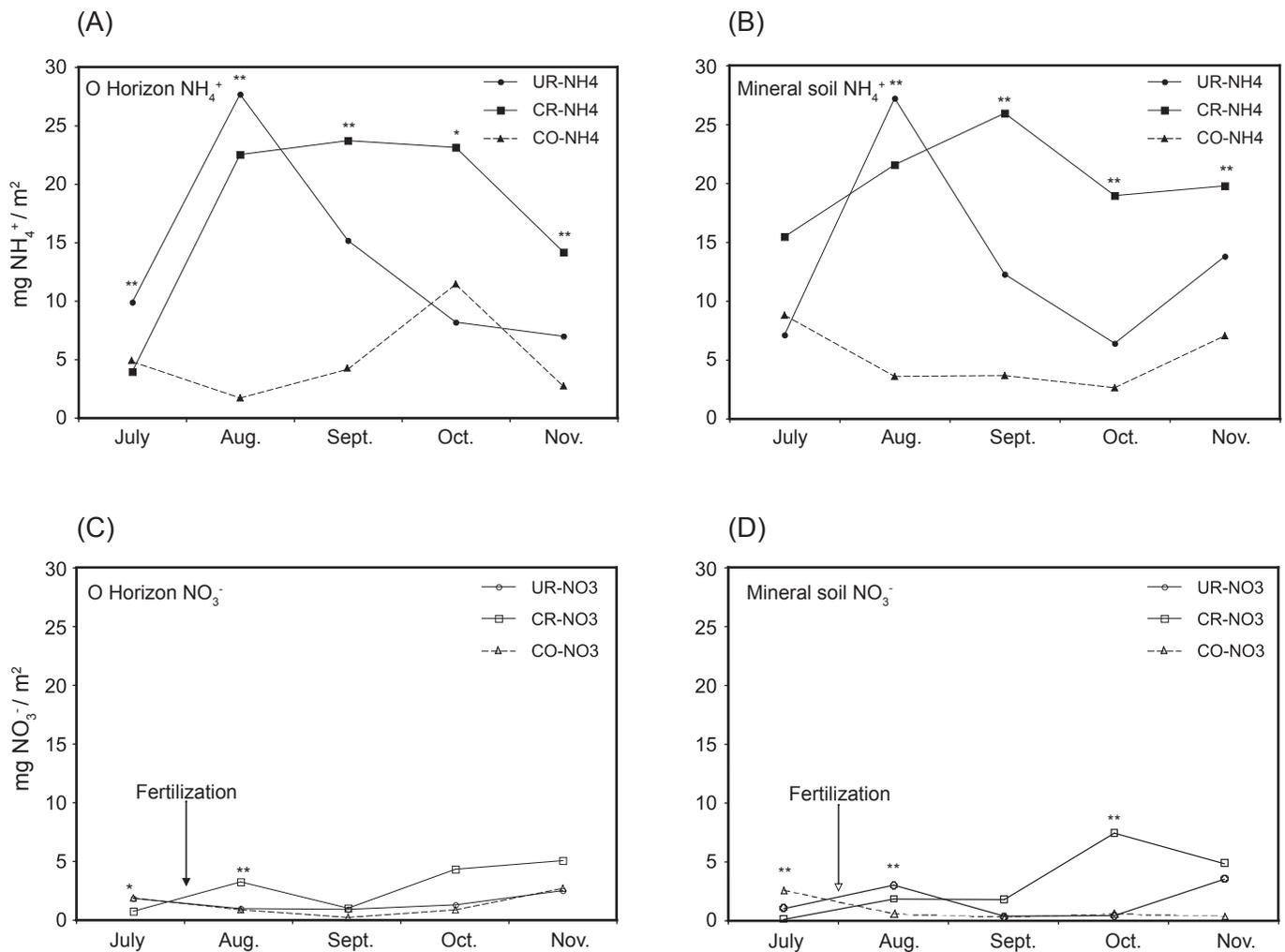


Figure 3—Monthly resin exchangeable-N during a 5 month period in 2004: (A) O Horizon NH<sub>4</sub><sup>+</sup>-N, (B) mineral soil NH<sub>4</sub><sup>+</sup>-N, (C) O Horizon NO<sub>3</sub><sup>-</sup>-N, and (D) mineral soil NO<sub>3</sub><sup>-</sup>-N. \* and \*\* show significance at the 0.01 and 0.05 level, respectively.

UR demonstrated greater positive response during the first month after fertilization, while not being significantly > CO for the remainder of the sampling period. These data are consistent with previous studies; fertilization with urea provides a brief spike in available NH<sub>4</sub><sup>+</sup> for 30 to 60 days. Over all, the most notable trend in the data was that CR demonstrated more positive stimulatory effects in soil N-dynamics with increased N-mineralization, nitrification, and total extractable-N pool in the mineral soil.

Further sampling is necessary to determine if and how far these trends continue through the following growing season. Also, in order to determine whether controlled-release ureaform fertilizers increase tree N-uptake efficiency throughout the growing season and rotation, foliar N analyses will be required and are currently being performed. From this data, it appears that over a 5 month period, N-retention in the soil is significantly greater when fertilized with controlled-release ureaform.

#### ACKNOWLEDGMENTS

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#### LITERATURE CITED

- Alexander, A.; Helm, H.U. 1990. Ureaform as a slow release fertilizer: a review. *Zeitschrift für Pflanzenernährung und Bodenkunde*. 153: 249-255.
- Allen, H.L.; Ballard, R. 1982. Forest fertilization of loblolly pine. Symposium on the loblolly pine ecosystem (east region). Raleigh, NC: North Carolina State University, School of Forest Resources: 163-181.
- Ballard, R. 1981. Optimum nitrogen rates for fertilization of loblolly pine plantations. *Southern Journal of Applied Forestry*. 5: 212-216.
- Cooperband, L.R.; Logan, T.J. 1994. Measuring in situ changes in labile soil phosphorus with anion-exchange membranes. *Soil Science Society of America Journal*. 58: 105-114.
- Huang, W.Z.; Schoenau, J.J. 1996. Microsite assessment of forest soil nitrogen, phosphorus, and potassium supply rates in-field using ion exchange membranes. *Communications in Soil Science and Plant Analysis*. 27: 2895-2908.
- Kissel, D.E.; Cabrera, M.L.; Vaio, N. [and others]. 2004. Rainfall timing and ammonia loss from urea in a loblolly pine plantation. *Soil Science Society of America Journal*. 68: 1744-1750.

- Mudano, J.E. 1986. Assessment of soil nitrogen availability following nitrogen and phosphorus fertilization of a loblolly pine stand. Raleigh, NC: North Carolina State University. 52 p. M.S. thesis.
- Pritchett, W.L.; Smith, W.H. 1972. Fertilizer response in young pine plantations. *Soil Science Society of America Proceedings*. 36: 660-664.
- Raison, R.J.; Connell, M.J.; Khanna, P.K. 1987. Methodology for studying fluxes of soil mineral-N in situ. *Soil Biology and Biochemistry*. 19: 521-530.
- Rose, R. 2002. Slow release fertilizers 101. National proceedings: forest and conservation nursery associations 1999, 2000, and 2001. RMRS-P-24. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 304-308.
- SAS Institute. 2002. SAS user's guide. Version 9.1. Cary, NC: SAS Institute.
- Strader, R.H. 1982. Nitrogen fertilization of two loblolly pine plantations: biomass production and nitrogen recovery and distribution after 10 and 11 years. Raleigh, NC: North Carolina State University. 40 p. M.S. thesis.

# NITROGEN DISTRIBUTION WITHIN THE SOIL-PLANT-MICROBIAL SYSTEM IN RESPONSE TO PRE-THINNING FERTILIZATION TREATMENTS IN LOUISIANA

Michael A. Blazier and D. Andrew Scott<sup>1</sup>

**Abstract**—Improvements in nitrogen (N) uptake efficiency and plantation growth require refined silvicultural systems that consider soil type, stand development, ecology, and their interactions. On four unthinned, mid-rotation loblolly pine plantations in Louisiana located on a gradient of soil drainage classes, soil, plant, and microbial N dynamics were measured in response to fertilization and understory vegetation control. Treatments consisted of an untreated control, N and phosphorus (P) fertilization, and N + P fertilization with herbicide understory suppression. Results indicated understory suppression was necessary to effectively promote increases in pine foliage N concentrations when stands had no prior history of herbicide application. Understory control was most effective in enhancing pine response to fertilization on a well-drained site. Soil N returned to background levels within 6 months of application at all sites, and microbial biomass N was relatively unaffected by fertilization and brush control at all sites.

## INTRODUCTION

Loblolly pine plantations are commonly fertilized near mid-rotation, typically after thinning (Dickens and others 2003), to synchronize nutrient supply with plant demand, increase leaf area, and improve productivity. Chemical release treatments are also sometimes applied at this time to ensure that site resources are available for planted crop trees. However, further gains in production efficiency will require more than simply increasing resource inputs; they will require more comprehensive understanding and management of the interactions among crop trees, non-crop vegetation, soil properties, and applied nutrients (Jokela and others 2004). One method of affecting resource use efficiency is to alter the timing of various treatments, as is commonly practiced in row-crop agriculture.

Fertilization is conventionally conducted after thinning to ensure that only the remaining crop trees are exposed to the applied nutrients. However, the low-nutrient concentration, soluble carbon (C)-rich slash remaining on-site after thinning may facilitate increased microbial immobilization of nutrients, particularly of N. Additionally, basal areas of many of these stands are well below 35 m<sup>2</sup> ha<sup>-1</sup>, which is the level identified by Jokela and others (2004) at which fertilization effectiveness declines for loblolly pine plantations in the Southeastern United States.

Alternatively, fertilizing mid-rotation stands prior to thinning may have several benefits. If N fertilizer is applied within 1 year prior to thinning, crop trees have sufficient time to exploit elevated soil N, which tends to persist for approximately 1 year (Blazier 2003). Competition for applied N from understory vegetation is relatively low due to light limitations caused by canopy closure (Dickens and others 2003). Higher pine biomass at the time of fertilization would promote high stand-level pine fertilizer uptake. This high pine fertilizer uptake could in turn reduce movement of applied nutrients below pine rooting zones via leaching on well-drained sites and denitrification on poorly drained sites. In addition, elevated nutrient levels within the fertilized trees may promote faster early growth following thinning.

This study was established to explore loblolly pine, understory vegetation, and microbial N uptake in response to fertilizer timing relative to mid-rotation thinning and understory vegetation suppression across a gradient of soil types in Louisiana. The objectives of this paper were to determine how pre-thinning fertilization and understory vegetation control affected extractable soil N, microbial biomass N (N<sub>mic</sub>), understory vegetation N content, and crop tree foliar N concentrations across a gradient in site types.

## METHODS

### Study Sites

In September and October, 2003, four study sites were established in north, central, and southwest Louisiana. The sites were similar in age and management history, but they differed in soil drainage classes (table 1). The Lucky site was established in Bienville Parish, LA (32.3029° N, 92.9240° W), on a Betis loamy fine sand (thermic Lamellic Paleudult). The Dodson site was established in Jackson Parish, LA (32.0727° N, 92.6697° W) on a Bowie very fine sandy loam (thermic Plinthic Paleudult). The DeRidder site was established in Vernon Parish, LA (30.7742° N, 93.2493° W) on a Beauregard silt loam (thermic Plinthaquic Paleudult). The Oakdale site was established in Allen Parish, LA (30.8164° N, 92.6914° W) on a Caddo silt loam (thermic Typic Glossaqualf). All sites had originally been treated with chop-and-burn site preparation after harvest and planted with 1-0 seedlings.

### Treatments

The effects of fertilization on the soil-plant-microbial system of unthinned loblolly pine plantations were tested by comparing a N + P fertilization treatment to an untreated control. The fertilizer treatment consisted of 135 kg N ha<sup>-1</sup> and 13 kg P ha<sup>-1</sup> applied as a urea and DAP mixture. Fertilizer was applied with shoulder-mounted spreaders in April, 2004. At each site, fertilization was done within 1 week prior to a precipitation event to promote uniformity of fertilizer dissolution. The effects of understory vegetation suppression were tested by comparing a basal bark spray of a 5 percent solution of triclopyr to

<sup>1</sup> Assistant Professor, Hill Farm Research Station, Louisiana State University AgCenter, Homer, LA 71040; and Research Soil Scientist, USDA Forest Service, Southern Research Station, Pineville, LA 71360, respectively.

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**Table 1—Location, stand age in 2003, soil characteristics, and management history of four study sites established in loblolly pine plantations in north, central, and southwestern Louisiana**

Location	Age	Soil series	Soil drainage	Previous release <sup>a</sup>	Previous fertilization <sup>b</sup>
Lucky	12	Betis	Well-drained	None	None
DeRidder	15	Beauregard	Moderately well	1997 <sup>c</sup>	170 Kg Dap Ha <sup>-1</sup>
Dodson	13	Bowie	Moderately well	None	None
Oakdale	15	Caddo	Poorly drained	None	280 Kg Dap Ha <sup>-1</sup>

<sup>a</sup> All sites had originally been treated with a chop and burn site preparation.

<sup>b</sup> Both fertilizer applications were in 1997.

<sup>c</sup> The site was treated with 415 g imazapyr and 70 g sulfometuron ha<sup>-1</sup> in 1997.

an untreated control. Triclopyr was applied with backpack sprayers in March, 2004. The fertilizer × herbicide treatments were applied as a split-plot treatment structure, with fertilizer as the whole-plot treatment and the herbicide treatment as the subplot treatment. However, a no-fertilizer × herbicide treatment combination was not conducted in this phase of the study. Plots were 0.20 ha in size, and subplots were 0.10 ha. Each plot is separated by at least 8 m, and each subplot is separated by 5 m to ensure independence of treatments. The experimental design was an incomplete block design, with soil texture differences at each site used as a blocking factor. Treatments were replicated 3 times at each site.

### Measurements

In February and September, 2004, foliage was sampled for nutrient analysis. In February, five trees were sampled per plot, and three trees per subplot were sampled in September. A 12-gauge shotgun was used to extract branches from the upper, middle, and lower portions of the crowns. Ten fascicles per flush were collected from each sampled branch. Fascicles from each flush were combined to create composite samples for each plot (in February) or subplot (in September). Samples were oven-dried at 70 °C to constant weight, and foliage N was determined with a Leco-2000 C/N/S analyzer (Leco Instruments, St. Joseph, MI). Foliage N values per plot or subplot were then determined by calculating the weighted average of foliage N from each crown position and flush, with the ratio of foliage to branch mass in each crown third used as the weighting factor. The ratio of foliage to branch mass was determined from data collected on destructively harvested trees, described below.

In September 2004, a destructive harvest of 10 trees per site was conducted to develop site-specific models that predict dry weight of each aboveground biomass component (table 2). Trees that represented the range of diameters (as based on d.b.h. measurements taken on all study trees in August 2004) and fertilization treatments at each site were selected for harvest. Destructively harvested trees were selected from within subplots. Prior to felling, total height, height to live crown, and d.b.h. were measured. Trees were then felled, all branches were cut from the stem and separated by crown position (upper, middle, lower), and the stem was cut into 1-m bolts. Fresh weights of crown biomass (branch + foliage) from each crown position and stem bolts were weighed in the field. Three random branches were subsampled per crown position. Branch and foliage mass of these subsamples were separated, and fresh branch and foliage weights were measured.

**Table 2—Regression coefficients for equations used in prediction of foliage, branch, and stem biomass of mid-rotation loblolly pine at four study sites (identified by nearest town) in north, central, and southwestern Louisiana**

Dependent Variable <sup>a</sup>	Parameter estimates			Statistics <sup>b</sup>	
	b <sub>0</sub>	b <sub>1</sub>	b <sub>2</sub>	FI	SE
<b>Lucky</b>					
FOLWT <sup>c</sup>	0.018	2.155	—	0.94	0.60
BRWT <sup>d</sup>	0.104	4.414	-3.213	0.99	0.33
STEMWT <sup>c</sup>	0.266	1.926	—	0.99	1.65
<b>Dodson</b>					
FOLWT <sup>d</sup>	23.535	2.144	-2.733	0.99	0.50
UBRWT <sup>c</sup>	0.232	2.223	—	0.99	0.05
FBRWT <sup>c</sup>	0.057	1.826	—	0.96	1.37
USTEMWT <sup>c</sup>	1.023	1.555	—	0.99	1.85
FSTEMWT <sup>c</sup>	6.695	0.808	—	0.99	2.95
<b>DeRidder</b>					
UFOLWT <sup>c</sup>	3.4×10 <sup>-6</sup>	5.277	—	0.99	0.37
FFOLWT <sup>c</sup>	0.005	2.769	—	0.98	0.63
BRWT <sup>c</sup>	6.4×10 <sup>-4</sup>	3.534	—	0.97	0.64
STEMWT <sup>d</sup>	0.189	1.787	0.324	0.99	1.21
<b>Oakdale</b>					
FOLWT <sup>c</sup>	0.021	2.070	—	0.98	0.45
BRWT <sup>c</sup>	0.017	2.428	—	0.94	2.21
STEMWT <sup>d</sup>	3.1×10 <sup>-4</sup>	1.175	3.403	0.97	5.37

<sup>a</sup> FOLWT = foliage dry weight for fertilized and unfertilized trees (kg), BRWT = branch dry weight for fertilized and unfertilized trees (kg), STEMWT = stem dry weight for fertilized and unfertilized trees (kg), UBRWT = branch dry weight for unfertilized trees (kg), FBRWT = branch dry weight for fertilized trees (kg), USTEMWT = stem dry weight for unfertilized trees (kg), FSTEMWT = stem dry weight for fertilized trees (kg), UFOLWT = foliage dry weight for unfertilized trees (kg), FFOLWT = foliage dry weight for fertilized trees (kg).

<sup>b</sup> FI = fit index, SE = standard error of the estimate.

<sup>c</sup> Model form:  $Y = b_0 \times dbh^{b_1}$ .

<sup>d</sup> Model form: where Y = foliage, branch, or stem dry weight (kg), dbh = diameter at breast height (cm), and ht = total tree height (m).

Disks approximately 2.54-cm thick were cut from the top and bottom of each stem bolt, and fresh weight of disks was measured (Blazier and others 2002). Branch, foliage, and stem subsamples were oven-dried to constant weight at 70 °C and weighed. The dry to fresh weight ratio of all samples was determined and averaged for each crown third of each tree. The ratio of foliage to branch mass was also determined for all crown subsamples. Total dry foliage and branch weights were estimated for each destructively harvested tree by multiplying the fresh weight of each crown position by its average dry to fresh weight and foliage to branch weight ratios and summing the dry weight estimates of each crown position. Model fitting procedures will be discussed below. N contents of branch, foliage, and stem subsamples were determined using a Leco-2000 C/N/S analyzer. Tree dimensions used as model inputs were measured in September or October at each site. Unfortunately, some of the plots at the Lucky site were mistakenly thinned before tree dimensions could be measured.

In September, 2004, understory vegetation was sampled in three random 0.04-ha subsample plots per subplot. Total height of hardwood trees, total number of stems, and species composition was recorded in each subsample plot. Herbaceous vegetation was clipped within a 1-m<sup>2</sup> quadrat randomly placed in each subsample plot. These variables were then used as inputs in models developed by Stagg and Scott (2006) to predict understory vegetation biomass and N content.

Soil NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup> were sampled using a punch auger to collect soil in March, May, August, and September, 2004. In each subplot, 3 soil samples from the top 20 cm of soil were collected from 2 randomly placed subsample areas. All soil samples were composited for each subplot. Once samples were air-dried to constant weight, soil NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup> were quantified by the diffusion-conductivity method (Carlson 1978, Carlson and others 1990) using a TL-550A Ammonia/Nitrate Analyzer (Timberline Instruments, Inc., Boulder, CO) following extraction with a 2 M solution of KCl (Mulvaney 1996). Total extractable N was determined by summing NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup> values for each observation.

Microbial biomass nitrogen (N<sub>mic</sub>) was sampled using a punch auger to collect soil in September, 2004. In each subplot, 3 soil samples from the top 10 cm of soil were collected from 2 randomly placed subsample areas. All soil samples were composited for each subplot. Soil samples were kept at 5 °C during transport and storage. Samples remained in storage a maximum of 1 week prior to analysis. N<sub>mic</sub> was assessed by the chloroform fumigation-incubation method (Horwath and Paul 1994). Procedures included a 10-day pre-incubation of soil samples at 25 °C followed by fumigation with alcohol-free CHCl<sub>3</sub> vapor for 24 hours. Extraction of NH<sub>4</sub> was conducted with 2 M KCl, and NH<sub>4</sub> in extracts was analyzed by the diffusion-conductivity method (Carlson 1978, Carlson and others 1990) using a TL-550A Ammonia/Nitrate Analyzer. Samples were incubated at 25 °C for 10 days. A proportionality constant of 0.68 was used to convert NH<sub>4</sub>-N to N<sub>mic</sub> (Shen and others 1984).

### Data Analysis

During biomass model development, the influence of fertilization on the relationship between each biomass component and tree dimensions (height, diameter, crown width) was investigated using procedures described by Blazier and others (2002).

Categorical (dummy) variables were incorporated into the models to account for fertilizer and brush control influences. When the dummy variables were found to be significant, separate models for prediction of a biomass component were estimated for fertilized and non-fertilized study trees. When the dummy variables were not significant, data were pooled and a single model for prediction of a biomass component was estimated for fertilized and non-fertilized study trees.

After the need for separate or single models was assessed with analyses of dummy variables, a stepwise procedure was performed on each model using a significance level of P = 0.15 to ensure that only variables that significantly affected foliage and stem weight were included in the regression equations. Residual analyses were then performed on each model to investigate any significant departures from linearity. Cook's distance and DFFITS tests were conducted to search for any outliers that substantially influenced each model (Neter and others 1996). After stepwise procedures, residual analyses, and outlier tests were completed, the NLIN procedure of the SAS System (SAS Institute Inc., Cary, NC) was used to estimate regression coefficients for each nonlinear biomass model.

Analyses of all response variables except soil N were conducted by analysis of variance using the MIXED procedure of the SAS System with site, block, treatment, and the interaction between site and treatment as fixed effects. The treatment effect was comprised of three levels: control (CONT), fertilizer-only (NP), and fertilizer + herbicide (NPBC). This definition of the treatment effect was necessary due to the missing no-fertilizer × herbicide treatment combination in this phase of the study. A significance level of P = 0.10 was used to increase the power of the test given the inherent relatively high variability of soil and plant N quantification. Soil N was analyzed with a repeated measures model with an autoregressive correlation structure with: (1) site, (2) block, (3) treatment, (4) month, and (5) the interactions between treatment, site, and month as fixed effects. When an ANOVA indicated significant treatment effects, treatment means were calculated and separated by the DIFF and SLICE options of the LSMEANS procedure. The DIFF option provided multiple comparisons of treatment means by invoking t-tests to determine significant differences between all possible treatment combinations. The SLICE option provided t-tests of treatment means in which the effect of one treatment is evaluated at each level of another treatment. The SLICE option was used to investigate treatment main effects when significant 2-way interactions were found. N<sub>mic</sub> and soil N values were log-transformed for analysis after the null model likelihood ratio test revealed significant heterogeneity in variances within the dataset.

## RESULTS AND DISCUSSION

No significant pre-treatment differences among treatments in foliage N concentrations were revealed by the February, 2004 foliage sampling. However, foliage N concentrations of the trees on the poorly drained Oakdale site were significantly greater than those of the trees on the other sites (table 3). Average foliage N concentrations were greater than the critical level of 1.2 percent for loblolly pine foliage N (Dickens and others 2003) at all sites, while the average N concentration of the Oakdale site trees exceeded the critical value by about 0.2 percent.

**Table 3—Foliage nitrogen concentrations (%) of mid-rotation loblolly pine at four study sites (identified by nearest town) in north, central, and southwestern Louisiana in response to untreated control (CONT), fertilization with nitrogen and phosphorus (NP), and fertilization with nitrogen and phosphorus with triclopyr used for understory brush control (NPBC)<sup>a</sup>**

Site	February 2004			September 2004		
	CONT	NP	NPBC	CONT	NP	NPBC
Lucky	1.23a	1.22a	1.22a	0.95c	1.18b	1.32a
Dodson	1.24a	1.17a	1.17a	1.06b	1.24ab	1.21a
DeRidder	1.16a	1.24a	1.24a	0.92b	1.25a	1.06a
Oakdale	1.40a	1.32a	1.32a	1.13b	1.14b	1.26a

<sup>a</sup> For each month, means within a row followed by a different letter differ significantly at  $P < 0.10$ .

The site  $\times$  treatment effect was significant in September, 2004 (table 3). At the Oakdale and Dodson sites, foliage N concentrations were significantly increased only by the combined fertilization and brush control treatment. At the moderately well-drained DeRidder site, foliage N concentrations were comparably increased by the NP and NPBC treatments. At the well-drained, sandy Lucky site, fertilization increased foliage N concentrations by a significantly greater magnitude with understory suppression. Albaugh and others (2003) similarly found variable responses to mid-rotation vegetation suppression and fertilization treatments across well- and poorly drained sites.

Understory vegetation trends may partially explain differences in foliage N concentrations at the four sites (fig. 1). The Oakdale and Dodson sites were characterized by relatively high understory biomass, so understory biomass may have severely reduced pine uptake of applied nutrients. Understory biomass may have been more problematic in this study than with operational fertilization, because our fertilization

rates were 25 percent lower than commonly used N and P rates (NCSFNC 2002). Although understory biomass at the Lucky and DeRidder sites was comparable, pine foliage N concentrations were significantly enhanced by the NPBC treatment only at the Lucky site. Because tree nutrient uptake and growth potential are lower on well-drained soils due to poorer moisture availability, understory suppression may have been more important in promoting pine N uptake at the sandy Lucky site (Powers and Reynolds 1999).

The lack of significantly lower understory biomass between the NP and NPBC treatments at the Lucky site (fig. 1) is possibly due to the presence of similarly high numbers of southern red oak (*Quercus falcate* Michx.) stems in both treatments. Southern red oak was relatively resistant to the maximum labeled rate of triclopyr used in this study. Similarly, the seemingly anomalous understory biomass trends observed at the Oakdale site were partially influenced by Chinese tallow (*Sapium sebiferum* L.) and sweetgum (*Liquidambar styraciflua* L.) trees  $> 8$  cm in d.b.h. that were resistant to basal spray of triclopyr as well as southern red oak. Understory biomass estimates may be biased at the Oakdale site due to the presence of hardwood trees  $> 6$  m in height, because the model used was not developed for trees  $> 4$  m tall. In future years of this study, destructive harvests of hardwood trees in excess of 4 m in height will be conducted to make the models more accurate for these sites.

The site  $\times$  treatment and month  $\times$  treatment interactions were significant in the analyses of soil  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ , and total extractable N (table 4). Total extractable N of the Oakdale site was significantly greater than that of all other sites, and the Lucky site had significantly lower extractable N than the DeRidder site. All soil N variables significantly differed only in May, and significant differences among treatments were found at only the Lucky and DeRidder sites. At Lucky, total extractable N and  $\text{NH}_4^+$  were significantly greater in May in response to the fertilization treatments, but no differences were found between the NP and NPBC treatments. Interestingly, at the DeRidder site total N,  $\text{NH}_4^+$ , and  $\text{NO}_3^-$  were significantly increased by only the NP treatment. The lack of soil N response at the Oakdale and Dodson sites may be indicative of a large native pool of N, a relatively low N fertilization rate for this study, and high variability of soil N after fertilization. The return of extractable soil N to native levels within 6 months of fertilization at

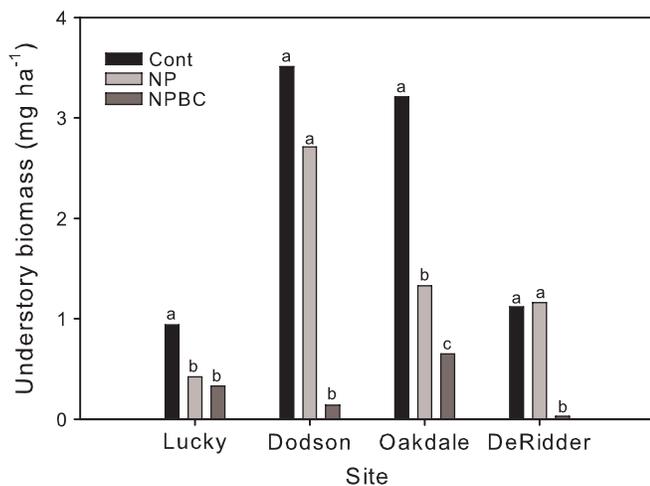


Figure 1—Understory vegetation biomass in mid-rotation loblolly pine plantations at four study sites (identified by nearest town) in north, central, and southwestern Louisiana in response to untreated control (Cont), fertilization with nitrogen and phosphorus (NP), and fertilization with nitrogen and phosphorus with triclopyr used for understory brush control (NPBC).

**Table 4—Soil nitrogen concentrations (mg kg<sup>-1</sup>) in mid-rotation loblolly pine plantations at four study sites (identified by nearest town) in north, central, and southwestern Louisiana in response to untreated control (CONT), fertilization with nitrogen and phosphorus (NP), and fertilization with nitrogen and phosphorus with triclopyr used for understory brush control (NPBC)<sup>a</sup>**

Treatment	NO <sub>3</sub> <sup>-</sup>			NH <sub>4</sub> <sup>+</sup>			Total extractable N		
	CONT	NP	NPBC	CONT	NP	NPBC	CONT	NP	NPBC
<b>Lucky</b>									
March	1.58a	1.79a	1.25a	3.85a	4.07a	3.56a	5.43a	5.87a	4.81a
May	2.79a	6.84a	5.82a	7.07b	15.19a	19.57ab	9.86b	22.02a	25.39a
August	1.65a	1.98a	2.30a	2.76a	4.04a	3.62a	4.41a	6.02a	5.92a
<b>Dodson</b>									
March	3.71a	3.31a	3.09a	3.02a	4.01a	4.02a	6.74a	7.32a	7.11a
May	3.74a	4.82a	7.88a	9.34a	18.05a	15.28a	13.09a	22.87a	23.16a
August	4.99a	2.40a	3.40a	3.25a	4.45a	4.03a	8.24a	6.86a	7.43a
<b>DeRidder</b>									
March	1.88a	2.10a	1.65a	5.26a	4.70a	4.49a	7.13a	6.80a	6.14a
May	4.87b	40.69a	7.67b	5.29b	35.78a	7.06b	10.16b	76.47a	14.72b
August	1.52a	0.82a	1.30a	5.47a	3.72a	5.58a	7.00a	4.54a	6.89a
<b>Oakdale</b>									
March	4.14a	4.21a	3.71a	5.89a	5.82a	5.19a	10.02a	10.02a	8.90a
May	2.82a	5.86a	11.27a	12.45a	39.63a	34.86a	15.28a	45.49a	46.13a
August	3.13a	8.33a	4.33a	9.59a	15.99a	10.98a	12.73a	24.32a	15.31a
September	6.60a	7.17a	8.46a	11.84a	11.89a	11.32a	18.44a	19.06a	19.78a

<sup>a</sup> For each form of nitrogen, means within a row followed by a different letter differ significantly at P < 0.10.

all sites highlights the rapid movement of applied N into soil, plant, or microbial pools in these unthinned mid-rotation stands.

The fate of the applied N was unclear. By the end of the growing season, none of the measured N pools were significantly greater on the fertilized plots than on the unfertilized plots (fig. 2). The N fertilization rate was relatively low within the context of the total N budget for these sites. Furthermore, pine root biomass N was not quantified, and the methods for understory biomass N were not site-specific. Refinement of measurement procedures may detect more N in subsequent years of this study. The lack of differences in total pine biomass N was partially attributable to the variation in tree density inherent to unthinned mid-rotation stands. Interestingly, although the understory vegetation biomass contained relatively little N, the presence of understory vegetation significantly impeded increases in foliage N concentrations at the Oakdale and Dodson sites. N<sub>mic</sub> was unaffected by fertilization and understory control through the end of the growing season, which may indicate that the treatments did not substantially affect soil C and N dynamics. More N was present in the N<sub>mic</sub> pool than in the extractable N pool at the Oakdale, Dodson, and DeRidder sites, which may indicate that NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup> availability in mid-rotation stands could be increased by practices that promote release of N from this pool.

## CONCLUSIONS

Although insufficient time has elapsed since fertilization to assess pine growth responses to fertilization, this study's early results provide some information about the stand and soil conditions that influence the effectiveness of fertilizing unthinned mid-rotation loblolly pine plantations. When reducing N and P fertilization rates to a level 25 percent lower than conventional rates, understory biomass suppression was necessary to promote pine uptake of applied N at sites that had no history of herbicide treatment. The beneficial impact of understory suppression in conjunction with fertilization was most pronounced on the well-drained Lucky site. The significant gains in foliage N concentrations seen in this phase of the study may impart growth benefits to these stands after thinning, but the variable density of unthinned stands may cause high variability in stand growth responses to fertilization. This study will continue to monitor pine, understory, and microbial biomass and nutrient and growth dynamics to understand such trends should they occur.

## ACKNOWLEDGMENTS

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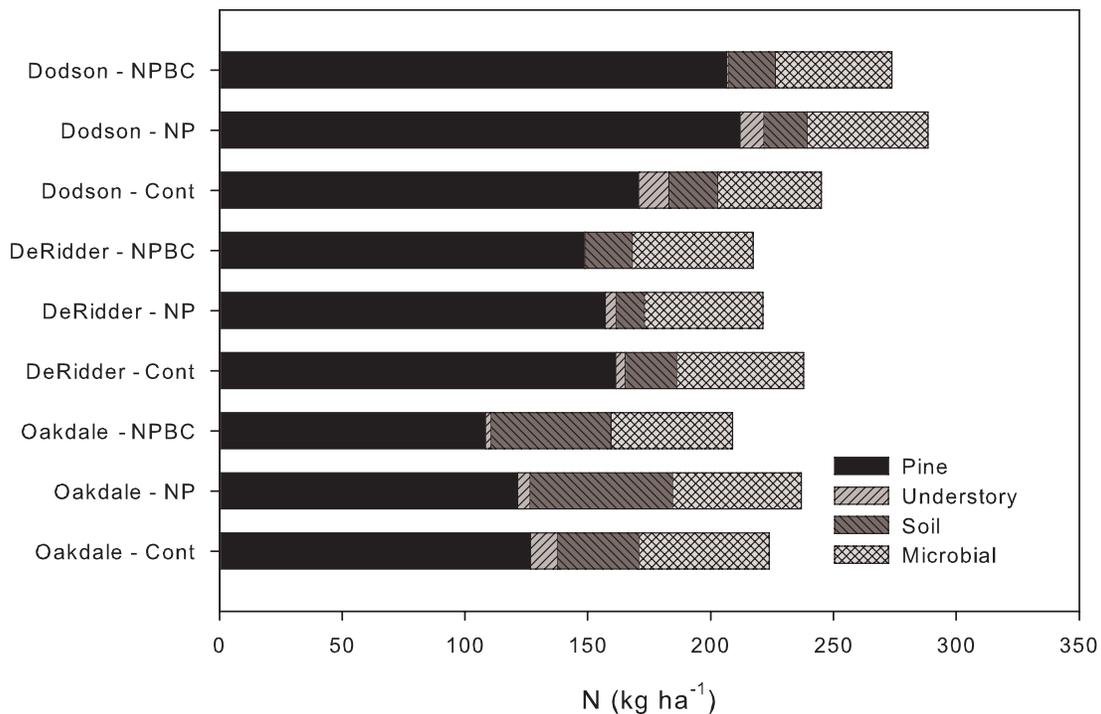


Figure 2—Total nitrogen contents of aboveground loblolly pine biomass, aboveground understory biomass, microbial biomass, and extractable nitrogen at four study sites (identified by nearest town) in north, central, and southwestern Louisiana in response to untreated control (Cont), fertilization with nitrogen and phosphorus (NP), and fertilization with nitrogen and phosphorus with triclopyr used for understory brush control (NPBC) in August-September, 2004.

## LITERATURE CITED

- Albaugh, T.J.; Allen, H.L.; Zutter, B.R. [and others]. 2003. Vegetation control and fertilization in midrotation *Pinus taeda* stands in the Southeastern United States. *Annals of Forest Science*. 60: 619-624.
- Blazier, M.A. 2003. Nutrient dynamics of the soil/plant/microbial system of a young loblolly pine plantation: effects of fertilizer date of application and formulation. Stillwater, OK: Oklahoma State University. 199 p. Ph.D. dissertation.
- Blazier, M.A.; Hennessey, T.C.; Lynch, T.B. [and others]. 2002. Comparison of branch biomass relationships for North Carolina and Oklahoma/Arkansas loblolly pine seed sources growing in southeastern Oklahoma. *Forest Ecology and Management*. 159: 241-248.
- Carlson, R.M. 1978. Automated separation and conductimetric determination of ammonia and dissolved carbon dioxide. *Analytical Chemistry*. 50: 1528-1531.
- Carlson, R.M.; Cabrera, J.L.; Paul, J. [and others]. 1990. Rapid direct determination of ammonium and nitrate in soil and plant tissue extracts. *Communications in Soil Science and Plant Analysis*. 21: 1519-1529.
- Dickens, E.D.; Moorhead, D.J.; McElvany, B. 2003. Pine plantation fertilization. *Better Crops*. 87: 12-15.
- Horwath, W.R.; Paul, E.A. 1994. Microbial biomass. In: Weaver, R.W.; Angle, J.S.; Bottomley, P.S. *Methods of soil analysis. Part 2. Microbiological and biochemical properties*. Soil science society of America book series 5. Madison, WI: Soil Science Society of America, Inc.: 757-760.
- Jokela, E.J.; Dougherty, P.M.; Martin, T.A. 2004. Production dynamics of intensively managed loblolly pine stands in the Southern United States: a synthesis of seven long-term experiments. *Forest Ecology and Management*. 192: 117-130.
- Mulvaney, R.L. 1996. Nitrogen—inorganic forms. In: Sparks, D.L. *Methods of soil analysis. Part 3. Chemical methods*. Soil science society of America book series 5. Madison, WI: Soil Science Society of America, Inc.: 1129-1131.
- Neter, J.; Kutner, M.H.; Nachtsheim, C.J. [and others]. 1996. Building the regression model II: Diagnostics. In: *Applied linear regression models*. 3<sup>rd</sup> ed. Chicago, IL: Irwin Publishers: 361-400.
- North Carolina Forest Nutrition Cooperative (NCSFNC). 2002. Operational fertilization. 31<sup>st</sup> Annual Report. North Carolina state forest nutrition cooperative. Raleigh, NC: North Carolina State University, Department of Forestry. 21 p.
- Powers, R.F.; Reynolds, P.E. 1999. Ten-year responses of ponderosa pine plantations to repeated vegetation and nutrient control along an environmental gradient. *Canadian Journal of Forest Research*. 29: 1027-1038.
- Shen, S.M.; Pruden, G.; Jenkinson, D.S. 1984. Mineralization and immobilization of nitrogen in fumigated soil and the measurement of microbial biomass nitrogen. *Soil Biology and Biochemistry*. 16: 437-444.
- Stagg, R.H.; Scott, D.A. 2006. Understory growth and composition resulting from soil disturbances on the long-term soil productivity study sites (LTSP) in Mississippi. In: Connor, K.F., ed. *Proceedings of the thirteenth biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 52-56.

# EFFECTS OF APPLICATION OF MILL-GENERATED PRIMARY SLUDGE AND BOILER ASH ON LOBLOLLY PINE SURVIVAL AND GROWTH

Emily J. Goodwin and Andrew M. Burrow<sup>1</sup>

**Abstract**—Use of Kraft primary sludge and boiler ash in forest production systems holds promise as a cost-effective alternative to landfilling. From a soil quality perspective, particularly in coarse-textured sandy soils, increases in organic matter content from inputs of sludge/ash may improve soil chemical, biological, and physical properties. The objective of this study was to determine the impacts of a single application of sludge/ash at site preparation on loblolly pine (*Pinus taeda* L.) survival and growth. In the summer of 2002, a 2:1 sludge/ash mixture from a Kraft mill was mixed into beds during site preparation at three levels: 0, 39, and 77 tons per acre. Loblolly pine was planted in February 2004, followed by N fertilization at two levels (0 and 125 pounds per acre) in May. First-year measurements of survival (SURV), ground line diameter (GLD), total height (HT), and height to live crown (HTLC) were taken in February 2004. HT and HTLC were used to calculate vertical crown length (VCL). All sludge/ash treated plots showed greater HT and VCL than control (CTL) plots. Results showed greater HT and VCL in trees receiving 39 tons per acre with no fertilization and those receiving 77 tons per acre with fertilization. GLD was significantly greater for trees receiving 77 tons per acre with fertilization. Second year results show similar results for HT but not for VCL or GLD. VCL showed less stratification by the second year, and GLD had no significant differences. There was no difference in SURV between treatments for either year. The sludge/ash mixture showed HT growth benefit. Operational costs are somewhat prohibitive without more efficient methods of transport and application.

## INTRODUCTION

The pulp and paper industry generates millions of tons of by-products in the manufacturing process. Most by-product solids are disposed of in costly private landfills or are incinerated. Land application accounts for a small fraction of by-product use but has the potential to be extremely beneficial for the mill and the forest landowner.

During the pulping process, wastewater is generated and treated to remove solids and dissolved organic material. The material left is referred to as wastewater treatment plant (WTP) residuals or mill sludge. Primary WTP residuals contain mainly wood fibers, which are derived from the clarification of raw effluent. Consequently, they have high carbon (C) content; this can pose a problem when land-applied because of the low nitrogen (N) concentrations of the material (Buckman and Brady 1969). Severe N-deficiencies can occur as microorganisms take up available soil N to balance their internal C:N ratio with a high external one (Pritchett 1979).

Secondary WTP residuals undergo a process in which N and phosphorous (P) are added to stimulate naturally occurring microorganisms. These microorganisms consume the remaining dissolved organic constituents, mainly lignin and other wood-based molecules. Secondary residuals may be more beneficial to trees and crops because of the added nutrients. When secondary sludge is land-applied, N and P rates must be monitored closely to protect water quality.

Boiler ash is a by-product of the incineration of wood and other fuels for energy. Ash is generally high in P and possibly potassium and is often used as a lime substitute in agricultural applications. Calcium and magnesium concentrations in the ash may also benefit nutrient-deficient sites. Ash may increase soil pH causing greater volatilization of N (NCASI 2003a).

All of these materials, as organic matter, may improve the physical properties of forest soils, particularly on sandy sites.

Additions of organic matter may influence the cation exchange capacity and the stability of soil aggregates (Buckman and Brady 1969). Water-holding capacity of a soil may also be improved (NCASI 2000, Pritchett 1979). Since tree roots take up nutrients in solution, increasing water-holding capacity may enhance nutrient availability. Incorporating the residuals into the soil may increase decomposition rate and reduce erosion of the material off the site (NCASI 2000).

Benefits of mill sludge and ash must be tempered with environmental concerns. Much of this material is considered non-hazardous; however, levels of metals and dioxins have been controversial. Land application is regulated at the state level under laws regarding municipal sewage biosolids. Metals in WTP residuals are mainly derived from residual wood fiber and are relatively low in concentration when compared to municipal sewage biosolids. Lower metal concentrations in inks and processing chemicals have decreased the residual concentration of metals in recent years. Additionally, the last decade has seen dramatically reduced dioxin concentrations with the substitution of chlorine dioxide for chlorine in pulp bleaching. WTP residuals at mills may have accumulated for a number of years, so material stored before 1990 may have higher levels; however, these are still generally far lower than municipal sewage biosolids (NCASI 2000). Careful scrutiny of material is important to developing a land application program. Best Management Practices should also be applied for protection of water systems and environmentally sensitive areas.

Past studies have shown mixed results in improving survival and growth through the use of WTP residuals and ash on pine species. Georgia-Pacific applied a mixture of primary and secondary sludge (13.4 tons per acre) and ash (12.5 tons per acre). The study found an increase in loblolly pine (*Pinus taeda* L.) height when compared to a control but a decrease in survival, most likely due to increased weed competition. Another test found ash rates as high as 50 tons per acre had

<sup>1</sup> Research Forester and Research Forester, respectively, Temple-Inland Forest Products Corporation, Diboll, TX 75941.

positive growth effects. A Weyerhaeuser study showed a 15 percent growth increase with 12.5 tons per acre of ash on a P-deficient site. Jefferson-Smurfit examined slash pine (*Pinus elliotii* Engelm.) growth with WTP residual additions. A 6-inch layer of residuals incorporated into the soil prior to planting caused severe seedling mortality (>90 percent) presumably due to inadequate mineral soil contact with seedling root systems (NCASI 2000).

## METHODS

The study site is located in Hardin County, TX (30° 19' N, 94° 12' W). Soils on the study site are deep, well-drained sands that are Fluvis in nature. Flooding occurs regularly from a nearby creek. This site was chosen because of its deep sands, its proximity to a mill, and its ability to represent a characteristic site in southeast Texas.

A 2:1 mixture of sludge/ash was applied at three levels (0, 39, and 77 tons per acre) to three replicates across the study site. This in combination with two levels of fertilization and a control comprised four treatments:

- (1) 39 tons per acre with no fertilization (39N)
- (2) 39 tons per acre with fertilization (39F)
- (3) 77 tons per acre with no fertilization (77N)
- (4) 77 tons per acre with fertilization (77F)
- (5) control with normal silviculture (CTL)

The original study design called for 31 (3 truckloads) and 62 (6 truckloads) tons per acre. Available equipment dictated that the material be applied in strips and not broadcast over the entire acre. This change increased the effective treatment rate that each individual tree experienced to 39 and 77 tons per acre.

The 2:1 sludge/ash mixture was premixed and delivered in trucks averaging 10.3 tons per truck. A total of 72 truckloads were utilized. Average hauling cost per truckload was \$112, totaling \$8,087 for the 12 acres that were treated. A three-pass system using a shear, a manure spreader, and a Savannah plow was utilized to distribute the sludge/ash mixture: (1) A path was sheared, (2) the mixture was spread, and (3) the mixture was incorporated into a bed. Application costs were \$691 per acre. Each treatment was applied across 1 acre in each of the three replicates in the summer of 2002. Loblolly pine seedlings were planted in February 2003, with urea fertilization (125 pounds per acre) following in May 2003.

Every 1-acre treatment plot was subsampled by 8 15-tree-space subplots. All trees within each subplot were labeled to track individual growth and survival (SURV) over time. Tree spaces were used to construct subplots to better represent the actual area each tree occupied. Plot level measurements of SURV were calculated from the average of the eight subplots. Individual tree measurements of total height (HT), height to live crown (HTLC), and ground line diameter (GLD) were taken on each seedling. Vertical crown length (VCL) was calculated for each tree by subtracting HTLC from HT. HTLC was defined as the height to the first live whorl of two or more branches.

The experimental design for HT, GLD, and VCL is a replicated random design with nested subsamples. The linear mixed model,

$$y_{ijkl} = \mu + A_i + B_j + [AB]_{ij} + C_{k(ij)} + e_{l(ijk)} \quad (1)$$

where

$i = 1$  to 3 (replications),

$j = 1$  to 5 (treatments),

$k = 1$  to 8 (subplots), and

$l = 1$  to 15 (trees),

includes random terms for replication ( $A$ ), replication/treatment interaction ( $AB$ ), subplots ( $C$ ), and a fixed term for treatments ( $B$ ). The individual tree measurements comprise the error term ( $e$ ).

The experimental design for SURV is a replicated random design. The linear mixed model,

$$y_{ijk} = \mu + A_i + B_j + [AB]_{ij} + e_{k(ij)} \quad (2)$$

where

$i = 1$  to 3 (replications),

$j = 1$  to 5 (treatments), and

$k = 1$  to 8 (subplots),

includes random terms for replication ( $A$ ) and replication/treatment interaction ( $AB$ ), and a fixed term for treatments ( $B$ ). The subplot level measurements of SURV comprise the error term ( $e$ ).

Year 1 and year 2 measurements of HT, HTLC, and GLD were taken in February 2004 and 2005, respectively. SURV for each year was assessed as the percentage of live trees in each subplot.

## RESULTS AND DISCUSSION

The main objective of this study was to determine if 39 or 77 tons per acre of a sludge/ash mixture could be applied without detriment to the crop trees. With this in mind, it must be noted that although significant differences were found between treatments, the magnitude between growth responses may be considered minimal. Table 1 summarizes results for HT, GLD, VCL, and SURV.

### Total Height Comparisons

All sludge/ash treated plots yielded greater HT growth than the CTL for both the first and second years with best HT growth from 77F. For year 1, all treatments were significantly > the CTL, and 39N and 77F were significantly > 39F and 77N. For year 2, 77F was significantly > all other treatments; 39N, 39F, and 77N comprised a second homogeneous group, with 39N and 39F showing significant difference from the CTL. There was no change in the HT growth pattern between treatments from year 1 to year 2.

Interactions between the P in the sludge/ash mixture and N fertilization are apparent in the HT growth comparisons. At 39 tons per acre, N fertilization showed a decrease in HT growth. At this rate, P supplied by the sludge/ash may not be sufficient to allow full utilization of available N. Also, N fertilization often results in an increase in leaf area (Colbert and others 1990, Jokela and Martin 2000, Kozlowski and Pallardy 1997, Samuelson 1998, Vose and Allen 1988) and reduced allocation to fine root production (Albaugh and others 1998,

**Table 1—First and second year total height, ground line diameter, vertical crown length, and survival for each treatment**

Variable	Year	39N	39F	77N	77F	CTL
TH <sup>a</sup> (feet)	1	2.02a	1.88b	1.84b	2.07a	1.69c
	2	5.51AB	5.42AB	5.06BC	5.77A	4.87C
GLD (inches)	1	0.459ab	0.433b	0.443ab	0.470a	0.460ab
	2	1.23A	1.44A	1.13A	1.27A	1.12A
VCL (feet)	1	1.42ab	1.34b	1.32b	1.48a	1.16c
	2	4.55A	4.35A	4.23AB	4.64A	3.70B
SURV (percent)	1	97.1ab	98.3ab	98.9a	94.6b	97.8ab
	2	96.8AB	98.2AB	98.9A	94.6B	97.8AB

<sup>a</sup> Lowercase letters represent homogenous groups ( $\alpha=0.05$ ) within each variable for year 1; capital letters represent homogenous groups ( $\alpha=0.05$ ) within each variable for year 2.

Samuelson 2000). Greater maintenance respiration of these N fertilized trees may have caused greater water stress during the growing season, especially on this sandy, bedded site. Additionally, research has shown greater relative declines for photosynthesis and stomatal conductance at high N levels than at low N levels for trees experiencing water stress (Kozlowski and Pallardy 1997, Walters and Reich 1989).

At 77 tons per acre, N fertilization showed an increase in HT growth. Differences in response at this level of sludge/ash may be caused by an N deficiency. The sludge/ash mixture had a C:N ratio of 10,000:1, far above normal levels of 200:1 to 300:1 (NCASI 2003b) and recommended levels of 20:1 to 30:1 (NCASI 2000). Soil microorganisms immobilize inorganic N from the soil matrix to offset the imbalance between their internal C:N ratio and the external one affected by the sludge/ash mixture.

N may have been lost due to significant volatilization caused by the alkaline nature of the ash. Urea also raises the pH of the soil creating greater potential for loss of N. Although timing of the treatments were staggered with sludge/ash application taking place the season before the urea application, this high level of sludge/ash may have caused more alkaline conditions.

### Ground Line Diameter Comparisons

Although year 1 measurements yielded significant differences in GLD, the differences are  $\leq 0.01$  inches, a level that would scarcely impact overall seedling volume growth. It is more likely that the differences are a product of minute variations in average seedling size at planting than any real differences in treatments. Unfortunately, year 0 measurements were not taken to validate this theory.

Year 2 measurements of GLD yielded no significant differences. Excluding an inexplicable shift in 39F, GLD growth patterns were fairly stable from year 1 to year 2.

### Vertical Crown Length Comparisons

Significant differences were found for VCL between treatments for both year 1 and year 2, but again the magnitude was rather small. For both years, differences between the greatest and least VCL were only 10 to 20 percent of HT for those treatments. Comparative growth patterns for both years were unchanged. The relationship between HT and HTLC controls VCL. Trees with greater HT tended to have greater HTLC,

possibly due to a reallocation of resources to the top of the tree.

### Survival Comparisons

An arcsin square root transformation was employed to approximate normality for the percentage response variable. Patterns in SURV were similar from year 1 to year 2. None of the treatments were significantly different from the CTL, and all survival rates were above 94 percent. Interestingly enough, the only difference in treatments lie between 77N, which had the highest survival, and 77F, which had the lowest survival. Survival rates for slower-growing trees could possibly be > faster-growing trees.

### CONCLUSIONS

Growth responses over the CTL are predominantly responses to the P supplied by the sludge/ash mixture. Interactions with the N fertilization may increase or decrease the P growth response as more N supplied lowers the C:N ratio. At 39 tons per acre, N fertilization may not be beneficial. At 77 tons per acre, P may not be limiting, so N fertilization may improve growth. At either level, survival was not adversely affected.

Well-drained sandy sites that may flood frequently typically have too much water during the wet season and too little water during the dry season. Bedding helps to control water during the wet months, but during droughty periods, beds may cause excessive drainage resulting in low survival and growth. Sludge/ash amendments incorporated into the beds may increase the water holding capacity, thus increasing survival and growth.

Currently, the high cost of transport and application may be the greatest limitation for sludge/ash application at an operational scale. Refinement of the application technique and strategic selection of near-to-mill sites could help to lower the cost. However, if stockpiling of sludge or ash receives stricter regulations or if the mill runs out of landfill space, higher associated costs may transform the tasks of transport and application into cost-effective ones.

### LITERATURE CITED

Albaugh, T.J.; Allen, H.L.; Dougherty, P.M. [and others]. 1998. Leaf area and above- and belowground growth responses of loblolly pine to nutrient and water additions. *Forest Science*. 44: 317-328.

- Buckman, H.O.; Brady, N.C. 1969. The nature and properties of soils. London: The MacMillan Company. 653 p.
- Colbert, S.R.; Jokela, E.J.; Neary, D.G. 1990. Effects of annual fertilization and sustained weed control on dry matter partitioning, leaf area, and growth efficiency of juvenile loblolly and slash pine. *Forest Science*. 36: 995-1014.
- Jokela, E.J.; Martin, T.A. 2000. Effects of ontogeny and soil nutrient supply on production, allocation, and leaf area efficiency in loblolly and slash pine stands. *Canadian Journal of Forest Research*. 30: 1511-1524.
- Kozlowski, T.T.; Pallardy, S.G. 1997. *Physiology of woody plants*. San Diego, CA: Academic Press. 411 p.
- National Council for Air and Stream Improvement (NCASI). 2000. Utilizing paper mill by-products as forest soil amendments: forest responses, recommendations, and industry case studies. Technical Bulletin No. 798. Research Triangle Park, NC: National Council for Air and Stream Improvement. 31 p.
- National Council for Air and Stream Improvement (NCASI). 2003a. Planning guide and state regulation summary for land application of mill by-product solids. Technical Bulletin No. 863. Research Triangle Park, NC: National Council for Air and Stream Improvement. 22 p.
- National Council for Air and Stream Improvement (NCASI). 2003b. Land application of forest industry mill by-product solids. Research Brief No. 9. Research Triangle Park, NC: National Council for Air and Stream Improvement. 8 p.
- Pritchett, W.L. 1979. *Properties and management of forest soils*. New York, NY: John Wiley & Sons. 500 p.
- Samuelson, L.J. 1998. Influence of intensive culture on leaf net photosynthesis and growth of sweetgum and loblolly pine seedlings. *Forest Science*. 44: 308-316.
- Samuelson, L.J. 2000. Effects of nitrogen on leaf physiology and growth of different families of loblolly and slash pine. *New Forests*. 19: 98-107.
- Vose, J.M.; Allen, H.L. 1988. Leaf area, stemwood growth, and nutrition relationships in loblolly pine. *Forest Science*. 34: 547-563.
- Walters, M.B.; Reich, P.B. 1989. Response of *Ulmus americana* seedlings to varying nitrogen and water status. I. Photosynthesis and growth. *Tree Physiology*. 5: 159-172.

# GROWTH OF PRECOMMERCIALY THINNED LOBLOLLY PINE 4 YEARS FOLLOWING APPLICATION OF POULTRY LITTER

Scott D. Roberts, Alex L. Friend, and Stephen H. Schoenholtz<sup>1</sup>

**Abstract**—Application of poultry litter to southern pine stands represents a potentially attractive litter disposal option. Many pine stands are nutrient-limited and might respond positively to the added nutrients. However, the ability of pine stands to respond to nutrients contained in the litter, as well as contain the nutrients on site, has not been thoroughly investigated. We applied poultry litter to a recently-thinned 8-year-old loblolly pine (*Pinus taeda* L.) stand at 0, 5.6, and 23 Mg ha<sup>-1</sup> (dry-weight basis), supplying 0, 200, and 800 kg N ha<sup>-1</sup>. Growth was tracked for four growing seasons following application. Average height growth was generally unaffected by treatments over the 4-year period. Diameter, basal area, and total cubic volume increments were all elevated by the litter application over the first three growing seasons, but annual increments in all treatments dropped substantially in year 4. Total basal area and standing volume at end of year 4 were significantly greater in the N<sub>200</sub> and N<sub>800</sub> treatments.

## INTRODUCTION

Disposal of waste materials generated in confined animal feeding operations is becoming an increasing problem. In the Southeastern United States, poultry production is one of the region's major agricultural activities, raising nearly 6.6 billion broiler chickens annually with a production value of over \$11.7 billion (U.S. Department of Agriculture 2004). Production is concentrated in densely populated chicken houses, resulting in large amounts of litter. In 1998, an estimated 12 million mt of poultry litter was produced nationally (Endale and others 2002).

Historically, the primary disposal mechanism for litter generated in poultry production has been application to pastureland as an organic fertilizer (Endale and others 2002, Sauer and others 1999). Years of repeated applications, however, have elevated soil nutrient levels, particularly phosphorus, to the point of concern over potential effects of nutrient-rich runoff on water quality (Sauer and others 1999, Sims and Wolf 1994).

An alternative to pasture application could be the abundant pine forests of the South (Beem and others 1998, Roberts and others 2004, Samuelson and others 1999). Many southern pine stands are nutrient-limited and respond positively to added nutrients (Allen and others 1990). However, the ability of pine stands to contain the nutrients added in poultry litter and respond to those nutrients with added growth has not been investigated thoroughly.

This study was initiated to investigate (1) the ability of pine stands to contain nutrients applied in poultry litter on the site, and (2) the ability of trees to respond to the nutrients contained in the poultry litter. This paper reports on the growth over four seasons following poultry litter application to a precommercially-thinned 9-year-old loblolly pine (*Pinus taeda* L.) stand in central Mississippi.

## METHODS

The study was located in Newton County, MS, on the Mississippi State University Coastal Plain Branch Experiment

Station (32°20'N, 89°04'W). Average annual daily high and low temperatures at the site are approximately 24 °C and 11 °C, respectively. Average annual precipitation is approximately 1,400 mm. Soils on the study site are a fine sandy loam in the Shubuta Series, classified as a fine, mixed, thermic Typic Paleudults. Treatments were implemented in an 8-year-old loblolly pine stand that initiated as a plantation following clearcut harvest but, due to heavy natural regeneration, contained over 4,000 trees ha<sup>-1</sup> (table 1).

Nine 20-m x 20-m treatment plots were established and thinned to a basal area of approximately 11 m<sup>2</sup> ha<sup>-1</sup>. Within each treatment plot, a 10-m x 10-m measurement plot was established containing between 27 and 56 trees. In March, 2000, poultry litter in the form of stock-piled cake collected from a local broiler operation near Newton, MS, was applied to the plots. At the time of application, litter moisture content was 21 percent. The elemental composition of the litter on a dry-weight basis was 380 g kg<sup>-1</sup> C, 43 g kg<sup>-1</sup> N, 20 g kg<sup>-1</sup> P, 32 g kg<sup>-1</sup> K, 28 g kg<sup>-1</sup> Ca, 7 g kg<sup>-1</sup> Mg, 6 g kg<sup>-1</sup> S, 590 mg kg<sup>-1</sup> Zn, 60 mg kg<sup>-1</sup> B, 680 mg kg<sup>-1</sup> Mn, 987 mg kg<sup>-1</sup> Fe, and 969 mg kg<sup>-1</sup> Cu. Beginning in May, 2000, understory vegetation was controlled annually with herbicides.

**Table 1—Pretreatment stand conditions for each of three poultry litter application treatments. No significant treatment differences existed between any of the variables**

	Treatment		
	N <sub>0</sub>	N <sub>200</sub>	N <sub>800</sub>
Stem density (trees ha <sup>-1</sup> )	4,267	4,067	3,433
Reineke's stand density index	397	394	391
Mean height (m)	6.4	6.6	7.0
Quadratic mean diameter (cm)	5.9	6.2	6.7
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	11.3	11.4	11.7
Total cubic volume (m <sup>3</sup> ha <sup>-1</sup> )	24.6	26.5	29.1

<sup>1</sup> Associate Professor, Mississippi State University, Department of Forestry, Starkville, MS 39762; Research Scientist, USDA Forest Service, North Central Research Station, Houghton, MI 49931; and Professor, Oregon State University, Department of Forest Engineering, Corvallis, OR 97331, respectively.

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Litter was applied at three treatment rates to three plots per treatment in a completely randomized design. The three treatment rates were 0 Mg ha<sup>-1</sup> (N<sub>0</sub> = Control), 5.6 Mg ha<sup>-1</sup> (N<sub>200</sub>), and 23 Mg ha<sup>-1</sup> (N<sub>800</sub>). Application rates were based on the N assay of the litter to supply approximately 0, 200, and 800 kg N ha<sup>-1</sup>, respectively. The N<sub>200</sub> treatment was designed to add N at approximately the same rate as would typically be applied in an operational commercial fertilization. This resulted in adding approximately 2 to 3 times more P than would typically be applied operationally. The three treatments resulted in P applications of approximately 0, 92, and 370 kg ha<sup>-1</sup>.

Trees on each measurement plot were measured pretreatment, and bi-monthly thereafter, for stem diameter at breast height (d.b.h., 1.37 m) and total height. Basal area (m<sup>2</sup>) was calculated for each tree. Total volume inside bark (m<sup>3</sup>) was computed using the equation of Baldwin and Feduccia (1987) for thinned loblolly pine stands.

Analysis of variance using a general linear models procedure was used to test for treatment differences in annual plot mean tree increments for height and diameter, and annual increments in plot-level basal area and total cubic stem volume. Also tested for after 4 years were treatment differences in plot mean tree size, basal area, and volume. Determinations of significant treatment differences were made using Tukey's LSD test with a critical value of  $\alpha=0.05$ .

## RESULTS

Annual height increments did not differ among treatments during the first 3 years following treatment (fig. 1a). In year 4, height growth of all three treatments differed, with treatment N<sub>800</sub> having the greatest height increment and N<sub>0</sub> having the lowest increment. Height increments in year 4, however, only ranged from 0.2 to 0.4 m, compared to increments of 0.7 to 1.0 m in the previous years. The cumulative height increment over the 4-year period following treatment did not differ by treatment. Average height after year 4 also did not differ by treatment (table 2, fig. 2a).

Average annual diameter growth in each of the two growing seasons following treatment was greater on the plots receiving litter than on the N<sub>0</sub> plots (fig. 1b). Diameter increment did not differ between the N<sub>800</sub> and N<sub>200</sub> treatments over the first 2 years. In year 3, diameter growth on the N<sub>800</sub> plots remained significantly higher than both the N<sub>200</sub> and N<sub>0</sub> plots. In year 4, there were no significant treatment differences in diameter increment. Over the entire 4-year period, diameter growth on the N<sub>800</sub> and N<sub>200</sub> plots was higher than on the N<sub>0</sub> plots. Total 4-year diameter increments were: N<sub>800</sub> = 4.3 cm, N<sub>200</sub> = 3.8 cm, and N<sub>0</sub> = 2.6 cm. Despite significant treatment differences in annual diameter increments, there were no significant treatment differences in quadratic mean diameter at the end of 4 years (table 2, fig. 2b), even though quadratic mean diameter on the N<sub>800</sub> plots (11.0 cm) was, on average, 1.0 cm

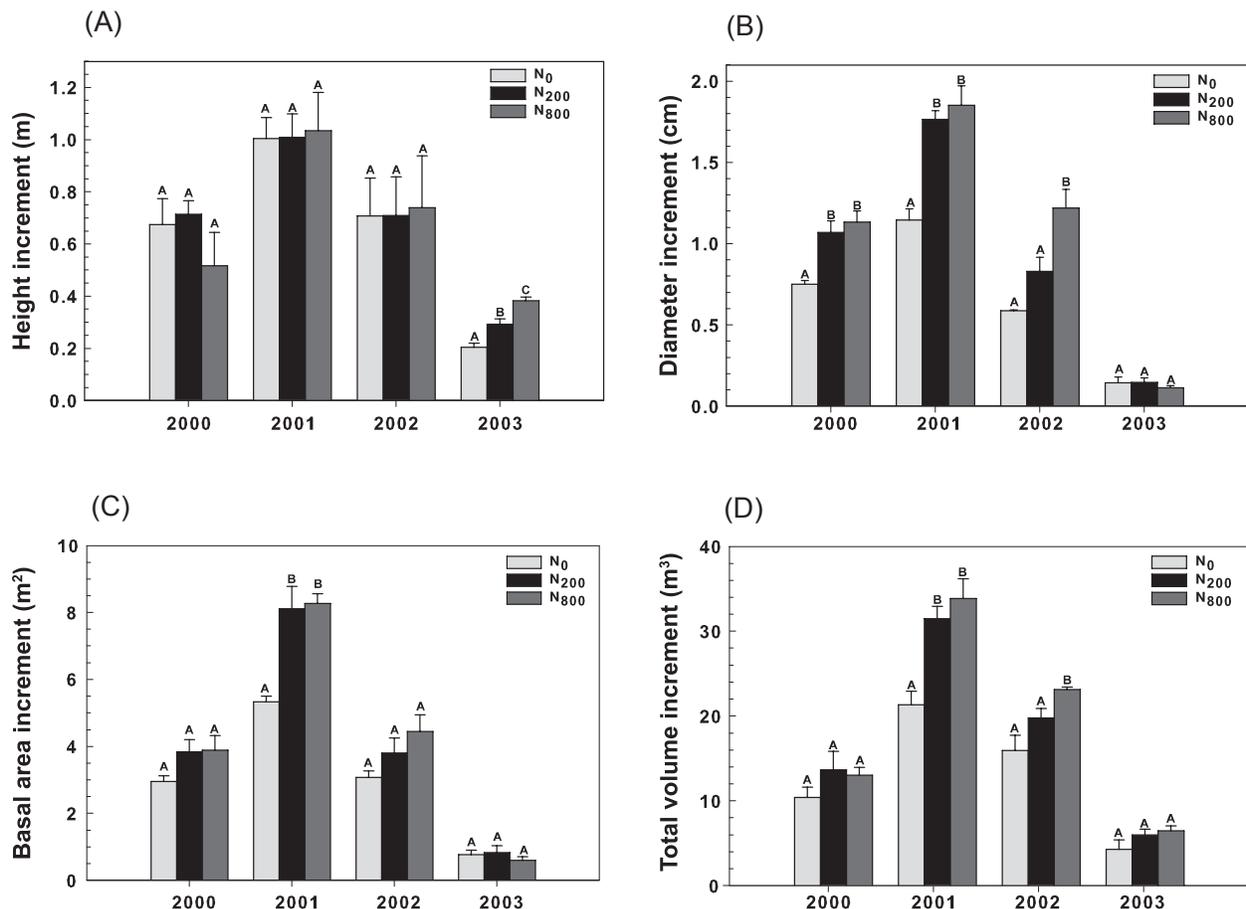


Figure 1—Annual growth increments in (A) mean height, (B) mean diameter, (C) basal area per hectare, and (D) total cubic volume per hectare. Similar letters among treatments within a given year indicate no significant treatment effect according to Tukey's LSD test ( $\alpha = 0.05$ ).

**Table 2—Stand conditions for each of three poultry litter treatments 4 years following application. Similar letters or no letters among treatments indicate no significant treatment effects according to Tukey’s LSD test ( $\alpha = 0.05$ )**

	Treatment		
	N <sub>0</sub>	N <sub>200</sub>	N <sub>800</sub>
Stem density ( <i>trees ha<sup>-1</sup></i> )	4,233	3,733	3,133
Reineke’s stand density index	717	809	803
Mean height ( <i>m</i> )	9.0	9.3	9.7
Quadratic mean diameter ( <i>cm</i> )	8.6	10.0	11.0
Basal area ( <i>m<sup>2</sup> ha<sup>-1</sup></i> )	23.5a	28.0b	28.9b
Total cubic volume ( <i>m<sup>3</sup> ha<sup>-1</sup></i> )	76.5a	97.4a	105.6b

greater than on the N<sub>200</sub> plots (10.0 cm) and 2.4 cm greater than on the N<sub>0</sub> plots.

There were no significant treatment differences in annual basal area increment in the first year following litter application (fig. 1c), nor were there significant differences in years 3 and 4. Year 2 was the only year in which treatment differences occurred, with N<sub>800</sub> and N<sub>200</sub> both significantly greater than N<sub>0</sub> but not different from each other. Over the 4-year period following treatment, the average cumulative basal area increments on the N<sub>800</sub> plots (17.2 m<sup>2</sup> ha<sup>-1</sup>) and N<sub>200</sub> plots (16.6 m<sup>2</sup> ha<sup>-1</sup>)

were significantly greater than on the N<sub>0</sub> plots (12.1 m<sup>2</sup> ha<sup>-1</sup>). Total basal area at the end of year 4 on the N<sub>800</sub> plots (28.6 m<sup>2</sup> ha<sup>-1</sup>) and N<sub>200</sub> plots (28.0 m<sup>2</sup> ha<sup>-1</sup>) were significantly greater than on the N<sub>0</sub> plots (23.5 m<sup>2</sup> ha<sup>-1</sup>) (table 2, fig. 2c).

Volume increments did not differ among treatments in the first year following litter application (fig. 1d). In year 2, average volume growth on both the N<sub>800</sub> and N<sub>200</sub> treatments was significantly greater than on the N<sub>0</sub> plots. In year 3, volume growth on the N<sub>800</sub> plots remained greater than both of the other treatments. In year 4, there were once again no treatment differences in volume increment. Over the 4-year period, the cumulative volume increments on the N<sub>800</sub> (76.5 m<sup>3</sup> ha<sup>-1</sup>) and N<sub>200</sub> (70.9 m<sup>3</sup> ha<sup>-1</sup>) plots were significantly greater than on the N<sub>0</sub> plots (51.9 m<sup>3</sup> ha<sup>-1</sup>). Total standing volume at the end of the 4-year period on the N<sub>800</sub> plots (105.6 m<sup>3</sup> ha<sup>-1</sup>) was significantly greater than on the N<sub>200</sub> (97.4 m<sup>3</sup> ha<sup>-1</sup>) and N<sub>0</sub> (76.5 m<sup>3</sup> ha<sup>-1</sup>) plots (table 2, fig. 2d).

## DISCUSSION

Tree and stand growth responded positively to the treatments. Some of this growth response was likely caused by the thinning that took place prior to application of the poultry litter, as indicated by the growth increase that occurred on the N<sub>0</sub> plots. The addition of nutrients in the litter, however, clearly had a positive effect on growth.

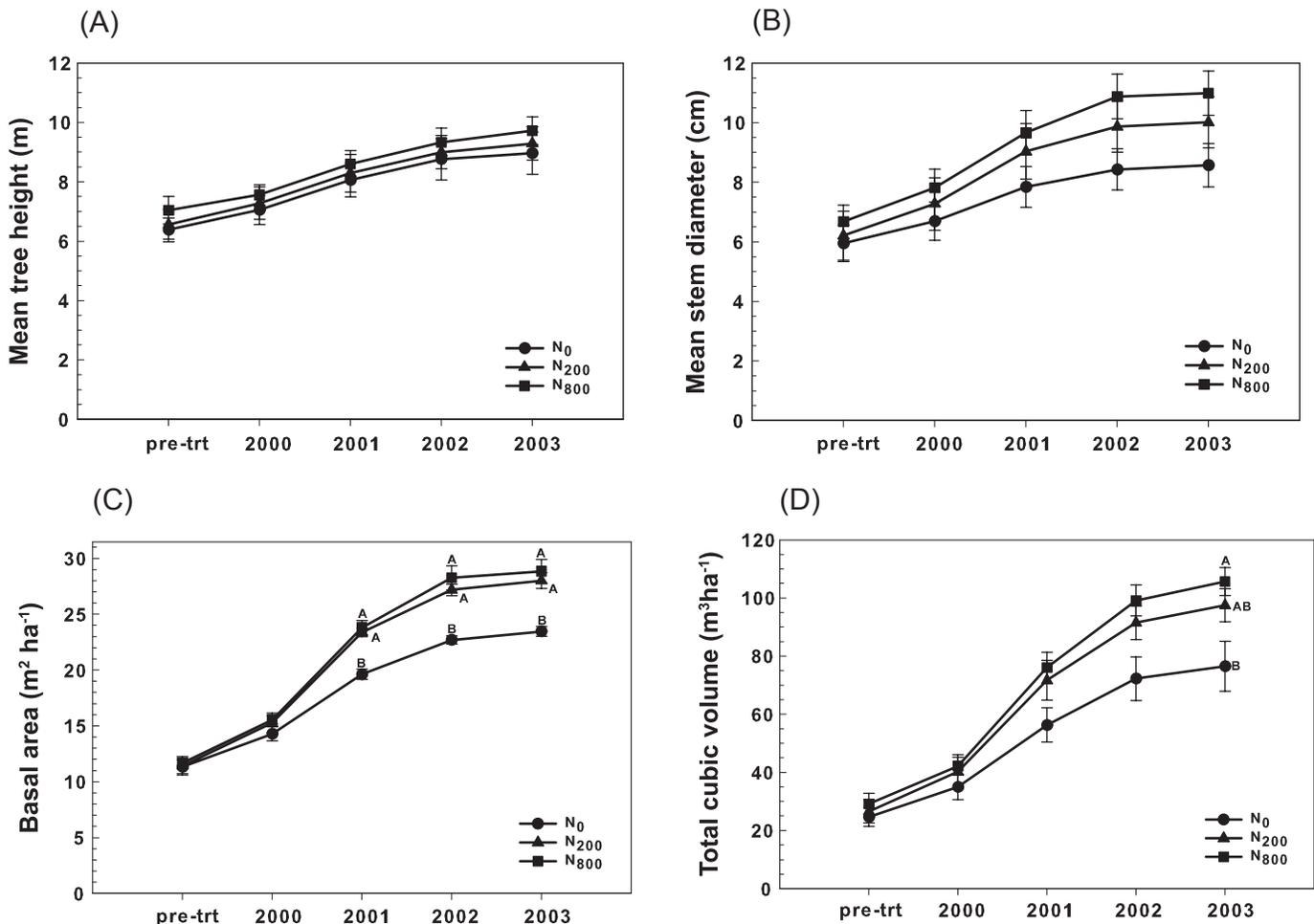


Figure 2—Change in treatment mean values for (A) height, (B) diameter, (C) basal area, and (D) total cubic volume over 4 years following poultry litter application. Similar letters or no letters among treatments indicate no significant treatment effects according to Tukey’s LSD test ( $\alpha = 0.05$ ).

A significant increase in diameter increment occurred as early as the first growing season following litter application in both the  $N_{200}$  and  $N_{800}$  treatments. The greatest growth increases, however, occurred in the second growing season where diameter, basal area, and volume increments were all greater on the treated plots than on plots not receiving litter. Diameter increments in year 2 were, on average, 54 to 61 percent higher on the treated plots. Basal area increments were 52 to 55 percent higher, and volume increments were 48 to 59 percent higher.

Treatment effects started to dissipate by the third year. Growth increments on the  $N_{200}$  treatment, while still slightly higher on average, were no longer significantly different from the  $N_0$  plots. Annual increments on the  $N_{800}$  plots remained significantly elevated for diameter and volume growth but not for basal area growth. Overall, the annual growth increments in year 3 were similar to the growth increments in year 1.

There were no significant treatment differences in year 4 for diameter, basal area, or volume increment. For some reason, however, annual height increment did show a significant treatment effect, although the differences in height increment were rather small. Growth increments of all measures showed sharp decreases in year 4, dropping to levels well below those exhibited in year 1. Some of these decreases make sense, while others are difficult to explain. The decrease in diameter growth, for example, was likely the result of all of the plots having reached relatively high levels of growing stock. Reineke's stand density index (SDI) on the  $N_0$  plots averaged nearly 64 percent of the reported maximum for loblolly pine (table 2). On the  $N_{200}$  and  $N_{800}$  plots, SDI averaged nearly 72 percent of maximum. Individual tree growth at these levels of stocking would be expected to be relatively low.

Reasons for decreases in basal area and volume increment are a bit more elusive. Although increments in basal area would be expected to decline eventually, the basal area of these stands at the end of year 4 (approximately  $28 \text{ m}^2 \text{ ha}^{-1}$  on the plots receiving litter) are not so high that increments should be greatly reduced. Total cubic volume growth, particularly in the absence of self-thinning, should remain high given the levels of growing stock on these plots. Height increment, which should be rather insensitive to stand density, also showed a sharp decline in year 4. While there were small treatment differences, the average height growth increment across all nine plots was  $< 0.3 \text{ m}$ . This is much lower than would be expected in a 12-year-old loblolly pine stand, particularly one that had recently been thinned and, in the case of the  $N_{200}$  and  $N_{800}$  plots, had added nutrients.

The sharp decrease in growth increments in year 4 cannot be explained by annual weather conditions. In 2003, precipitation at the study site was nearly 360 mm above average, much of that occurring in June and July. By comparison, the year 2000 (year 1 of the study) was the last in a series of years with below-average rainfall, and precipitation at the study site in that year was nearly 350 mm below normal.

The year 4 declines in growth increment appear to have been due to the weakening of both the thinning effect and the treatment effect. The plots were thinned to about 35 percent of maximum SDI, and they have now reached levels of growing stock where the thinning is probably no longer having

substantial effects on tree growth. Unfortunately, we do not have growth increment data pretreatment or from an unthinned control to compare with the year 4 increments.

The growth benefits of the added poultry litter appear to have been rather short-lived on these sites. By the end of the fourth growing season soil, foliar, and forest floor P levels on the treated plots remain slightly elevated, although there were few treatment differences in the levels of other nutrients (data not shown). However, while most nutrient levels were no longer elevated, results from past fertilization studies would suggest that growth responses to the added nutrients should last more than 3 years (Allen 1987, Hynynen and others 1998). Future measurements will determine whether the treatment effect in fact only lasted for 3 years or whether the year-4 declines in growth were anomalous.

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## LITERATURE CITED

- Allen, H.L. 1987. Forest fertilizers: nutrient amendment, stand productivity, and environmental impact. *Journal of Forestry*. 85(2): 37-46.
- Allen, H.L.; Dougherty, P.M.; Campbell, R.G. 1990. Manipulation of water and nutrients – practice and opportunity in southern U.S. pine forests. *Forest Ecology and Management*. 30: 437-453.
- Baldwin, V.C., Jr.; Feduccia, D.P. 1987. Loblolly pine growth and yield prediction for managed west gulf plantations. Res. Pap. SO-236. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 27 p.
- Beem, M.; Turton, D.J.; Barden, C.J.; Anderson, S. 1998. Application of poultry litter to pine forests. OSU Extension Facts F-5037. Stillwater, OK: Oklahoma Cooperative Extension Service. 4 p.
- Endale, D.M.; Cabreze, M.L.; Steiner, J.L. [and others]. 2002. Impact of conservation tillage and nutrient management on soil water and yield of cotton fertilized with poultry litter or ammonium nitrate in the Georgia Piedmont. *Soil and Tillage Research*. 66: 55-68.
- Hynynen, J.; Burkhart, H.E.; Allen, H.L. 1998. Modeling tree growth in fertilized midrotation loblolly pine plantations. *Forest Ecology and Management*. 107: 213-229.
- Roberts, S.D.; Friend, A.L.; Gerard, P.D. 2004. The effect of large applications of nutrients from organic waste on biomass allocation and allometric relations in loblolly pine. In: Connor, K.F., ed. Proceedings of 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 398-402.
- Sauer, T.J.; Daniel, T.C.; Moore, P.A., Jr. [and others] 1999. Poultry litter and grazing animal waste effects on runoff water quality. *Journal of Environmental Quality*. 28: 860-865.
- Samuelson, L.; Wilhoit, J.; Stokes, T.; Johnson, J. 1999. Influence of poultry litter fertilization on an 18-year-old loblolly pine stand. *Communications in Soil Science and Plant Analysis*. 30: 509-518.
- Sims, J.T.; Wolf, D.C. 1994. Poultry waste management: agricultural and environmental issues. *Advances in Agronomy*. 52: 1-83.
- U.S. Department of Agriculture. 2004. Poultry – production and value: 2003 summary. Pou 3-1. Washington, D.C.: National Agricultural Statistics Service. 10 p.

## **Vegetation Management**

*Moderator:*

**JIMMIE YEISER**  
Stephen F. Austin University



# TIMING OF CHOPPER HERBICIDE SITE PREPARATION RELATIVE TO BEDDING IN THE ESTABLISHMENT OF LOWER COASTAL PLAIN PINE PLANTATIONS

Dwight K. Lauer and Harold E. Quicke<sup>1</sup>

**Abstract**—The timing of Chopper® (BASF Corporation, Research Triangle Park, NC) herbicide applications before and after bedding was examined at four Lower Coastal Plain locations. Two bedding regimes, mid-season and late-season, were included at each location. Mid-season bedding occurred between May and July and late-season bedding between September and November. No post-plant herbaceous weed control treatments were included in this study series. Results indicate that many of the historical timing limitations placed on Chopper applications are not necessary. Woody vegetation control was achieved by all application dates, but lesser control was achieved by applications made when target vegetation was dormant or by applications made within 3 weeks after bedding. There was no need to allow vegetation to fully resprout after bedding to achieve control. Herbaceous control the year after treatment was better for applications made at least several weeks after mid-season bedding and applications made before late-season bedding.

## INTRODUCTION

Lower Coastal Plain sites have a diverse vegetation complex of waxy-leaved evergreen shrubs, deciduous trees, grasses, broadleaf herbs, and other herbaceous species that compete aggressively with planted pines (Miller and others 2003, Shiver and others 1990). These sites are usually bedded before planting. Bedding consists of plowing soil into a continuous raised mound to create a non-saturated condition for planted seedlings. Bedding also disturbs established woody and herbaceous vegetation. The objective of this study series was to develop management guidelines on how best to time operational applications of Chopper® (BASF Corporation, Research Triangle Park, NC) herbicide with bedding operations. These guidelines are intended to help managers improve the productivity of their forest operations.

Herbicide applications after bedding are usually made after August and after woody vegetation has resprouted on beds. This timing was developed from previous work with triclopyr and glyphosate. These herbicides depend on foliar uptake and provide better control of woody vegetation with late-season applications (Kline and others 1994, Minoque 1985). Timing may not be as critical with Chopper herbicide because it has both foliar and soil activity. However, late-season Chopper applications are favored because they are thought to improve residual control of herbaceous weeds during the first pine growing season.

Herbicide applications before bedding target developed woody plants before disturbance by the bedding plow. Guidelines for herbicide applications were to allow 4 weeks between application and bedding to allow time for the herbicide to translocate before disturbance. Herbicide timing limitations can be difficult to execute because both bedding and herbicide applications can be limited by weather conditions and contractor availability. In 2001, BASF Corporation in cooperation with private industrial timber companies initiated a regional study to investigate the need for these historical timing limitations.

## METHODS

### Study Design

The designed experiment included two bedding timings, mid-season and late-season, at each location. Timing of herbicide applications were replicated within each bedding regime with applications made as early as February and as late as November. Pre-bedding herbicide treatments were made up to the day before bedding; post-bedding treatments occurred as soon as the day of bedding. Since the primary objective was to assess the impact of Chopper site preparation treatments, no post-plant herbaceous weed control treatments were used.

### Locations and Bedding

Four locations were selected to cover a range of soil conditions and vegetation complexes. Vegetation at the two locations with sandy surface soils was dominated by gallberry [*Ilex glabra* (L.) Gray], bluestem grasses (*Andropogon* spp.), and low panicgrass (*Dichantherium* spp.). Two locations with finer-textured soils had vegetation characterized by a wider range of species, including arborescent hardwoods. Major species at the Whiteville location included red maple (*Acer rubrum* L.), sweetgum (*Liquidambar styraciflua* L.), sweetbay (*Magnolia virginiana* L.), sweet pepperbush (*Clethra alnifolia* L.), titi (*Cyrilla racemiflora* L.), fetterbush [*Lyonia lucida* (Lam.) Koch], and tall panic grasses (*Panicum* spp.). Major species at the Oakdale location included sweetgum, Chinese tallow-tree [*Sapium sebiferum* (L.) Roxb.], American beautyberry (*Callicarpa americana* L.), St. John's wort (*Hypericum cistifolium* Lam.), waxmyrtle (*Myrica cerifera* L.), sumac (*Rhus* spp.), swamp sunflower (*Helianthus angustifolius* L.), dogfennel [*Eupatorium capillifolium* (Lam.) Small], and purple Mecardonia [*Mecardonia acuminata* (Walter) Small.]. Grasses and sedges were also present at Oakdale. Redroot [*Lachnanthes caroliniana* (Lam.) Dandy], a broadleaf herb, was present on parts of both the Yulee and Whiteville locations. Blackberry (*Rubus* spp.) was present to some extent at all locations but was more common at Oakdale.

<sup>1</sup> Research Analyst, Silvics Analytic, Richmond, VA 23238; and Research Specialist, BASF Corporation, Research Triangle Park, NC 27709, respectively.

**Table 1—Bedding and planting dates for each location in 2001**

Location	Mid-season bed date	Late-season bed date
Tennille, FL	May 23	November 1
Yulee, FL	June 7	November 19
Oakdale, LA	July 25	September 27
Whiteville, NC	June 22	October 23

Each location was split with half receiving mid-season bedding and the other half receiving late-season bedding. Bedding dates were determined by contractor availability and soil moisture levels and thus differed by location. Mid-season bedding occurred between May 23 and July 25. Late-season bedding occurred between September 25 and November 19 (table 1). Pines were planted in winter following the site preparation treatments.

**Herbicide Treatments**

The herbicide treatment was 48 ounces per acre Chopper with 5 quarts per acre methylated seed oil (MSO) applied at a total mix volume of 10 gallons per acre. Garlon 4® (Dow Agrosciences) was included at 32 ounces per acre at 3 locations and 16 ounces per acre at 1 location. Herbicide treatments were applied using a backpack pole sprayer equipped with a single KLC-9 nozzle (Spraying Systems Co.). Treatment plots were 60 feet long and 2 beds wide. An untreated bed was included as buffer between treatment plots.

There were between seven and nine herbicide application timings for each bedding regime at each location. Application timings were selected so that applications were made throughout the season, with more applications occurring close to the time of bedding. Initial target dates were similar for all locations, but dates were modified as needed to accommodate environmental constraints. The most restrictive factor was high soil moisture delaying bedding.

**Assessments**

Woody and herbaceous vegetation cover was assessed in June of the first pine growing season. Woody cover included trees, shrubs, blackberry, and vines. Competition measurement plots (CMPs) were 50 feet long and centered in the treatment plot. Vegetation cover was assessed on two bed CMPs and one inter-bed CMP with the exception of the Tennille location where only bed CMPs were assessed because the bed spacing was close enough to preclude a meaningful inter-bed assessment.

**Statistical Analysis**

A statistical analysis of total vegetation cover and woody vegetation cover was performed for each bedding regime at each location. This analysis compared the check to Chopper treatments, compared the before- and after-bed treatments, and tested for trends with application timing both before and after bedding. Effects were considered significant at the 5 percent level.

**RESULTS**

Total vegetation cover in June of the first year after treatment was significantly reduced by Chopper applications at all four locations regardless of application timing or bedding regime. There were, however, differences among application timings for specific bedding regimes. Significant differences varied by location but indicated general trends observed under a wide range of conditions. Vegetation control was related to seasonality of the treatment as well as timing relative to bedding.

**Mid-Season Bedding**

The relationship between Chopper timing and mid-season bedding is summarized in figure 1 as an average of results observed at four locations. After-bed applications provided better control of herbaceous vegetation than before-bed applications. Applications early in the growing season (February or early March) provided poorer control of deciduous woody species and some herbaceous species. Chopper applications made up to the day before bedding provided excellent control of woody competitors. Applications made between 0 to 3 weeks after bedding provided poorer vegetation control compared to later timings. It is interesting to note that applications just after bedding improved woody vegetation control compared to the untreated check, but control was not as complete as later applications; and that applications made just several weeks after bedding achieved excellent control even though vegetation was scattered and sparse at time of application.

**Late-Season Bedding**

The general patterns of vegetation control with late-season bedding, summarized in figure 2, were that all Chopper treatments significantly reduced competing vegetation relative to the untreated check. Before-bed applications were more effective than after-bed treatments. Applications made in February and March were not as effective as those made later. Both these early applications and late growing season after-bed applications provided poorer control of herbaceous and deciduous woody vegetation. Chopper treatments applied

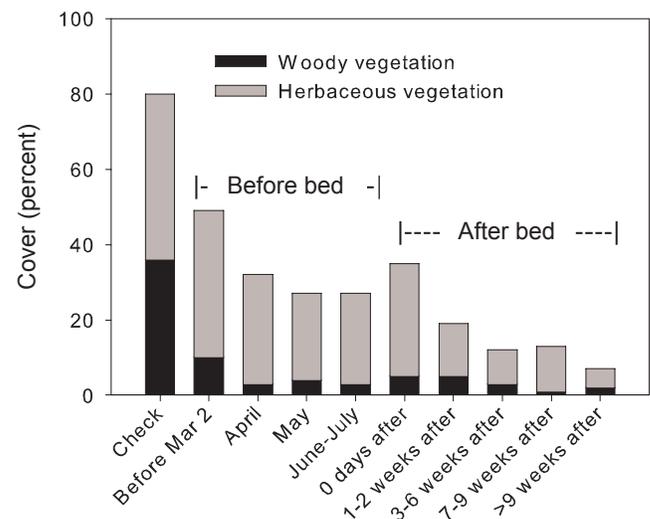


Figure 1—Average woody and herbaceous cover in June the year after treatment for Chopper timings combined with mid-season bedding. Cover is by application month for applications made before bedding and by timing for applications made after bedding.

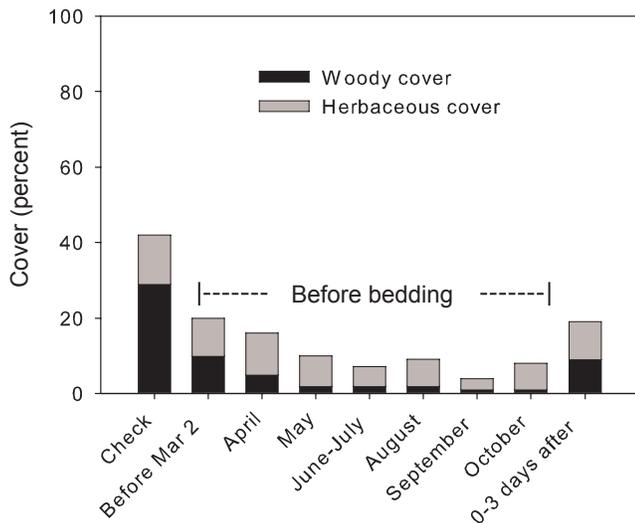


Figure 2—Average woody and herbaceous cover in June the year after treatment for Chopper timings combined with late-season bedding. Cover is by application month for applications made before bedding and by timing for applications made after bedding.

within a few days of bedding (including the day before) controlled woody vegetation.

It is also noteworthy that total cover in June of the first year after treatment was generally lower for late-season bedding than mid-season bedding. A comparison of the bed-only check plots indicates that late-season bedding reduced competition relative to mid-season bedding. The generally lower cover on all treatments following late bedding is due to the late tillage that retarded colonization of mainly herbaceous vegetation the year after treatment.

### VEGETATION CONTROL RECOMMENDATIONS

The historical limitations on timing of Chopper applications combined with bedding were found to have little basis in actual treatment performance. All Chopper timings improved

control of vegetation and may be acceptable under specific operational circumstances. However, woody and herbaceous vegetation control can be improved by following these recommendations:

#### Mid-Season Bed (May-July)

For after bed applications, make applications at least 3 weeks after bedding. Additional post-plant herbaceous weed control may not be necessary with this application timing, particularly on sandy soils.

For before bed application, make applications from February up until the time of bedding and follow with post-plant herbaceous weed control for improved herbaceous control. On sites with deciduous species such as blackberry and hardwood trees, delay application until these species have leafed out.

#### Late-Season Bed (September-November)

Avoid applications soon after late-season bedding. Make before-bed applications from February up to the day of bedding. On sites with deciduous species such as blackberry and hardwood trees, delay application until these species have leafed out and make applications before leaf-drop at the end of the growing season. Herbaceous weed control may not be necessary with late-season bedding, particularly on sandy soils.

### LITERATURE CITED

- Kline, W.N.; Troth, J.L.; Shiver, B.D. 1994. Maximizing pine yields in the southern flatwoods using Garlon herbicide. *Down to Earth*. 49(2). 8 p.
- Miller, J.H.; Zutter, B.R.; Zedaker, S.M. [and others]. 2003. Growth and yield relative to competition for loblolly pine plantations to midrotaton – a Southeastern United States regional study. *Southern Journal of Applied Forestry*. 27(4): 237-252.
- Minogue, P.J. 1985. Second-year results of 1983 Flatwoods site preparation herbicide screening trials. Research Note 85-13. Auburn University, AL: Auburn University Silvicultural Herbicide Cooperative. 35 p.
- Shiver, B.D.; Rheney, J.W.; Oppenheimer, M.J. 1990. Site-preparation method and early cultural treatments affect growth of flatwoods slash pine plantations. *Southern Journal of Applied Forestry*. 14(4): 183-188.

# COMPARISON OF TREATMENTS OF CONTROLLING KUDZU PRIOR TO PLANTING TREE SEEDLINGS

Andrew W. Ezell and Larry Nelson<sup>1</sup>

**Abstract**—Seven herbicide treatments were applied to well-established patches of kudzu in Mississippi and South Carolina. Six treatments were applied at each location; five treatments were the same at both locations, and one treatment was applied at one site only. Treatments were evaluated for brownout of the kudzu at 30 and 60 days after treatment (DAT). Percent control of the kudzu was evaluated at 30-day intervals during the growing season following application. Five of the seven treatments demonstrated excellent control of the kudzu. Escort® XP (4 ounces per acre; hereafter acre = A), Oust® Extra (8 ounces per A), Escort + Telar tank mixes (4 ounces + 2 ounces and 2 ounces + 4 ounces, respectively) and Tordon® K (1 gallon per A) all provided more than 90 percent control of the kudzu. Transline® (21 ounces per A) and Krenite® (1 gallon per A) did not provide desirable levels of control.

## INTRODUCTION

Kudzu [*Pueraria montana* (Lour.) Merr.] could be considered the original exotic invasive species of the South. It has been present in the southern United States for more than 100 years and continues to spread over more acres each year. Estimates of total coverage vary, but all agree that millions of acres are covered by the vine, and these acres are now considered non-productive. While the plant does not reproduce well by seed, it spreads aggressively by vegetative growth and excludes all other plants after it colonizes an area.

## MATERIALS AND METHODS

### Study Sites

The study site in Mississippi was located approximately 8 miles southeast of Winona, MS, on land owned by non-industrial private landowners. The kudzu on this site is at least 14 years old, and previous land use was agricultural cultivation. The South Carolina site was a former homeplace located on the Clemson School Forest. The kudzu is at least 40 years old.

### Treatments

A complete list of treatments is presented in table 1. These treatments include both proven "standards" for use in kudzu as well as previously untested applications.

**Table 1—Treatments applied in 2003 kudzu control project**

Treatment number	Herbicide <sup>a</sup> and rate/acre
1	Escort® XP (4 oz)
2	Transline® (21 oz)
3	Oust® Extra (8 oz)
4	Escort® XP (4 oz) + Telar (2 oz)
5	Tordon® K (128 oz)
6 <sup>b</sup>	Escort® XP (2 oz) + Telar (4 oz)
7 <sup>c</sup>	Krenite® (128 oz)

<sup>a</sup> All treatments had Timberland 90 surfactant added at 1 percent v/v.

<sup>b</sup> Mississippi site only.

<sup>c</sup> South Carolina site only.

### Plot Information

All treatment plots were 0.125 acre. Most were rectangular areas 55 feet x 109 feet, but some were of different dimensions due to the parameters of the kudzu patch. All treatments were replicated three times at each site for a total of 18 treated plots at each location. Plot corners were marked with PVC pipe, and the plot number, treatment number, and replication information was imprinted on a metal tag attached to a designated corner post of each plot.

### Application Information

All treatments were applied using an ATV equipped with a 30-gallon tank, electric pump, 50 feet of rubber hose, and a hand-held wand with an adjustable cone nozzle. Total spray volume for all applications was 60 gallons per acre (gpa). Treatments in Mississippi were applied on August 9, 2003, and in South Carolina on September 4, 2003. The perimeter of all plots in Mississippi were treated with Escort XP® (4 ounces per A) to prevent encroachment by kudzu. This outside perimeter treatment was not conducted in South Carolina.

### Evaluation

An ocular evaluation of percent brownout was completed at 30 and 60 days after treatment (DAT). Ocular estimates of the percent ground coverage by kudzu was completed in June, July, August, and September, 2004 in Mississippi. The same estimate was completed in June and September, 2004, in South Carolina.

### Data Analysis

All data was subjected to analysis of variance. Means were separated using Duncan's New Multiple Range Test with  $\alpha = 0.05$ .

## RESULTS

### Brownout

Average brownout results are presented in table 2. Generally, the treatments containing metsulfuron provided 60-70 percent brownout at 30 DAT and 90 percent at 60 DAT. The Transline treatment resulted in 67 brownout at 30 DAT and 87 percent at 60 DAT. The Krenite did not result in as much brownout

<sup>1</sup> Professor, Mississippi State University, Department of Forestry, Mississippi State, MS 39762; and Associate Professor, Clemson University, Department of Forest Resources, Clemson, SC 29634, respectively.

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**Table 2—Average percent brownout at 30 and 60 days after treatment (average all replications)**

Treatment	Time of observation	
	30 DAT	60 DAT
	----- percent -----	
Escort XP (4 oz)	70	91
Transline (21 oz)	67	83
Oust Extra (8 oz)	57	93
Escort XP (4 oz) + Telar (2 oz)	73	92
Tordon K (128 oz)	95	99
Escort XP (2 oz) + Telar (4 oz)	77	91
Krenite (128 oz)	*	35

\* No data

response and had only 35 percent response by 60 DAT. Tordon® K is highly effective on kudzu and was 95 and 100 percent brown at 30 and 60 DAT evaluations, respectively.

### Percent Control

Percent control was estimated by the amount of ground covered by the kudzu—i.e., the less ground covered, the greater the control. This was a viable approach since both study sites began with 100 percent coverage. Average percent coverage in Mississippi is presented in table 3. In June, all treatments

except Transline had reduced the kudzu to approximately 5 percent ground cover. At that time, all resprouting tubers were marked with a pin flag. Subsequent evaluation recorded that increased coverage was due to growth of the kudzu vines, but no new origins were noted in any plots except in Transline treatments. Overall, control was excellent, and the patch could have been eliminated if follow-up treatment had been applied in all treatment areas except Transline. In South Carolina, percent ground cover was greater than in Mississippi (table 4), but those estimates included vine growth which was encroaching from outside the treatment plots. Tordon® K treatments provided very good control, which appeared to allow less encroachment than the other herbicides. While ground coverage was greater, control with the treatment plots appeared to be as good as comparable treatments in Mississippi. Only the Krenite and Transline treatments failed to provide desirable levels of control in the South Carolina plots.

### SUMMARY

Five of the seven treatments provided control which could eradicate kudzu with proper follow-up treatments. The previously untested treatments of Oust Extra and Escort/ Telar mixes provided control comparable to the proven Escort XP and Tordon® K treatments. All treatments except Tordon® K can be applied in areas with pines and many species of hardwoods with no damage to the trees. Forest land managers should be able to use these five treatments successfully on established kudzu areas.

**Table 3—Average percent kudzu cover by treatment and time of observation-MS (average all replications)**

Treatment	Time of 2004 observations			
	June	July	August	September
	----- percent -----			
Escort XP (4 oz)	3.3a <sup>a</sup>	8.3a	18.0a	23.3a <sup>b</sup>
Transline (21 oz)	28.3b	37.3b	57.0b	76.7b
Oust Extra (8 oz)	1.7a	6.7a	8.3a	13.3a
Escort XP (4 oz) + Telar (2 oz)	3.0a	5.0a	6.3a	13.3a
Tordon K (128 oz)	3.0a	10.0a	16.7a	20.0a
Escort XP (2 oz) + Telar (4 oz)	6.0a	6.7a	8.3a	21.7a

<sup>a</sup> Values in a column followed by the same letter do not differ at  $\alpha = 0.05$ .

<sup>b</sup> Increase in coverage due to vine growth; no new sprouts in any treatment area except Transline treatment.

**Table 4—Average percent kudzu cover by treatment and time of observation-SC (average all replications)**

Treatment	Time of 2004 observations	
	June <sup>a</sup>	September
	----- percent -----	
Escort XP (4 oz)	21.7a <sup>b</sup>	50.0b
Transline (21 oz)	70.0c	60.0b
Oust Extra (8 oz)	16.7a	56.7b
Escort XP (4 oz) + Telar (2 oz)	20.0a	66.7b
Tordon K (128 oz)	11.7a	21.7a
Krenite (128 oz)	36.7b	96.7c

<sup>a</sup> Includes kudzu coverage from vines encroaching from outside plot boundaries.

<sup>b</sup> Values in a column followed by the same letter do not differ at  $\alpha = 0.05$ .

# CHOPPER HERBICIDE SITE PREPARATION FOR DIFFERENT BEDDING TIMINGS AND VEGETATION COMPLEXES IN NORTH FLORIDA

Dwight K. Lauer, Harold E. Quicke, and David Adams<sup>1</sup>

**Abstract**—The use of Chopper® (BASF Corporation, Research Triangle Park, NC) herbicide applied with an oil and water carrier was tested for site preparation. Tests were installed at eight locations to examine slash pine (*Pinus elliotii* Engelm.) response and vegetation control with different vegetation types and timings of bedding. Chopper was applied in October at three rates by itself and tank-mixed with triclopyr or glyphosate. Two locations bedded in September included post plant herbaceous weed control treatments of Arsenal AC® (BASF) or Oustar® (Dupont) instead of Chopper tank mixes. Chopper site prep treatments were effective on poorly to somewhat poorly drained spodosols with either gallberry [*Ilex glabra* (L.) Gray] or titi (*Cyrilla racemiflora* L.) and fetterbush [*Lyonia lucida* (Lam.) Koch] vegetation. Chopper rates < 32 ounces-per-acre resulted in poorer pine growth. Tank mixes with triclopyr or glyphosate did not improve pine response or vegetation control in most instances. Pine response and vegetation control following Chopper site prep was variable on moderately well-drained soils. Herbaceous weed control treatments differed in performance, but Oustar did not control woody vegetation and Arsenal only suppressed woody vegetation.

## INTRODUCTION

Recognition that lack of woody and herbaceous weed control can reduce pine yields by more than 50 percent (Miller and others 2003) has increased the use of site prep herbicides in the lower Coastal Plain of north Florida. Early pine growth is hampered by both herbaceous and waxy leafed woody shrub species common to the area (Lauer and Glover 1998). The use of herbicides is commonly combined with bedding, but bedding cannot all be done in a short period of time. The large number of acres bedded and changing soil moisture conditions necessitate that bedding operations are performed throughout the year prior to planting.

Chopper® is a 2-pounds-per-gallon active ingredient emulsifiable concentrate formulation of imazapyr. The use of this formulation in an oil and water carrier improves uptake on waxy leafed species. The efficacy of Chopper and Chopper tank mixes used with oil carriers has not been widely tested on vegetation complexes in the lower Coastal Plain region to determine optimal prescriptions.

There were two objectives to this investigation: (1) to examine efficacy of Chopper and tank mixes of Chopper applied with a high percentage oil carrier on several vegetation complexes common to north Florida; and (2) to investigate slash pine response and vegetation control to these treatments following a range of bed timings. Timing of bedding across several vegetation complexes was examined by installing a study series at eight different locations.

## PROCEDURES

### Treatment Regimes

There were two treatment regimes used in this study series. Chopper site prep and tank mixes with Chopper were investigated using locations bedded between January and August. Woody vegetation at these locations had top growth by the time of the October application. Alternatively, two locations that were bedded in September had relatively clean beds,

and tank mixes with foliar active herbicides were not considered. Instead, Chopper site prep was compared to post plant herbaceous weed control.

The first treatment regime was used at the six locations bedded between January and August. The 10 treatments were an untreated check, 3 rates of Chopper (24, 32, and 48 ounces-per-acre), and these 3 Chopper rates tank-mixed with 32 ounces-per-acre Garlon 4® (Dow Agrosciences) (triclopyr) or 64 ounces-per-acre of a 4 pounds-per-gallon active ingredient formulation of glyphosate. Triclopyr and glyphosate were only included with Chopper and were not tested by themselves.

The second treatment regime was used at the two locations bedded in September. The 6 treatments were the untreated check, 3 rates of Chopper (24, 32, and 48 ounces-per-acre), and 2 post plant herbaceous weed control (HWC) treatments. The HWC treatments were Arsenal AC® (imazapyr) at 6 ounces-per-acre and Oustar at 13 ounces-per-acre.

### Treatment Application

Treatments were applied to plots that were 3 beds wide and 80 feet long. All treatments were replicated three times in a randomized complete block design at each location. Site prep treatments were applied at 15 gallons-per-acre using water and 12.5 percent (by volume) methylated seed oil. These broadcast applications were made in October before planting using a three-nozzle boom sprayer with Turbo Flood® (Spraying Systems Co.) 2.0 nozzles. HWC treatments were banded applications made March 28 over planted trees. A 6-foot band was treated with a two-nozzle boom sprayer equipped with Turbo Flood 2.0 nozzles.

### Soils and Vegetation

A total of eight study locations were installed across a range of soils and vegetation complexes. There were three main groupings of soils and vegetation. The spodosols with gallberry group included three locations (March, July, and

<sup>1</sup> Research Analyst, Silvics Analytic, Richmond, VA 23238; Research Specialist, BASF Corporation, Research Triangle Park, NC 27709; and Land Resources Manager, Foley Timber and Land Company, Perry, FL 32348, respectively.

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September bed) located on poorly to somewhat poorly drained spodosols with vegetation dominated by gallberry and low panic grass (*Dichanthelium* spp.). The spodosols with titi and fetterbush group included two locations (January and August bed) located on poorly drained spodosols dominated by titi and fetterbush. The moderately well-drained soils group included three locations (May, July, and September bed). Vegetation varied by location, but common species were oaks (*Quercus* spp.), saw palmetto [*Serenoa repens* (Bartr.) Small], sumac (*Rhus* spp.), bracken fern [*Pteridium aquilinum* (L.) Kuhn], blackberry (*Rubus* spp.), greenbriar (*Smilax* spp.), low panic grass, sedges (*Cyperus* spp.), poorjoe (*Diodia teres* Walt.), spurges (*Euphorbia* spp.), fireweed [*Erechtites hieracifolia* (L.) Raf. ex DC.], dogfennel [*Eupatorium capillifolium* (Lam.) Small], and pokeweed (*Phytolacca americana* L.).

### Measurements

Measurements were made on a 60-foot length of the middle bed within each treatment plot. Vegetation was assessed using ocular estimates of percent cover in June and October of the first growing season and in June of the second growing season. Pines were measured in December of the second growing season. Pine groundline diameter (nearest 0.04 inch) and total height (nearest 0.03 foot) were measured for each tree.

### Analysis

This summary compares year 2 average pine volume index, total percent cover in June of the first growing season, and total woody percent cover in June of the second growing season. Pine volume index was computed as the volume of a cone in cubic inches using groundline diameter and total height. Total percent cover is the total cover of all vegetation and includes all woody and herbaceous vegetation. Total woody cover is the total cover in woody vegetation and includes trees, woody shrubs, woody vines, and blackberry.

Major factors that affect pine growth are the level of vegetation control by June of the first growing season, longer term woody control, and pine tolerance. Early pine growth is a measure of pine tolerance and response to early herbaceous and woody vegetation control but does not account for the longer term impact of woody vegetation. Consideration should be made for the level of woody control achieved 20 months after treatment (June of the second growing season).

These measures were compared at each location using analysis of variance. Direct treatment comparisons were made to determine if herbicide treatments differed from the check, if there were linear or quadratic trends with Chopper rate, if using a tank mix with Chopper made a difference, and if there were any interactions between Chopper rate and tank mixes. The check treatment was considered a baseline in this analysis. Chopper treatments were compared to this baseline check, but tests of rate effects only consider differences among the 24, 32, and 48 ounce Chopper rates. Comparisons were considered significant if the probability of no difference was < 5 percent. Triclopyr and glyphosate are only tested with Chopper, because they were not included as stand alone treatments.

## RESULTS AND DISCUSSION

### Pine Response

General patterns of pine response and the magnitude of response were related to soil drainage class and vegetation complex. The greatest pine response occurred on poorly to somewhat poorly drained spodosols with gallberry or titi and fetterbush vegetation. Response was more variable on moderately well-drained soils that did not have gallberry or titi and fetterbush.

Pine response was significant for all herbicide treatments on spodosols with gallberry or titi and fetterbush vegetation with two exceptions (fig. 1). The first exception was the lack of pine response at the July bed–gallberry location. Pine response at this location was limited by poorly formed beds. The second exception was that only the HWC treatments and site prep treatments with 32 ounces of Chopper improved pine response at the September bed–gallberry location. All herbicide treatments increased pine volume at the three other locations. Pine volume increased as the rate increased from 24 to 32 ounces of Chopper with the best pine response achieved with 32 ounces of Chopper at 3 locations. Tank mixes of Chopper with either triclopyr or glyphosate did not significantly change pine volume response except for the August bed—titi and fetterbush location where comparable maximum responses were achieved by 32 ounces of Chopper, 32 ounces of Chopper with glyphosate, or 48 ounces of Chopper with triclopyr (significant interaction). Slash pine volume averaged across the 4 responsive locations was 98 cubic inches and 16 cubic inches per tree for the best responding treatments and the untreated check, respectively.

Pine response was variable (fig. 2) for the moderately well-drained soil locations that had little or no gallberry, titi, or fetterbush. Chopper site prep treatments increased pine

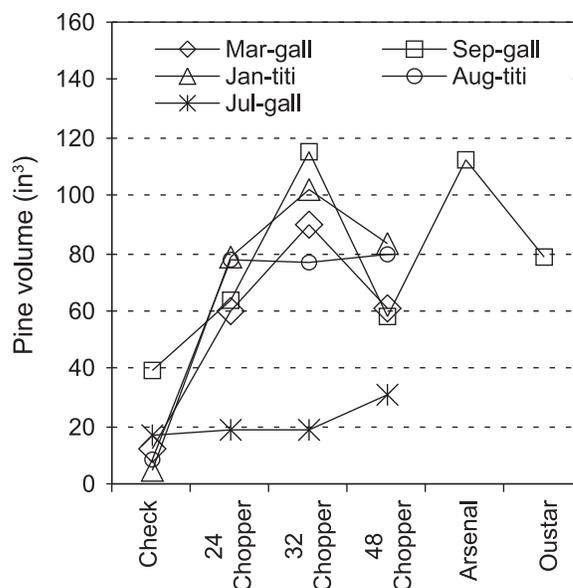


Figure 1—Year 2 pine volume index for locations on spodosols with gallberry or titi and fetterbush vegetation. Volume averages for Chopper include Chopper tank mixes except the location with Arsenal and Oustar treatments that had no tank mixes.

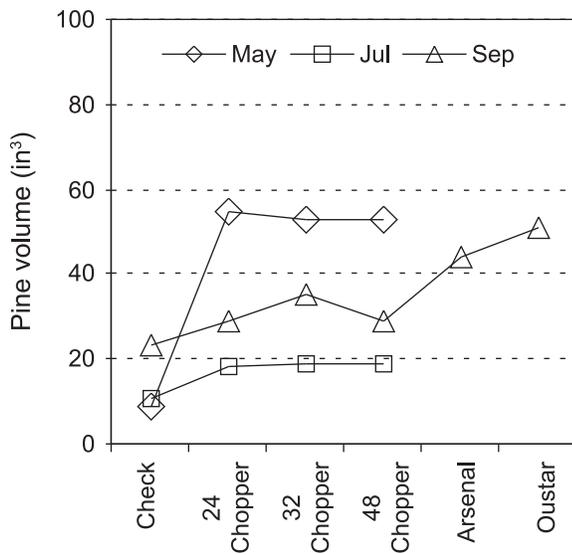


Figure 2—Year 2 pine volume index for locations on moderately well-drained soils with little or no gallberry or titi and fetterbush vegetation. Volume averages for Chopper include Chopper tank mixes except the location with Arsenal and Oustar treatments that had no tank mixes.

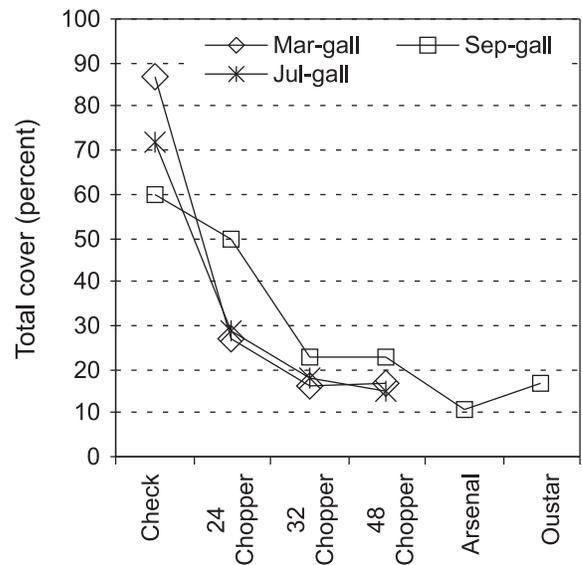


Figure 3—Total cover in June of the first growing season for spodosols with gallberry. Cover means for Chopper include Chopper tank mixes except the location with Arsenal and Oustar treatments that had no tank mixes.

volume only at the May bed location. HWC treatments increased pine volume at the September bed location. Pine volume responses to the best herbicide treatments ranged from 19 to 54 cubic inches per tree compared to an average check volume of 14 cubic inches.

### Spodosols with Gallberry

Pine response to herbicide treatments was impressive except at the location with poorly formed beds. The use of tank mixes did not improve pine response even though they improved vegetation control to some extent. This is probably due to the small magnitude of improved control. First June cover on the check ranged from 60 to 87 percent compared to 22 percent or less cover for most of the herbicide treatments (fig. 3). The better pine response for the 32 ounce Chopper rate is probably due to improved control, particularly herbaceous control, over the 24 ounce Chopper rate. All rates of Chopper and tank mixes with Chopper reduced gallberry to < 2 percent cover. The addition of triclopyr did improve control at the March bed location by 10 percent, but this did not translate into improved pine growth. The post plant Arsenal and Oustar treatments had less than 20 percent cover but were only included at the September bed location which had low levels of woody vegetation.

All herbicide treatments provided woody control through June of the second growing season with the exception of the lowest Chopper rate at the September bed location and the Arsenal and Oustar treatments (fig. 4). All Chopper rates controlled woody vegetation that had resprouted on beds. The higher 32 and 48 ounce Chopper rates were required at the September bed location where resprouting was limited at time of application. Although pines responded to Arsenal and Oustar treatments, the Arsenal treatment did not completely control woody vegetation, and the Oustar treatment provided no control of woody vegetation. This was only acceptable at this location because woody cover was relatively low.

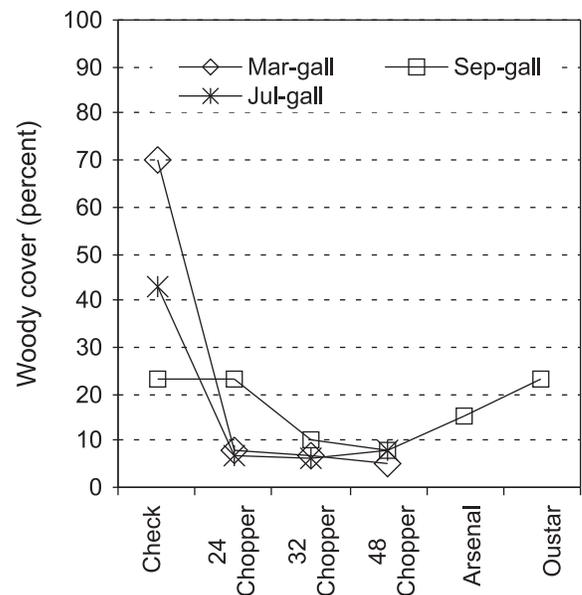


Figure 4—Woody cover in June of the second growing season for spodosols with gallberry vegetation. Cover means for Chopper include Chopper tank mixes except the location with Arsenal and Oustar treatments that had no tank mixes.

### Spodosols with Titi and Fetterbush

Pine response peaked from using 32 ounces of Chopper on these sites. There was no benefit to using tank mixes. However, no treatments provided total woody control. These sites are characterized by good pine response and little colonization of herbaceous vegetation once woody vegetation is controlled. These treatments controlled or suppressed woody vegetation (fig. 5), so total vegetation cover was close to 20 percent or less in June of the first growing season. Initial

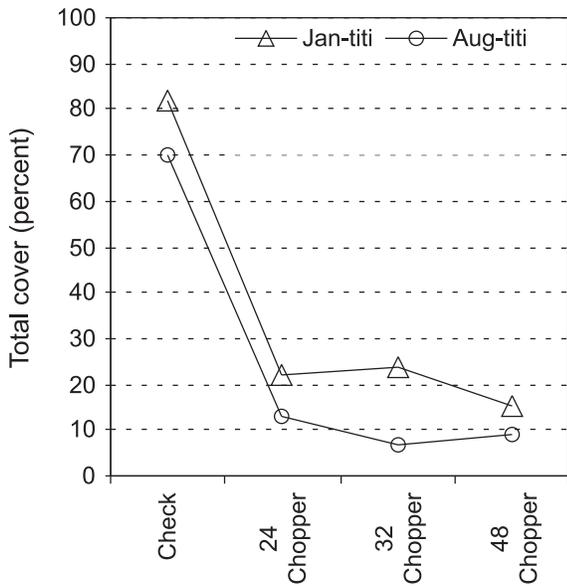


Figure 5—Total cover in June of the first growing season for spodosols with titi and fetterbush vegetation. Cover means for Chopper rates are the average of Chopper and Chopper tank mixes.

control appeared better at the August bed location, but woody cover was about 30 percent in June of the second growing season at both locations (fig. 6).

### Moderately Well-Drained Soils

Pine response was variable at these three locations, but much of this variation was related to the level of vegetation control achieved by herbicide treatments. Vegetation control was probably related more to vegetation present than month of bedding. Application of these results requires a better under-

standing of the differences in vegetation development on moderately well-drained soils.

The May bedded location vegetation was primarily brackenfern, oaks, blackberry, low panic grass, sumac, and saw palmetto. All herbicide treatments decreased cover in June of the first growing season to about 31 percent (fig. 7). Treatments controlled brackenfern, oaks, low panic grass, and sumac. Fireweed and sedges made up about two-thirds of the cover on herbicide treated plots but were minor species on the untreated check. Blackberry and saw palmetto made up the other third of cover on treated plots. Woody cover in June of year 2 was significantly lower than the check (fig. 8) and was primarily blackberry and saw palmetto for all treated plots. Triclopyr provided better woody control than did glyphosate (34 versus 17 percent cover), but blackberry cover was reduced by all herbicide treatments. Pine response was comparable for all treatments and was not affected by the minor differences in vegetation control.

The June bed location was on a moderately well-drained spodosol. The surface horizon was droughty and low in fertility. Vegetation control was poor (fig. 7). Treatments controlled low panic grass, blackberry, and oaks, but this cover was replaced by broadleaf herbs by June of the first growing season. Broadleaf herbs on treatment plots were predominantly poorjoe and spurge. Woody control was good for all treatments (fig. 8), and all treatments controlled oaks and blackberry. Pine response was positive but not significant at this location due to poor control of herbaceous vegetation.

The September bed location was responsive to vegetation control, but the quality of vegetation control achieved was limited. First year vegetation composition included many species of broadleaf herbs, oak, sumac, blackberry, and greenbriar. Broadleaf herbs were fireweed, dogfennel, pokeweed, and brackenfern. This composition suggests a higher

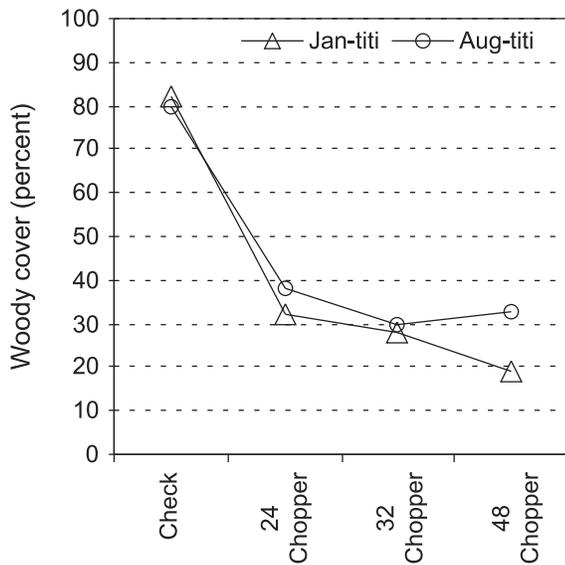


Figure 6—Woody cover in June of the second growing season for spodosols with titi and fetterbush vegetation. Cover means for Chopper rates are the average of Chopper and Chopper tank mixes.

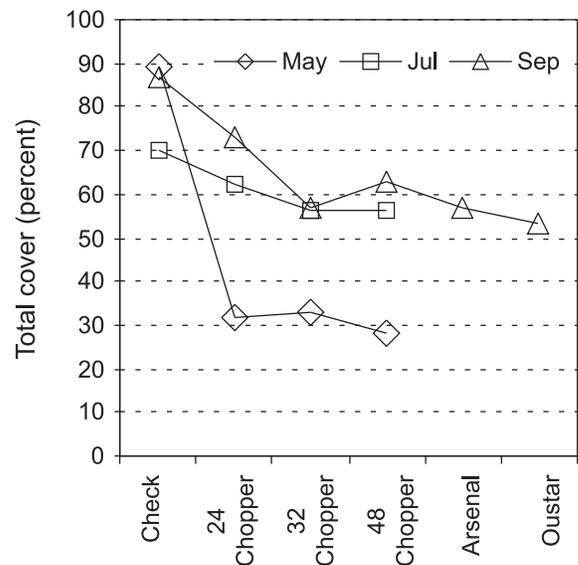


Figure 7—Total cover in June of first growing season for moderately well-drained soils with little or no gallberry or titi and fetterbush vegetation. Cover means for Chopper include Chopper tank mixes except the location with Arsenal and Oustar treatments that had no tank mixes.

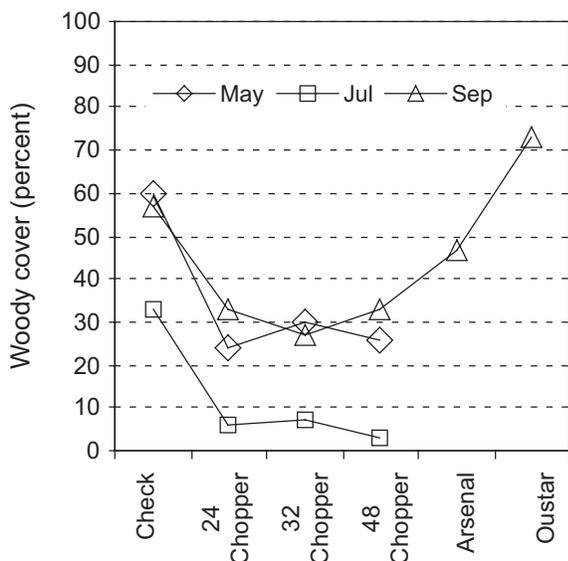


Figure 8—Woody cover in June of the second growing season for moderately well-drained soils with little or no gallberry or titi and fetterbush vegetation. Cover means for Chopper rates include tank mixes except the location with Arsenal and Oustar treatments that had no tank mixes.

fertility level than other locations. Chopper treatments controlled grass and woody vegetation but not broadleaf herbs. Arsenal did a better job of controlling a mixture of herbs and woody. Oustar provided the best control of herbs but not woody vegetation. Treatments only reduced total cover in June of the first year by about a third of that on the check (fig. 7). Early pine response was dependent on herbaceous control with Arsenal and Oustar providing the best response, but longer term response may be limited by the lesser control of woody vegetation (fig. 8). Pine response was relatively large compared to the level of weed control achieved, and more effective herbicide treatments should be sought for these fertile sites.

All Chopper site prep rates provided similar levels of vegetation control on moderately well-drained soils. Chopper site prep controlled woody vegetation and provided the best control of herbaceous vegetation where it was well established (May bed) at the time of application. Post-plant herbaceous weed control provided the best control of herbaceous vegetation for the September bedding and the best early pine response. Woody vegetation was not controlled by post plant HWC and may limit future pine growth. Pine response to vegetation control improved with site quality, but treatments need to be developed that provide more complete vegetation control on moderately well-drained soils.

## CONCLUSIONS

Chopper applied with oil and water carrier performed well on poorly and somewhat poorly drained spodosols with either

gallberry or titi and fetterbush vegetation. The 32 ounce Chopper rate usually provided the best pine response and often improved vegetation control compared to the 24 ounce Chopper rate. Tank mixes of Chopper with triclopyr or glyphosate did not improve vegetation control or pine response. Total cover in June of the first year was near 20 percent or less for the 32 and 48 ounce Chopper rates, so first year herbaceous weed control may not be required. Arsenal performed better than Oustar at the one location where these treatments were included, because Arsenal suppressed woody vegetation and Oustar did not. However, post plant herbaceous treatments will not provide the expected longer term response if woody vegetation levels are high.

The titi and fetterbush vegetation complex was not completely controlled by any treatment, but Chopper treatments provided enough control in the first year to achieve a sizable pine response. Tank mixes did not improve control, and there was evidence that tank mixes with the 24 ounce rate of Chopper sometimes provided poorer control. These results also indicate that tank mixes with higher rates of glyphosate and triclopyr should be tested to determine if more complete control of titi and fetterbush is possible.

Pine response and vegetation control on moderately well-drained soils was variable. These locations varied with respect to bed timing and fertility. Best control was achieved by the May bedding with established vegetation at the time of the October Chopper application. All treatments reduced first June cover to about 31 percent, controlled woody shrubs and trees, and controlled brackenfern and grasses. Chopper provided poorer control at the other two locations where broadleaf herbs emerged the year after planting. All Chopper with oil treatments provided some level of blackberry control at all locations and did not “release” blackberry.

Herbaceous weed control treatments performed better than Chopper site prep for the September bed location on a moderately well-drained soil. This location appeared to have higher fertility than other locations based on first year vegetation. Although herbaceous weed control treatments were the best treatments, Oustar did not control woody vegetation and Arsenal did not control all herbaceous vegetation and only suppressed woody vegetation. These treatments did not reduce first year June cover to < 50 percent. Evidence suggests that doubling of pine response may be possible if more effective treatments could be developed for moderately well-drained soils.

## LITERATURE CITED

- Lauer, D.K.; Glover, G.R. 1998. Early pine response to control of herbaceous and shrub vegetation in the Flatwoods. *Southern Journal of Applied Forestry*. 15(4): 201-208.
- Miller, J.H.; Zutter, B.R.; Zedaker, S.M. [and others]. 2003. Growth and yield relative to competition for loblolly pine plantations to midrotaton – a Southeastern United States regional study. *Southern Journal of Applied Forestry*. 27(4): 237-252.

# HERBICIDE COMPARISONS FOR MID-ROTATION COMPETITION RELEASE IN LOBLOLLY AND SLASH PINE

Alan B. Wilson, William N. Kline, and Barry D. Shiver<sup>1</sup>

**Abstract**—In October, 2002, different combinations of herbicides (Arsenal®, Chopper®, and Forestry Garlon® 4) were applied with a tank-mounted skidder, in an experiment to evaluate their effectiveness for controlling competing vegetation in the understory of a 16-year-old loblolly (*Pinus taeda* L.) and slash pine (*Pinus elliottii* Engelm.) plantation in Louisiana. Two years after treatment, volume responses are significant for loblolly pine where the understory had been treated with 2 quarts Forestry Garlon® 4 and 48 ounces Chopper®. The best treatment reduced competing vegetation in percent cover and total height. Slash pine has not responded to release treatments.

## INTRODUCTION

In recent years, a number of studies have shown pines grow significantly faster when competing vegetation in the understory is controlled (Quicke and others 1996, Shiver 1994). A problem arises when difficult-to-control species are growing alongside crop trees. In the Gulf Coastal Plain, several species of arborescent and non-arborescent plants can grow just under or into the canopy of pines, making herbicide application difficult. Also, foresters are limited to a select group of herbicides that have proven effective when applied to waxy leafed species such as yaupon (*Ilex vomitoria* Ait.) and waxmyrtle (*Myrica cerifera* L.). This makes spraying a challenge, since aerial application is not an option.

## METHODS AND MATERIALS

Two sites in Allen Parish, LA, were selected for the study. The loblolly pine site is on a Malbis soil, planted in 1986, fertilized in 1995 with 35 pounds of nitrogen (N) and 40 pounds of phosphorus (P), commercially thinned in 2000, and fertilized again in 2002 with 200 pounds of N and 25 pounds of P. Prior to treatment application, trees averaged 5.8 inches d.b.h. and 42.9 feet in height. The slash pine site is located on a Caddo soil, planted in 1986, fertilized in 1995 with 35 pounds of N and 40 pounds of P, commercially thinned in 2001, and fertilized again in 2002 with 100 pounds of N and 25 pounds of P. Prior to treatment application, trees averaged 5.6 inches d.b.h. and 42.7 feet in height. The thinning procedure for each stand consisted of harvesting every fifth row, with selections from below coming from the two rows on either side of the harvested row.

Competing species included American beautyberry (*Callicarpa americana* L.), American holly (*Ilex opaca* Ait.), blackgum (*Nyssa sylvatica* Marsh.), Chinese tallow (*Sapium sebiferum* L.), red maple (*Acer rubrum* L.), sumac (*Rhus* spp.), sweetgum (*Liquidambar styraciflua* L.), water oak (*Quercus nigra* L.), waxmyrtle, and yaupon. Prior to treatment application, three species (sweetgum, waxmyrtle, and yaupon) constituted more than 50 percent of the competing vegetation cover on both sites (table 1).

A randomized complete block design was chosen for this experiment with three blocks per site. Four herbicide treatments

**Table 1—Percent cover and height of major competing species, prior to treatment, in Allen Parish, LA**

Species	Initial cover		Initial height	
	Loblolly site	Slash site	Loblolly site	Slash site
	----- % -----		----- feet -----	
Yaupon	52	19	15	14
Waxmyrtle	9	20	8	11
Sweetgum	9	13	19	23

were chosen for the loblolly pine site and one herbicide treatment for the slash pine site (table 2). All tank mixes included a 99 percent non-ionic surfactant. In order to ensure adequate coverage in these dense stands, a tank-mounted skidder was used to apply the herbicide mixture at 45 gallons per acre at 40 pounds per square inch pressure. Nozzles were mounted on a boom 20 feet above the ground. These higher volumes and increased boom height were used to ensure adequate cover in these dense stands. The skidder traveled the harvested rows for access and sprayed a swath approximately 50 feet wide. Four adjacent spray swaths, each 350 feet long, constituted a treated plot. Treatments for both sites were applied October 15, 2002. Control treatment plots were also present in each block.

**Table 2—Herbicide tank-mixes applied to control competing vegetation at the loblolly and slash pine sites in Allen Parish, LA**

	Treatment no.	Herbicide and rate ( <i>per acre</i> )
Loblolly	1	2 qt Garlon4 + 16 oz Arsenal
	2	3 qt Garlon4 + 12 oz Arsenal
	3	5 qt Garlon4
	4	2 qt Garlon4 + 48 oz Chopper
	5	Untreated
Slash	1	2 qt Garlon4 + 32 oz Chopper
	2	Untreated

<sup>1</sup> Silviculture Research Manager, Rayonier, Yulee, FL 32041; Senior Scientist, Dow AgroSciences, Duluth, GA 30096; and Professor, D.B. Warnell School of Forest Resources, University of Georgia, Athens, GA 30602, respectively.

Within each plot, three permanent 0.1-acre measurement plots were established. All pine trees were tagged and measured for d.b.h. and height prior to treatment application. Visual assessments for competing vegetation (percent cover by species and average height of species) were recorded prior to treatment application and each year thereafter. After treatment application, percent control of competing vegetation was recorded each year. Analysis of variance and Duncan's New Multiple Range Test ( $P < 0.05$ ) were used to test statistical significance of the results. This paper reports data for the period 2 years after treatment application.

## RESULTS AND DISCUSSION

### Loblolly Pine Site

Two years after treatment, diameter growth ranged from 0.52 inches for the untreated plot to 0.62 inches for the 2 quarts Garlon® 4 + 48 ounces Chopper® treatment (table 3). Height growth varied from 4.5 feet for the untreated plot to 5.7 feet for the 3 quarts Garlon® 4 + 12 ounces Arsenal® treatment. All treatments were statistically different from the untreated plot in terms of volume growth. An additional 68 cubic feet per acre of volume was gained on the 2 quarts Garlon® 4 + 48 ounces Chopper® treatment when compared to the untreated plot (table 4). This was the greatest volume response of any of the herbicide treatments.

Prior to any treatment application, yaupon cover levels averaged fifty percent or more across all plots (table 4). One year after treatment, all tank mixes were effective in reducing percent yaupon levels. The 5 quarts Garlon® 4 and the 2 quarts Garlon® 4 + 48 ounces Chopper® rate reduced yaupon to 10 percent cover while the 2 quarts Garlon® 4 + 16 ounces

Arsenal rate reduced yaupon percent cover to 18 percent. Even with the higher spray volumes per acre and increased boom height, not all yaupon was controlled regardless of the treatment. Individual plants were occasionally over topped by foliage and did not receive adequate spray. Two years after treatment, yaupon percent cover ranged from a high of 31 percent for 5 quarts Garlon® 4 to a low of 14 percent for the 2 quarts Garlon® + 48 ounces Chopper® treatment. Apparently, the better efficacy of the 2 quarts Garlon® + 48 ounces Chopper® treatment on yaupon resulted in greater volume response for loblolly pine.

### Slash Pine Site

Diameter growth, 2 years after treatment, ranged from 0.63 inches for the untreated plot to 0.70 inches for the 2 quarts Garlon® 4 + 32 ounces Chopper® treatment (table 3). Height growth for slash pine ranged from 5.2 feet for the untreated plot to 5.8 feet for the 2 quarts Garlon® 4 + 32 ounces Chopper® treatment. Although there was 31 cubic feet per acre volume gain from the treated plot, this was not statistically significant ( $P < 0.05$ ).

Initial understory competition for percent control was somewhat equally distributed among yaupon, waxmyrtle, and sweetgum (table 1). Two years after treatment, the 2 quarts Garlon® 4 + 32 ounces Chopper® treatment reduced percent cover for yaupon, waxmyrtle, and sweetgum 12, 8, and 6 percentage points, respectively (table 5). This reduction in competing vegetation was not enough to elicit a volume response from slash pine. Over the last 2 years, percent cover for yaupon and waxmyrtle on the untreated plot has remained relatively unchanged. However, for the same time period, sweetgum percent cover has increased from 13 to 25 percent.

**Table 3—Loblolly and slash pine growth 2 years after treatments were applied to control competition**

Species	Treatment	d.b.h. <i>in</i>	Height <i>ft</i>	Volume <i>ft<sup>3</sup></i>
Loblolly	2 qt Garlon4 + 16 oz Arsenal	0.56	5.0	627
	3 qt Garlon4 + 12 oz Arsenal	0.58	5.7	652
	5 qt Garlon4	0.57	5.2	669
	2 qt Garlon4 + 48 oz Chopper	0.62	5.5	678
	Untreated	0.52	4.5	610
Slash	2 qt Garlon4 + 32 oz Chopper	0.70	5.8	705
	Untreated	0.63	5.2	674

**Table 4—Percent yaupon cover on the loblolly pine site, before and after treatment, in Allen Parish, LA**

Treatment	Initial	1 year after treatment	2 years after treatment
2 qt Garlon4 + 16 oz Arsenal	52	18	29
3 qt Garlon4 + 12 oz Arsenal	52	12	26
5 qt Garlon4	50	10	31
2 qt Garlon4 + 48 oz Chopper	50	10	14
Untreated	56	59	50

**Table 5—Percent cover and height of major understory competition on the slash pine site 2 years after treatment in Allen Parish, LA**

Species	Cover		Height	
	Untreated	2 qt Garlon4 + 32 oz Chopper	Untreated	2 qt Garlon4 + 32 oz Chopper
	----- % -----		----- ft -----	
Yaupon	22	7	14	10
Waxmyrtle	16	12	7	5
Sweetgum	25	7	24	16

**CONCLUSIONS**

Two years after treatment, a tank mix of 2 quarts Garlon® 4 + 48 ounces Chopper® reduced understory competing vegetation which significantly increased loblolly pine volume. Over the same time period, slash pine did not respond to release from understory competition when 2 quarts Garlon® 4 + 32 ounces Chopper® was used. It will be important to monitor these studies in the future since additional responses may be measured.

**ACKNOWLEDGMENTS**

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**LITERATURE CITED**

Quicke, H.E.; Lauer, D.K.; Glover, G.R. 1996. Growth responses following herbicide release of loblolly pine from competing hardwoods in the Virginia piedmont. *Southern Journal of Applied Forestry*. 20(4): 177-181.

Shiver, B.D. 1994. Response and economics of mid-rotation competition control in southern pine plantations. *Proceedings of the Southern Weed Science Society*. 47: 85-92.

# TIMING OF HERBACEOUS WEED CONTROL IN LOWER COASTAL PLAIN LOBLOLLY PINE PLANTATIONS

Harold E. Quicke and Dwight K. Lauer<sup>1</sup>

**Abstract**—Pine response to different post-plant herbaceous weed control timings was evaluated following mechanical (bedding) and chemical site preparation. Results indicate that sizeable productivity gains are possible with site-specific timing of herbaceous weed control treatments. For sites with > 20 percent cover in June of the first year, the best timing for herbaceous weed control was early in the first year of pine growth. For sites with < 10 percent weed cover in June of the first year, the best timing was early in the second year of pine growth. Guidelines for predicting first year June cover are provided.

## INTRODUCTION

A region-wide experiment was installed on a range of soils to examine post-plant herbaceous weed control timing following different site preparation treatments with Chopper® (BASF Corporation, Research Triangle Park, NC) herbicide. Chopper site preparation treatments were applied after bedding and included two application dates (August versus November) and three rates (32, 48, and 64 ounces). Pines were planted in winter following site preparation. Post-plant herbaceous weed-control-timings included: (1) no herbaceous weed control, (2) March of the first year of pine growth (first early), (3) June of the first year of pine growth (first mid), and (4) March of the second year of pine growth (second early).

Recolonization of vegetation was evaluated in June, August, and October of the first pine growing season and June and October of the second growing season. Pines were measured at the end of the first and second growing seasons. Chopper site preparation treatments included Garlon® 4 (Dow Agrosciences, Indianapolis, IN) at 1 or 2 pints for control of blackberry. Herbaceous weed control treatments were 4 ounces Arsenal® (BASF) Applicators Concentrate plus 2 ounces Oust® (E.I. DuPont de Nemours and Company, Wilmington, DE). Site descriptions are provided in table 1.

## RESULTS

### Chopper® + Bedding Provided a Robust Site Preparation Treatment

All Chopper® site preparation treatments controlled woody vegetation and provided reduced levels of herbaceous vegetation that resulted in good growing conditions for crop pines. Woody cover was < 5 percent in June of the first growing season at all locations. Mid-season (August) Chopper® applications improved control of established perennials such as bluestem grasses, swamp sunflower, bracken fern, and sumac. November Chopper® applications and higher Chopper® rates improved control of annuals or perennials that colonized the site after planting, such as fireweed, tall panic grass, and dogfennel.

The value of a single bedding pass plus Chopper® herbicide for site preparation was documented at the Kings Ferry, FL, site. This installation included a site preparation treatment consisting of two bedding passes only (no Chopper® application) for comparison. Without herbaceous weed control, pine stem volume index was 80 cubic inches following bedding plus Chopper® herbicide compared to 35 cubic inches following double bedding (fig. 1). The response to herbaceous weed control following bedding plus Chopper® herbicide was more than 50 percent greater than the response to herbaceous weed control following double bedding (fig. 1).

**Table 1—Summary of study site attributes**

Location	Bedding date	Planting date	Soils <sup>a</sup>
Oakdale, LA	7/25/01	1/14/02	MW to PD silt loam, Glenora/Caddo-Messer series
Kings Ferry, FL	5/18/01	12/7/01	CRIFF A group, PD clay, Meggett series
Green Swamp, NC	5/29/01	2/11/02	VP to PD sandy loam, Nakina/Grifton Series
Mt. Pleasant, GA	6/15/01	2/9/02	CRIFF C group, sandy surface, spodic at 12 to 36", argillic at 30 to 48"

<sup>a</sup> MW=medium-well drained, PD=poorly drained, VP=very poorly drained.

<sup>1</sup> Research Specialist, BASF Corporation, Research Triangle Park, NC 27709; and Research Analyst, Silvics Analytic, Richmond, VA 23238, respectively.

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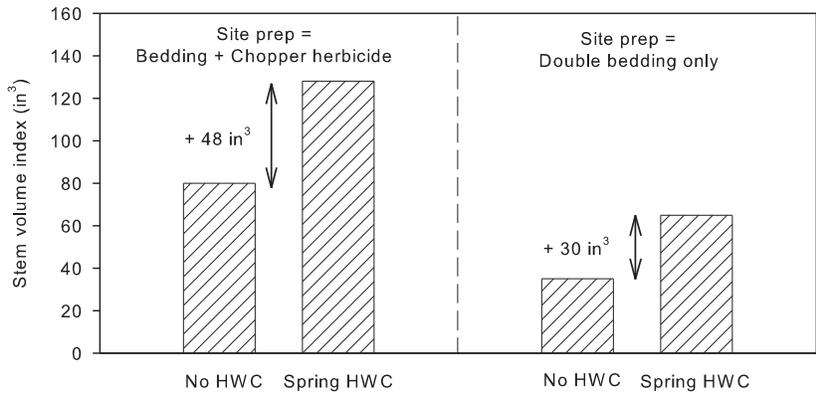


Figure 1—Pine growth after two growing seasons following bedding plus Chopper® herbicide site preparation compared to double bedding only (HWC=Herbaceous weed control).

The use of Chopper® site preparation is very important to performance of herbaceous weed control. Herbaceous weed control on bedded sites without Chopper® site preparation can release woody species that are not adequately controlled by the bedding alone. These uncontrolled woody species will continue to compete aggressively with pines for much of the rotation and can negate many of the benefits of herbaceous weed control (Miller and others 2003).

### Site-Specific Timing of Arsenal® Plus Oust® Herbaceous Weed Control

Sizable productivity gains are possible with site-specific timing of Arsenal plus Oust® herbaceous weed control following Chopper® herbicide site preparation. Competing vegetation cover in June of the first year of pine growth was a good indicator of the need for first or second year treatment (fig. 2, table 2). For the two sites with > 20 percent vegetation cover

in June of the first year, optimal timing for Arsenal® plus Oust® herbaceous weed control was early in the first year of pine growth. Good pine response to the June application of Arsenal® plus Oust® indicated that herbaceous weeds present later in the growing season do compete aggressively with pines. The Oakdale, LA, site demonstrated that when first-year colonization of herbaceous vegetation is aggressive, application of Arsenal® plus Oust® in June was better than waiting until the second year of pine growth. For the 2 sites with < 10 percent vegetation cover in June of the first year, the optimal timing for Arsenal® plus Oust® herbaceous weed control was the second year of pine growth.

From an operational planning standpoint, Arsenal® plus Oust® herbaceous weed control treatments offer maximum flexibility to managers. This combination of herbicides provides broad-spectrum control of weeds prior to emergence in addition to

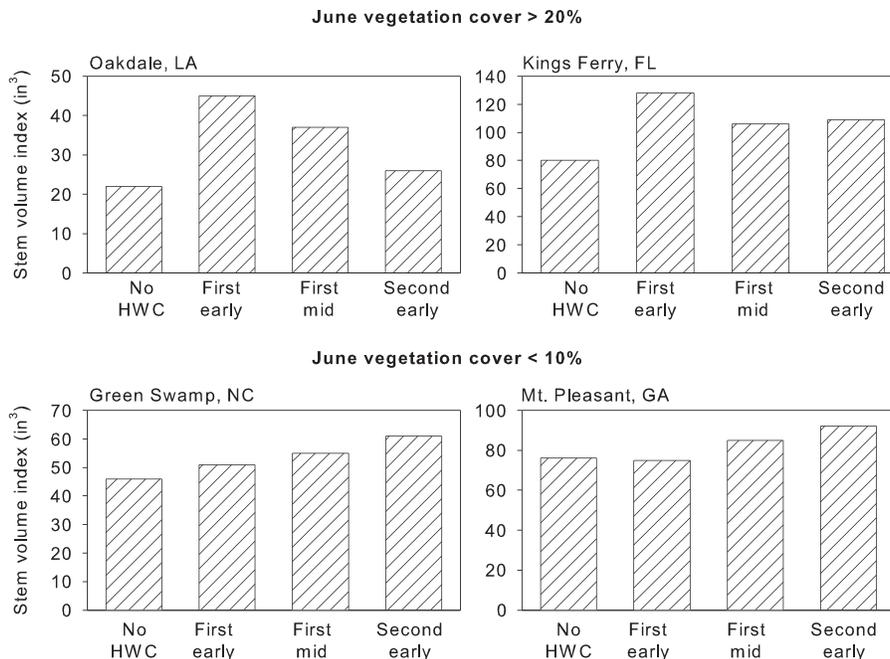


Figure 2—Pine response to different Arsenal plus Oust herbaceous weed control timings following site preparation with Chopper® herbicide.

**Table 2—Total vegetation cover and pine response through the first two growing seasons averaged by herbaceous weed control regime**

Herbaceous treatment timing	Vegetation cover (%)					Pine growth		
	Year 1			Year 2		Dia.	Ht.	Vol.
	June	Aug.	Oct.	June	Oct.			
						(in)	(ft)	(in <sup>3</sup> )
Oakdale, LA								
1. No weed control	27	71	93	85	97	1.1	4.5	22
2. First early	2	13	40	74	92	1.5	5.0	45
3. First mid	27	10	39	71	92	1.4	4.9	37
4. Second early	27	75	95	17	79	1.2	4.3	26
Kings Ferry, FL								
1. No weed control	27	36	46	68	75	1.8	6.7	80
2. First early	4	13	32	57	61	2.2	7.7	128
3. First mid	25	4	12	54	64	2.1	7.1	106
4. Second early	26	38	40	11	38	2.2	6.8	109
Green Swamp, NC								
1. No weed control	4	28	36	72	90	1.5	5.2	46
2. First early	2	10	14	63	88	1.6	5.3	51
3. First mid	4	4	6	61	86	1.6	5.6	55
4. Second early	4	29	37	9	29	1.7	5.3	61
Mt. Pleasant, GA								
1. No weed control	6	12	19	58	62	1.8	6.0	76
2. First early	3	5	7	51	60	1.9	5.7	75
3. First mid	4	3	3	44	57	2.0	6.0	85
4. Second early	4	9	17	7	20	2.1	5.9	92

broad-spectrum control of emerged herbaceous weeds. Arsenal® plus Oust® is tolerated well by loblolly pine in both the first and second years of pine growth. Prescription of herbaceous weed control timing on specific sites is dependent on our ability to predict June vegetation cover in advance. Sites in this study provide a small sampling of competing vegetation development under a limited set of management and environmental conditions. However, results indicate that soil texture is an important indicator of vegetation recolonization following site preparation with Chopper® herbicide. On coarser-textured soils (sandier soils), vegetation recolonization was slower than on finely textured soils (clays).

Other factors also impact vegetation recolonization: (1) Vegetation recolonization was slower following late season bedding (October through November) than following midseason bedding (Lauer and Quicke 2003); (2) Chopper® applied after mid-season bedding resulted in slower vegetation recolonization than Chopper® applied before midseason bedding (Lauer and Quicke 2003); and (3) rainfall patterns will also have an impact, with less rainfall resulting in slower vegetation recolonization.

While more studies installed over multiple years would provide a better inference base, results from this study indicate that immediate productivity benefits are possible with site-specific timing of Arsenal® plus Oust® herbaceous weed control following Chopper® site preparation. The following operations are recommended:

1. Use Chopper® in combination with bedding for site preparation. On sites with established perennial herbaceous species such as brackenfern or broomsedge, apply Chopper® during the active growing season (June through August). On other sites, apply Chopper® any time during the growing season.
2. On sites where vegetation cover is expected to exceed 20 percent by June of the first pine growing season, apply Arsenal plus Oust® early in the first pine growing season. If weather or other circumstances prevent early applications, spray anytime through June.
3. On sites where vegetation cover is expected to be < 10 percent by June of the first pine growing season, apply Arsenal® plus Oust® early in the second year of pine growth. If rainfall or other factors result in weeds developing faster than expected in the first year, spray anytime through June of the first year.

#### LITERATURE CITED

- Lauer, D.K.; Quicke, H.E. 2003. Timing of Chopper herbicide relative to bedding on Lower Coastal Plain pine sites. In: Dotray, P.A., ed. Proceedings, Southern Weed Science Society. Invasive weeds: real or imagined threat? 56: 131-132.
- Miller, J.H.; Zutter, B.R.; Zedaker, S.M. [and others]. 2003. Growth and yield relative to competition for loblolly pine plantations to midrotation – a Southeastern United States regional study. Southern Journal of Applied Forestry. 27(4): 237-252.

# INTENSIVE MANAGEMENT OF LOBLOLLY PINE DURING ESTABLISHMENT INFLUENCES NUTRITION AND PRODUCTIVITY THROUGH 15 GROWING SEASONS

James D. Haywood, Mary Anne Sword Sayer, and Allan E. Tiarks<sup>1</sup>

**Abstract**—Three cultural treatments in a 2<sup>3</sup> (yes or no) factorial combination were applied during establishment of a loblolly pine (*Pinus taeda* L.) plantation: phosphorus and nitrogen fertilization at planting, herbicide applications in the first 3 years, and litter application in the first year. Both the herbicide and litter treatments reduced loblolly pine survival. After 12 years, foliar phosphorus concentrations were still greater on the fertilized plots (0.98 g/kg) than on nonfertilized plots (0.73 g/kg), and fertilization had increased soil potassium, carbon, and nitrogen concentrations, probably indirect responses to improving the soil environment and changes in the understory plant community. The fertilization and herbicide treatments resulted in taller loblolly pine trees and greater volume per tree throughout 15 years. The litter treatment was ineffective after 15 years, but the fertilization and litter treatment combination resulted in the greatest loblolly pine volume/ha.

## INTRODUCTION

Herbicides are widely used for vegetation control in loblolly pine (*Pinus taeda* L.) plantations (Schultz 1997). However, where herbaceous plants are the primary competitors, herbicides are not the only vegetation management method available to reduce competition for light, water, and nutrients on pine planting sites (Haywood 2000). One option is to mulch or to keep forest floor litter relatively intact even after the overstory trees have been harvested. This is possible if litter is allowed to accumulate before harvest, herbicide or mechanical means are used to control the unmerchantable midstory trees and understory vegetation, and postharvest debris is shredded (Koch and McKenzie 1976). This option may be well suited to short-rotation forestry on intensively managed pine sites where possible losses in site productivity (Haywood and Tiarks 1995) could be mitigated by the beneficial retention of soil-covering mulch.

On sites of low fertility, such as those typically found on the West Gulf Coastal Plain, competing vegetation may limit nutrient availability to pine seedlings (Haywood and Tiarks 1990). On such sites, fertilization can result in greater loblolly pine growth (Allen 1987, Gent and others 1986, Haywood and Tiarks 1990, Jokela and others 2000, Schmidting 1984). Combinations of cultural treatments such as applying herbicides or mulch with fertilizer may further increase seedling productivity.

In this study, fertilizer, litter, and herbicides were applied in a 2<sup>3</sup> (yes and no) factorial combination (Cochran and Cox 1957) in a newly planted loblolly pine stand. We report on loblolly pine growth and yield, foliar nutrition, and soil chemistry through 15 growing seasons.

## METHODS

### Study Establishment

The study site is located on the Kisatchie National Forest in central Louisiana (long. 92°40' W., lat. 31°10' N.) at 75 m above sea level. The soil is a gently sloping (1 to 3 percent

Beauregard silt loam (fine-silty, siliceous, thermic Plinthaquic Paleudult) (Kerr and others 1980). The Beauregard soil is phosphorus (P) deficient (Tiarks 1982) and is well suited for forest management (Kerr and others 1980). Drainage is adequate and slope is sufficient so that ponding does not interfere with tree growth. The cover of grasses, forbs, and scattered hardwood and pine seedlings was rotary mowed and treated with herbicides in September 1987 (Haywood and others 2003).

Twenty-four 24.4- by 24.4-m treatment plots were established and grouped into three blocks of eight plots based on subsoil drainage (Haywood and others 1997). Plots were planted in November 1988, with 28-week-old container-grown loblolly pine seedlings using a planting punch of the correct size for the root plug. Each plot contained 10 rows of 10 planted pine trees spaced 2.44 m apart. The central six rows of six planted pine trees was the measurement plot (0.0214 ha).

The three cultural treatments were randomly assigned in each block in a 2<sup>3</sup> factorial randomized complete block design as follows (Cochran and Cox 1957):

Fertilization (F): 135 kg nitrogen (N)/ha and 151 kg P/ha broadcast as diammonium phosphate in March 1988 followed by 42 kg N/ha broadcast as urea in March 1989. The choice and rate of fertilizer were based on recommendations for loblolly pine grown on Beauregard silt loam soils (Tiarks 1982).

Herbicide application (H): annual post-planting applications of herbicides for mostly herbaceous plant control in the first through third growing seasons (1989 to 1991). Hexazinone [1.12 kg active ingredient (a.i.)/ha] and sulfometuron (0.21 kg a.i./ha) were broadcast in April 1989 and 1990. Spot applications of 1 percent glyphosate in aqueous solution were also applied for bluestem grass (*Andropogon* spp. and *Schizachyrium* spp.) control. In April 1991, glyphosate (1.55 kg a.i./ha) and sulfometuron (0.39 kg a.i./ha) were broadcast beneath the loblolly pine limbs followed by felling of volunteer woody competitors > 2.5 cm diameter at breast height (d.b.h.).

<sup>1</sup> Research Forester, Research Plant Physiologist, and Emeritus Research Soil Scientist, respectively, USDA Forest Service, Southern Research Station, Pineville, LA 71360.

Litter application (L): After planting, pine litter was broadcast over the plot surface to form a 10- to 15-cm litter layer. Pine litter was reapplied monthly through April 1989 to maintain the 10- to 15-cm depth. After litter application, four 1.25- by 1.25-m sections of the litter layer were randomly sampled from within the central measurement area of each plot. Samples were oven-dried at 70 °C, ground in a Wiley mill, and sieved through a 2-mm screen before determining the concentration of N by gas analysis. An additional sample was digested in acid before determining concentrations of calcium (Ca), potassium (K), magnesium (Mg), and P by spectrophotography. Results showed that we had applied 37 metric tons/ha (oven-dried weight) of litter, and it contained 200 kg N, 11 kg P, 13 kg K, 114 kg Ca, and 23 kg Mg on a per ha basis. Some of the litter was still present in the third growing season.

In the factorial design, the eight treatment combinations were check (no treatment), L, H, LH, F, FL, FH, and FLH.

### Measurements and Analyses

Within each measurement plot, we repeatedly measured the total height of all loblolly pines through 12 growing seasons (Haywood and others 2003) and again after 15 growing seasons using a laser instrument. Tree d.b.h. was measured with a diameter tape. Outside-bark volume per tree for ages 10, 12, and 15 years was calculated with Baldwin and Feduccia's (1987) equation.

In January 2001, foliar samples from the upper crown of half of the loblolly pines per plot were collected, and the needles were oven-dried at 70 °C, ground in a Wiley mill, and sieved through a 2-mm screen before determining percent N using a LECO CNS-2000 gas analyzer. An additional prepared sample was digested in acid before quantifying the concentrations of Ca, K, and Mg using a Perkin-Elmer 2100 atomic absorption spectrophotometer and the concentration of P with a Hewlett-Packard 8453 colorimetric spectrophotometer.

Ten soil samples to a 10-cm depth were randomly collected across each plot in 2002. After air-drying, samples were ground in a soil mill and sieved through a 2-mm screen before determining the percentages of C and N; Mehlich-3 extractable P (mg/kg of soil); and cmol/kg of Ca, K, Mg, and total cation exchange capacity using the same equipment as used in the foliar analyses. Soil pH in 10 g of soil/20 ml deionized water sample was measured using a Beckman-Coulter pH probe.

A repeated-measures 2<sup>3</sup> factorial randomized complete block model was used to analyze loblolly pine total height, volume per tree (dm<sup>3</sup>/tree) and volume per ha (m<sup>3</sup>/ha) at ages 10, 12 and 15 years to determine if changes in loblolly pine development were still occurring in response to the treatments (SAS Institute 1985). Main effects were F, H, and L, and these were considered fixed effects. For the main effects of age and interaction effects of age, the Huynh-Feldt correction was used in tests of significance. In our study, the correction made minuscule differences in the probabilities. A randomized complete block model was used to test treatment effects on the foliar nutrition variables collected after 12 growing seasons, soil pH and nutrition variables collected after 14 growing seasons, and loblolly pine survival after 15 growing seasons. All tests of significance were at  $\alpha = 0.05$ .

## RESULTS AND DISCUSSION

### Loblolly Pine Growth and Productivity

Survival was adversely affected by the H and L treatments at the beginning of the study (Haywood and others 1997), and these adverse effects were still significant after 15 years (table 1). However, despite lower average survival on the H and L plots, all treatment combinations were well stocked. After 15 years, survival among the 8 treatment combinations ranged from 73 to 95 percent (1,230 to 1,604 trees/ha) and averaged 87 percent (1,466 trees/ha).

Both the F and H treatments significantly affected loblolly pine height growth (fig. 1). However, the differences in height from ages 10 to 15 years remained similar between the F plots and the non-F (NF) plots and the H plots and the non-H (NH) plots, which resulted in an insignificant age-F and age-H interaction (table 2). After 15 years, trees on the F plots averaged 18 m tall and on the NF plots 16 m tall; trees on the H plots averaged 17 m tall and on the NH plots 16 m. The early height gains associated with the L treatment (Haywood and others 1997, 2003) faded after 15 years (fig. 1), which was expressed as a significant age-L interaction (table 2). Loblolly pine on both the L and non-L (NL) plots averaged 17 m tall after 15 years.

All three main effect treatments had at least some influence on volume per tree (table 2). However, the F and H plots continued to gain volume compared to the NF and NH plots from age 10 to 15 years, which was expressed as significant

**Table 1—Percent survival of loblolly pine after 15 growing seasons, degrees of freedom, probabilities of a greater F-value, and error mean square**

Treatments	Survival percent	
Check	95	
Herbicide (H)	87	
Litter (L)	89	
L and H	73	
Fertilization (F)	95	
F and H	88	
F and L	94	
F, L, and H	75	

Analysis sources	Degrees of freedom	Probabilities of a greater F-value
Block	2	0.9316
F	1	0.4995
L	1	0.0129
H	1	0.0008
Interactions		
F – L	1	0.5983
F – H	1	0.8206
L – H	1	0.1281
F – L – H	1	0.7059
EMS	14	54.1961

EMS = error mean square.

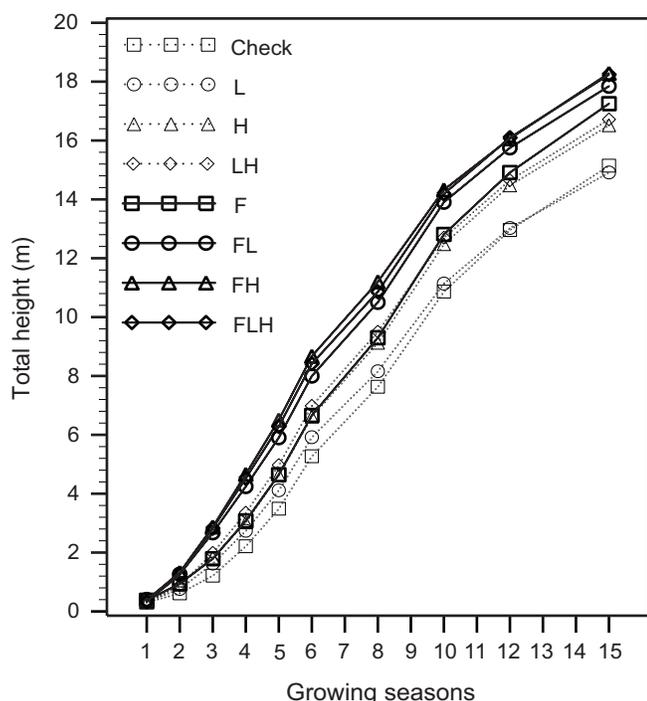


Figure 1—Total height (m) of loblolly pine through 15 growing seasons: Check = no treatment, L = litter, H = herbicides, F = fertilizers were applied.

age-F and age-H interactions. The L plots showed little gain in volume compared to the NL plots over the same period, and as a result there was not a significant age-L interaction. The F, H, and L plots averaged 312, 303, and 284 dm<sup>3</sup>/tree; and the NF, NH, and NL plots averaged 232, 241, and 259 dm<sup>3</sup>/tree, respectively, after 15 years (table 3).

Loblolly pine volume/ha was influenced by both survival and volume per tree. Although the H treatment reduced survival, the H plots still had significantly more volume/ha than the NH plots (table 2). Litter application also reduced survival, and because it only marginally increased volume per tree, the L treatment had no effect on stand yields after 15 years. Fertilization had the greatest influence on stand yields among the main-effect treatments. The F, H, and L plots averaged 458, 406, and 390 m<sup>3</sup>/ha; and the NF, NH, and NL plots averaged 329, 380, and 396 m<sup>3</sup>/ha, respectively, after 15 years (table 3). There was an F-H interaction because the H treatment reduced survival on the FH plots; the NF-NH, NF-H, F-NH, and F-H treatment combinations averaged 296, 361, 464, and 451 m<sup>3</sup>/ha, respectively, after 15 years. There was also an age-F-H interaction (table 2), because the F-H interaction was only significant between ages 12 and 15 years.

### Nutrition

After three growing seasons, we found N dilution in plant tissues as loblolly pine growth responded to fertilization (Sword and others 1998). After 12 years, however, fertilization had

**Table 2—Degrees of freedom, probabilities of a greater F-value, and error mean squares for loblolly pine total height, outside bark volume per tree, and volume per ha based on the repeated measures randomized complete block design analyses for ages 10, 12, and 15 years**

Analysis sources	Degrees of freedom	Probabilities of a greater F-value <sup>a</sup>		
		Total height <i>m</i>	Volume per tree <i>dm<sup>3</sup>/stem</i>	Volume per ha <i>m<sup>3</sup>/ha</i>
<b>Between subjects</b>				
Block effect	2	0.2860	0.0689	0.1146
Fertilization (F)	1	<0.0001	<0.0001	<0.0001
Litter (L)	1	0.2577	0.0514	0.9805
Herbicide (H)	1	<0.0001	0.0002	0.0399
<b>Interactions</b>				
F – L	1	0.5332	0.7572	0.5566
F – H	1	0.0898	0.1559	0.0229
L – H	1	0.4144	0.7354	0.1065
F – L – H	1	0.2450	0.5116	0.2469
Error mean square	14	0.85461	2018.3377	2728.9674
<b>Within subjects</b>				
Stand age (years)	2	<0.0001	<0.0001	<0.0001
<b>Interactions</b>				
Age – Blocks	4	0.0002	0.0005	0.0006
Age – F	2	0.1518	<0.0001	<0.0001
Age – L	2	0.0164	0.4722	0.0839
Age – H	2	0.4272	0.0012	0.7608
Age – F – L	2	0.8594	0.7025	0.7701
Age – F – H	2	0.4581	0.0863	0.0102
Age – L – H	2	0.0063	0.1133	0.9893
Age – F – L – H	2	0.6824	0.7817	0.5613
Error mean square	28	0.01766	46.0567	67.9095

<sup>a</sup> For age and interactions-with-age effects, we used the Huynh-Feldt correction in tests of significance.

**Table 3—Least square means for loblolly pine volume per tree and volume per ha after 15 growing seasons**

Treatments	Volume	Volume
	per tree	per ha
	<i>dm<sup>3</sup>/stem</i>	<i>m<sup>3</sup>/ha</i>
Check	187	300
Herbicide (H)	252	369
Litter (L)	194	292
L and H	293	354
Fertilization (F)	277	445
F and H	320	471
F and L	304	483
F, L, and H	346	431

no effect on foliar N concentration, suggesting that the direct effect of N amendment on tree growth had subsided between ages 3 and 12 years (table 4). Nevertheless, N nutrition was not the primary factor limiting loblolly pine growth in this study, because foliar N concentrations at ages 3 and 12 years were above the sufficiency level of 11.0 g/kg across all treatments (Allen 1987).

The F treatment significantly increased average foliar P concentration of 3-year-old loblolly pine from 0.9 g/kg to 1.4 g/kg (Sword and others 1998). Unlike foliar N, foliar P concentration continued to be directly affected by P fertilization at planting through 12 years (table 4). The foliar P levels on the NF plots averaged 0.73 g/kg, and those on the F plots averaged 0.98

g/kg, which was still at the sufficiency level of 1.0 g/kg (Allen 1987). Concentrations of Mehlich-3 extractable P in the soil confirmed that after 14 growing seasons, the F plots still had more available soil P than the NF plots (table 5).

Comparison of foliar nutrition at ages 3 and 12 years suggests that the H and F treatments had secondary effects on loblolly pine nutrition and that these effects changed as the stand developed. For example, the H treatment did not affect the foliar P concentration of 3-year-old loblolly pine seedlings (Sword and others 1998), but it significantly increased foliar P concentrations by 7 percent, from 0.83 g/kg to 0.88 g/kg after 12 years (table 4). Although the positive effect of the H treatment on foliar P concentration after 12 years did not result in P sufficiency, this trend suggests that the H treatment influenced site conditions that control loblolly pine foliar P nutrition. As the stand developed, H- and F-induced changes in site conditions also may have resulted in opposing effects on foliar Mg concentration. Specifically, foliar Mg changed from being reduced to being unaffected by the H treatment and from being unaffected to being increased by the F treatment between ages 3 (Sword and others 1998) and 12 years (table 4).

The H treatment also affected soil fertility differently as the stand developed. In the fourth growing season, the H treatment reduced exchangeable K and Mg (Sword and others 1998). After 14 years, however, the H treatment had no effect on exchangeable K and Mg but resulted in significantly less total C by 12 percent, total N by 21 percent, and exchangeable Ca by 27 percent, compared to the NH plots (table 5). However, these reductions in N and Ca supply were not sufficient to affect foliar concentrations of N and Ca.

**Table 4—Concentrations of N, P, K, Ca, and Mg in the loblolly pine foliage after 12 growing seasons—degrees of freedom, probabilities of a greater F-value, and error mean squares**

Treatments	N	P	K	Ca	Mg	
	----- g/kg -----					
Check	11.9	0.71	3.45	1.56	0.95	
Herbicide (H)	11.7	0.74	3.34	1.46	0.92	
Litter (L)	12.0	0.69	3.06	1.50	0.91	
L and H	11.8	0.78	3.60	1.27	0.94	
Fertilization (F)	11.9	0.93	3.53	1.48	1.03	
F and H	11.6	0.98	3.55	1.56	0.99	
F and L	11.6	0.97	3.80	1.56	1.00	
F, L, and H	11.9	1.03	3.87	1.37	0.98	
Analysis sources	Degrees of freedom	----- Probabilities of a greater F-value -----				
Block	2	0.9844	0.1696	0.0106	0.5335	0.3780
F	1	0.7798	<0.0001	0.0001	0.5932	0.0287
L	1	0.8601	0.1830	0.0890	0.3077	0.5943
H	1	0.8190	0.0042	0.0505	0.2098	0.6607
Interactions						
F – L	1	0.8408	0.2859	0.0111	0.6901	0.9484
F – H	1	0.6940	0.8474	0.2119	0.5348	0.6006
L – H	1	0.6414	0.3407	0.0135	0.2545	0.5869
F – L – H	1	0.5701	0.4736	0.0313	0.7093	0.7247
EMS	14	0.00468	0.00179	0.02268	0.04192	0.00537

N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; EMS = error mean square.

**Table 5—Percent of C and N, concentration of Mehlich-3 extractable P, and K, Ca, Mg, and CEC in the soil after 14 growing seasons—degrees of freedom, probabilities of a greater F-value, and error mean squares**

Treatments	C	N	P	K	Ca	Mg	CEC
	--- percent ---		mg/kg		----- cmol/kg -----		
Check	1.10	0.051	1.56	0.061	0.72	0.28	3.11
Herbicide (H)	0.91	0.041	1.60	0.050	0.52	0.20	2.45
Litter (L)	1.14	0.056	1.71	0.065	0.82	0.34	3.33
L and H	1.01	0.041	1.62	0.054	0.43	0.39	2.38
Fertilization (F)	1.34	0.063	3.28	0.068	0.74	0.38	4.60
F and H	1.19	0.049	8.34	0.073	0.59	0.27	3.86
F and L	1.33	0.062	7.91	0.064	0.89	0.39	4.88
F, L, and H	1.24	0.053	11.07	0.068	0.77	0.28	3.97

Analysis sources	Degrees of freedom	----- Probabilities of a greater F-value -----						
Block	2	0.5525	0.7747	0.3141	<0.0001	0.7347	0.8951	0.0185
F	1	0.0022	0.0079	0.0094	0.0189	0.1741	0.4648	0.0138
L	1	0.4936	0.4517	0.3639	0.9478	0.3477	0.0674	0.8109
H	1	0.0383	0.0016	0.3260	0.4357	0.0322	0.0919	0.1505
Interactions								
F – L	1	0.7304	0.8967	0.3851	0.3229	0.4124	0.1159	0.9149
F – H	1	0.7597	0.7789	0.3194	0.0780	0.3697	0.1654	0.9838
L – H	1	0.6416	0.9558	0.8049	0.9351	0.6725	0.4121	0.8356
F – L – H	1	0.9483	0.4536	0.8281	0.9699	0.5427	0.3709	0.9584
EMS	14	0.02386	0.00006	24.0868	0.00010	0.04770	0.00682	1.7215

C = carbon; N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; CEC = cation exchange capacity; EMS=error mean square.

Herbicide application during establishment reduced herbaceous and woody competition through the third growing season and herbaceous competition through the eleventh growing season (Haywood and others 1997, 2003). Less competing vegetation and soil C after 14 growing seasons suggested that the H treatment decreased long-term organic matter inputs to the soil from non-pine fine root and foliage turnover. Because organic matter inputs to soil from the forest floor and roots are the primary source of soil N, P, Mg, and Ca (Johnson 1995), we hypothesized that reductions in herbaceous vegetation throughout stand development decreased the supply of N and Ca to the loblolly pine trees.

In contrast, 23 percent more total C, 20 percent more total N, 19 percent more exchangeable K, and 53 percent more cation exchange capacity in the soil were found on the F plots compared to the NF plots after 14 growing seasons (table 5). We attribute this secondary effect of fertilization to greater herbaceous and woody vegetation production, including the planted loblolly pine trees and, subsequently, more organic matter deposition in the soil.

Of particular interest at our study site are trends in foliar and soil K concentrations, as well as among the H, F, and L treatments. After three growing seasons, for example, foliar K was unaffected by the F treatment, averaging 5.4 g/kg across the study site (Sword and others 1998), which is well above the sufficiency value for loblolly pine of 3.5 g/kg (Allen 1987). After 12 years, however, foliar K concentrations were significantly affected by the F treatment (table 4). Specifically, fertilization maintained a sufficient foliar K concentration (3.7 g/kg),

while the NF treatment resulted in a foliar K concentration (3.4 g/kg) less than sufficient for optimum loblolly pine growth. As previously stated, we also found that the F treatment significantly increased soil K after 14 years.

After 12 years, neither the L nor H treatments alone affected foliar K levels, but the LH treatment combination improved foliar K so that its concentration was maintained above the sufficiency level of 3.5 g/kg (table 4). Also, only K exhibited a significant response to interactions of the L, H, and F treatments among the foliar mineral nutrients evaluated. Understory vegetation at ages 3 and 10 years was also affected by interactions of the L, H, and F treatments (Haywood and others 1997, 2003). After three growing seasons, for example, herbaceous biomass and the number of hardwood trees and blackberry canes/ha were significantly affected by a two-way interaction between the L and H treatments; and after 10 years, herbaceous biomass/ha was significantly affected by F-L, F-H, and L-H interactions. The K cycle is dominated by hydrologic processes rather than organic matter deposition (Johnson 1995). Therefore, throughfall, interception, and foliar and soil leaching conditions created by the vegetation communities in our study may have controlled the K nutrition of loblolly pine at our study site. Soil pH was unaffected by treatment and averaged 5.3 across the study site (data not shown).

#### MANAGEMENT RECOMMENDATIONS

Fertilization continues to be the best main-effect treatment in terms of loblolly pine survival, height growth, and volume

(Haywood and others 1997, 2003; table 3). If land managers are able to apply only one treatment, they should fertilize nutritionally deficient silt loam soils. Herbicides were effective in increasing average stem growth, but they were also associated with decreased survival. If comparable survival is expected among treatment options, herbicides are a viable choice, especially on sites where brush is a more important competitor than in this study. Retention of litter becomes less important over time (Haywood and others 1997, 2003; table 2). However, on a fertilized site, litter retention is a no-risk option, and, in fact, among the eight treatment combinations, the FL plots were the most productive (table 3). Therefore, keeping organic matter in place rather than destroying it during harvest, site preparation, and stand establishment is a sound alternative on intensively managed lands.

Fertilization improved the nutritional status of the soil. Increases in P in the foliage and soil were direct effects of fertilization. Other nutritional effects were probably long-term, indirect effects of either modified organic matter deposition to the soil or changes in understory vegetation. A higher level of foliar P among loblolly pines on the F plots was associated with gains in loblolly pine height and volume growth over 15 years (fig. 1, table 3). The benefits from fertilization, however, may not continue. Foliar P levels on the F plots had returned to the sufficiency level of 0.1 percent by growing season 12 (Allen 1987); gains in height from fertilization had also ceased; and 15 years is about as long as a P-fertilizer boost is expected to last (Pritchett and Gooding 1975). If this were a commercial venture, the fertilized stand would need to be thinned and refertilized. The herbicide and litter treatments also affected site quality, often in subtle ways.

## LITERATURE CITED

- Allen, H.L. 1987. Forest fertilizers nutrient amendment, stand productivity, and environmental impact. *Journal of Forestry*. 85(2): 37-46.
- Baldwin, V.C., Jr.; Feduccia, D.P. 1987. Loblolly pine growth and yield prediction for managed West Gulf plantations. Res. Pap. SO-236. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 27 p.
- Cochran, W.G.; Cox, G.M. 1957. *Experimental design*. 2<sup>d</sup> ed. New York: John Wiley. 611 p.
- Gent, J.A.; Allen, H.L.; Campbell, R.G.; Wells, C.G. 1986. Magnitude, duration, and economic analysis of loblolly pine growth response following bedding and phosphorus fertilization. *Southern Journal of Applied Forestry*. 10(3): 124-128.
- Haywood, J.D. 2000. Mulch and hexazinone herbicide shorten the time longleaf pine seedlings are in the grass stage and increase height growth. *New Forests*. 19: 279-290.
- Haywood, J.D.; Tiarks, A.E. 1990. Eleventh-year results of fertilization, herbaceous, and woody plant control in a loblolly pine plantation. *Southern Journal of Applied Forestry*. 14(4): 173-177.
- Haywood, J.D.; Tiarks, A.E. 1995. Growth reductions in short-rotation loblolly and slash pines in central Louisiana: 10<sup>th</sup> year results. In: Edwards, M.B., comp. *Proceedings of the eighth biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 268-274.
- Haywood, J.D.; Tiarks, A.E.; Sword, M.A. 1997. Fertilization, weed control, and pine litter influence loblolly pine stem productivity and root development. *New Forests*. 14: 233-249.
- Haywood, J.D.; Goelz, J.C.; Sword Sayer, M.A.; Tiarks, A.E. 2003. Influence of fertilization, weed control, and pine litter on loblolly pine growth and productivity and understory plant development through 12 growing seasons. *Canadian Journal of Forest Research*. 33: 1974-1982.
- Johnson, D.W. 1995. Role of carbon in the cycling of other nutrients in forested ecosystems. In: McFee, W.W.; Kelly, J.M., eds. *Carbon forms and functions in forest soils*. Madison, WI: Soil Science Society of America: 299-328.
- Jokela, E.J.; Wilson, D.S.; Allen, J.E. 2000. Early growth responses of slash and loblolly pine following fertilization and herbaceous weed control treatments at establishment. *Southern Journal of Applied Forestry*. 24(1): 23-30.
- Kerr, A. Jr.; Griffis B.J.; Powell J.W. [and others]. 1980. *Soil survey of Rapides Parish, Louisiana*. Baton Rouge, LA: U.S. Department of Agriculture, Soil Conservation Service and Forest Service in cooperation with Louisiana State University, Louisiana Agricultural Experiment Station. 86 p.
- Koch, P.; McKenzie, D.W. 1976. Machine to harvest slash, brush, and thinnings for fuel and fiber: a concept. *Journal of Forestry*. 74(12): 809-812.
- Pritchett, W.L.; Gooding, J.W. 1975. *Fertilizer recommendations for pines in the southeastern coastal plain of the United States*. Bulletin 774. Gainesville, FL: University of Florida, Agricultural Experiment Stations, Institute of Food and Agricultural Sciences. 23 p.
- SAS Institute, 1985. *SAS User's guide: statistics*. 5<sup>th</sup> ed. Cary, NC: SAS Institute. 956 p.
- Schmidtling, R.C. 1984. Early intensive culture affects long-term growth of loblolly pine trees. *Forest Science*. 30(2): 491-498.
- Schultz, R.P. 1997. Loblolly pine: the ecology and culture of loblolly pine (*Pinus taeda* L.). *Agric. Handb.* 713. Washington, DC: U.S. Department of Agriculture, Forest Service: 1-1 to 12-27.
- Sword, M.A.; Tiarks, A.E.; Haywood, J.D. 1998. Establishment treatments affect the relationships among nutrition, productivity and competing vegetation of loblolly pine saplings on a Gulf Coastal Plain site. *Forest Ecology and Management*. 105: 175-188.
- Tiarks A.E. 1982. Phosphorus sorption curves for evaluating phosphorus requirements of loblolly pine (*Pinus taeda*). *Communications in Soil Science and Plant Analysis*. 13(8): 619-631.

# ELEVEN-YEAR LOBLOLLY PINE GROWTH IN RESPONSE TO SITE PREPARATION AND SEEDLING TYPE IN NORTH LOUISIANA

Michael A. Blazier and Terry R. Clason<sup>1</sup>

**Abstract**—On a well-drained site in northwest Louisiana, effects of seedling type (container, bareroot) and herbicide site preparation (hexazinone, hexazinone + sulfometuron, imazapyr + metsulfuron) on loblolly pine growth and survival have been tested for 11 years. All possible combinations of these treatments were applied to loblolly pine planted at 302 trees acre<sup>-1</sup>, and these treatments were compared to a special control treatment planted at a spacing of 605 trees acre<sup>-1</sup> to test tree density effects on yields. Results indicate container seedlings may be preferable to bareroot seedlings as planting stock for a well-drained site, and herbicide site preparation mixtures that provide broad-spectrum control are most effective in producing long-term growth benefits. Further research will be necessary to ascertain the effects of planting density on yields and product classes, but results thus far suggest container seedlings planted at a wide spacing are a viable management option for this type of site.

## INTRODUCTION

Well-drained soils are among the most problematic soils on which to establish and profitably manage loblolly pine (*Pinus taeda* L.) plantations in the Western Gulf region. Such soils are associated with relatively poor loblolly pine survival and growth due to inadequate moisture and nutrient supply and retention (Pritchett and Fisher 1987). Management practices that promote the allocation of moisture and nutrients to crop trees can increase the feasibility of managing loblolly pine plantations on such sites.

Inter-specific competition for moisture and nutrients from herbaceous and woody vegetation can be effectively suppressed with herbicides (Cain and Barnett 2002, Dixon and Clay 2004, Zutter and others 1999), particularly when using herbicide combinations that provide broad-spectrum control of understory vegetation (Yeiser and others 2004). Intra-specific competition for moisture and nutrients can be reduced on adverse sites early in the rotation by planting at lower densities (Schultz 1997). However, it is common for forest managers to plant at relatively high densities on inferior sites due to perceived survival problems. This tendency to plant “extra” trees to compensate for initial seedling mortality can negatively impact revenue over the course of the rotation by raising planting costs and reducing average diameter growth, resulting in fewer trees in the more valuable product classes (Dean and Chang 2002).

With their relatively higher root densities, container seedlings are superior to bareroot seedlings in their ability to gather moisture and nutrients immediately after planting. Consequently, early-rotation survival and growth is often significantly greater for container seedlings than for bareroot seedlings (Haywood and Barnett 1994, McDonald 1991). The survival and growth advantages of container seedlings are most pronounced on drought-prone sites (Barnett and Brissette 1986, South and Barnett 1986). However, container seedlings are as much as twice the cost of bareroot seedlings.

A combination of inter- and intra-specific competition control and seedling type selection may yield the best means by

which loblolly pine plantations can be established and profitably managed on droughty soils. However, there is a relative lack of long-term studies on how these silvicultural treatments act in concert on such sites. The objective of this study was to observe the survival and growth of loblolly pine in response to seedling type, a variety of herbicide site preparation treatments, and planting density on a well-drained soil in northern Louisiana.

## METHODS

In 1993, a loblolly pine plantation was planted at the Louisiana State University AgCenter Hill Farm Research Station in northwest Louisiana (32° 44'N, 93° 03' W) on a gravelly, fine sandy loam Darley-Sacul soil (an association of a fine, kaolinitic, thermic Hapludult and a fine, mixed, active, thermic Aquic Hapludult). This well-drained soil type is common in upland forests of northwestern Louisiana, southwestern Arkansas, and eastern Texas (USDA SCS 1989). Drought conditions are common in the region because late summer precipitation is typically substantially below potential evapotranspiration during the same period (fig. 1).

The effects of seedling type were tested by comparing growth and survival of container seedlings to that of bareroot seedlings. All container and bareroot seedlings were of the same loblolly pine family; the family was selected due to its good growth potential on well-drained soils. The effects of the herbicide formulation and timing used for chemical site preparation on loblolly pine growth and survival were assessed with four treatments listed in table 1. Herbicides were band-applied around seedlings on a 6-foot-wide swath using backpack sprayers. Seedlings receiving all possible combinations of these seedling type/herbicide treatments were planted on a 6 foot x 24 foot spacing (302 trees acre<sup>-1</sup>). This seedling density is nearly half that conventionally planted on similar sites.

A special control (CONV) treatment was also established to compare the effects of the seedling type x herbicide treatments on widely spaced loblolly pine survival and growth to

<sup>1</sup> Assistant Professor, Hill Farm Research Station, Louisiana State University AgCenter, Homer, LA 71040; and State Forester, USDA Natural Resources Conservation Service, Alexandria, LA 71302, respectively.

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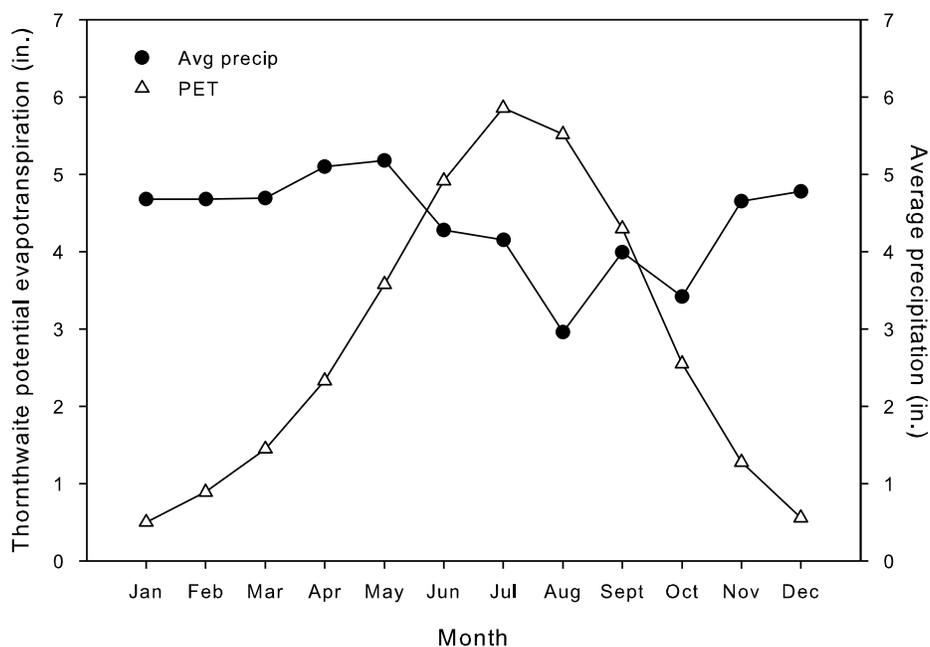


Figure 1—Average annual precipitation (Avg precip) and potential evapotranspiration (PET) for Claiborne Parish, LA.

**Table 1—Herbicide treatments applied to a loblolly pine plantation on a well-drained soil in north Louisiana**

Treatment	Herbicides	Application rate	Application date
		<i>lb acre<sup>-1</sup></i>	
LOHEX	Hexazinone	1.50	Spring pre-plant
HIHEX	Hexazinone	4.00	Summer post-plant
HEXSULF	Hexazinone,	1.50	Spring pre-plant
	Sulfometuron methyl	0.13	Summer post-plant
IMAZMET <sup>a</sup>	Imazapyr,	0.75	Summer post-plant
	Metsulfuron methyl	0.04	Summer post-plant

<sup>a</sup> Imazapyr and metsulfuron methyl were tank-mixed.

that associated with a more conventional combination of seedling type, herbicide, and planting spacing. The CONV treatment consisted of bareroot seedlings planted on a 6 foot x 12 foot spacing (605 trees acre<sup>-1</sup>) with a pre-plant application of 1.5 pounds hexazinone acre<sup>-1</sup> and post-plant application of 1 ounce sulfometuron methyl acre<sup>-1</sup> used for site preparation. This study design was thus comprised of a 2 x 4 treatment structure plus a control arranged in a randomized complete block design, with slope as a blocking factor. All seedling type x herbicide treatment combinations and the control treatment were replicated three times and applied to 0.10-acre plots.

In 1994, survival of seedlings after the first growing season was measured. In 2003, survival, height, and d.b.h. of all trees were measured. The height and d.b.h. measurements were used to estimate total outside-bark tree volume using the model developed by Van Deusen and others (1981).

Analyses of the seedling type x herbicide treatments applied to the widely spaced trees were conducted by analysis of variance (ANOVA) using the MIXED procedure of the SAS

System (SAS Institute, Inc., Cary, NC). Because no significant seedling type x herbicide interactions were found, when an ANOVA indicated significant ( $P < 0.05$ ) treatment effects, treatment means were calculated and separated by the DIFF option of the LSMEANS procedure. The DIFF option provided multiple comparisons of treatment means by invoking t-tests to determine significant differences between all possible treatment combinations. CONTRAST statements were used to evaluate treatment differences between the seedling type x herbicide treatments applied to the widely spaced trees and the CONV treatment.

## RESULTS AND DISCUSSION

Barnett and McGilvray (1993) found that survival differences between container and bareroot loblolly pine seedlings were most pronounced under stressful environmental conditions in the first growing season. In our study, survival of loblolly pines of container origin also significantly exceeded that of the bareroot seedlings planted at both wide and conventional spacings in 1994 and 2003 (table 2). These findings suggest

a long-term survival advantage to planting container seedlings on edaphically and/or environmentally adverse sites. Haywood and Barnett (1994) similarly found greater survival through age 15 of loblolly pine of container origin relative to that of bareroot origin on a silt loam soil in central Louisiana. However, the magnitude of difference between the survival of container and bareroot trees at our site was nearly three times that observed in that study, which suggests a greater advantage to planting container seedlings on well-drained sites.

Among trees planted at the wide spacing, there were no significant differences in survival attributable to the herbicide treatments in either 1994 or 2003 (table 3). However, survival associated with the CONV treatment was significantly lower than that of the HEXSULF treatment in 1994 and 2003. Furthermore, survival of the CONV treatment was moderately ( $0.05 < P < 0.10$ ) lower than that of the LOHEX, HIHEX, and IMAZMET treatments in 2003. Short-term survival and growth benefits of hexazinone and sulfometuron methyl mixtures have been well-documented (Miller and others 1994, Zutter and others 1987), and such mixtures have consequently become an industry standard (Muir and Zutter 1999, Yeiser and others 2004).

Individual-tree volume of the container trees in 2003 was significantly greater than that of bareroot seedlings planted at the wide and conventional spacings (table 2). This finding contrasts with that of Haywood and Barnett (1994), in which volume per tree was comparable between 15-year-old container and bareroot trees on a silt loam soil. The lack of difference in volume per tree among the bareroot seedlings planted at the conventional and low densities may indicate that intra-specific competition for site resources has not begun by age 11 even at the higher stand density.

Among the trees planted at the wide spacing, the HEXSULF and IMAZMET herbicide treatments produced the highest volumes per tree (table 3), which underscores the growth advantages conferred by broad-spectrum chemical site preparation on this well-drained site. The LOHEX treatment produced the lowest volumes per tree; the hexazinone rate of the LOHEX treatment was well below the optimum rate for hexazinone applied alone (Yeiser and others 2004) and likely did not adequately suppress understory vegetation. The HEXSULF treatment consisted of a hexazinone rate and timing identical to that of the LOHEX treatment, and its significantly greater volume per tree may indicate that the suite of

**Table 2—Effects of a conventional planting practice relative to bareroot and container seedlings planted at low density on loblolly pine survival and growth on a well-drained site in north Louisiana<sup>a</sup>**

Seedling type <sup>b</sup>	1994 survival	2003 survival	Tree volume	Stand volume	Stand BA <sup>c</sup>
	%	%	ft <sup>3</sup>	ft <sup>3</sup> ac <sup>-1</sup>	ft <sup>2</sup> ac <sup>-1</sup>
CONV	84b	66b	1.76b	808.4a	84.3a
BARE	85b	73b	1.69b	368.5c	38.7c
CONT	95a	89a	2.12a	565.2b	55.2b

<sup>a</sup> Means within columns followed by different letters differ significantly at  $P < 0.05$ .

<sup>b</sup> CONV = conventional planting practice (bareroot seedlings planted at 605 trees per acre); BARE = bareroot seedlings planted at 302 trees per acre; CONT = container seedlings planted at 302 trees per acre.

<sup>c</sup> BA = basal area.

**Table 3—Effects of a conventional planting practice relative to diverse chemical site preparation treatments applied to a low-density loblolly pine plantation on loblolly pine survival and growth on a well-drained site in north Louisiana<sup>a</sup>**

Seedling type <sup>b</sup>	1994 survival	2003 survival	Tree volume	Stand volume	Stand BA <sup>c</sup>
	%	%	ft <sup>3</sup>	ft <sup>3</sup> ac <sup>-1</sup>	ft <sup>2</sup> ac <sup>-1</sup>
CONV	84 b	66 b	1.76 b	808.4 a	84.3 a
LOHEX	89 ab	77 ab	1.68 c	407.7 c	42.3 c
HIHEX	88 ab	77 ab	1.88 b	447.4 c	44.9 c
HEXSULF	92 a	83 a	2.08 a	528.7 b	50.9 b
IMAZMET	87 ab	77 ab	1.97 ab	483.6 bc	47.7 bc

<sup>a</sup> Means within columns followed by different letters differ significantly at  $P < 0.05$ .

<sup>b</sup> CONV = conventional planting practice (605 seedlings planted per acre, pre-plant application of 1.5 pounds hexazinone, post-plant application of 0.13 pound sulfometuron acre<sup>-1</sup>); LOHEX = 302 seedlings planted per acre, pre-plant application of 1.5 pounds hexazinone per acre; HIHEX = 302 seedling planted per acre, post-plant application of 4.0 pounds hexazinone per acre; HEXSULF = 302 seedlings planted per acre, pre-plant application of 1.5 pounds hexazinone per acre, post-plant application of 0.13 pound sulfometuron per acre; IMAZMET = 302 seedlings planted per acre, post-plant application of 0.75 pound imazapyr + 0.04 pound metsulfuron per acre.

<sup>c</sup> BA = basal area.

vegetation controlled by sulfometuron on this site was a substantial competitor for site resources. Volume per tree associated with the CONV treatment was significantly lower than that of the HEXSULF treatment.

When compared to all seedling type x herbicide treatments, the CONV treatment had the highest stand volume and basal area due to its higher tree density (tables 2 and 3). Between the seedling types planted at the wider spacing, the container trees had significantly higher stand volume due to higher survival and individual-tree volumes. Among the herbicide treatments applied to widely spaced trees, the LOHEX treatment produced stand volumes significantly lower than that of all other treatments. Stand density may influence the product class of logs cut in intermediate harvests (Dean and Chang 2002). Stand basal area is currently much higher in plots receiving the CONV treatment, so thinning likely must occur sooner in those plots to stave off competition-induced mortality. Given the lower volumes per tree, it is likely that most material harvested in the first thinning will be in the relatively low-value pulpwood product class. As a result of the lower stand basal area and relatively high volumes per tree currently observed in the container treatments, thinning will likely occur later and more logs harvested in the first thinning may be of the higher-value chip-n-saw product class. Such a phenomenon would markedly increase the rate of return associated with planting container seedlings at 302 trees acre<sup>-1</sup> at this site. However, the larger crowns and branch diameters commonly associated trees planted at the wider spacing may be detrimental to product quality as well (Huang and others 2005), but the wider spacing would facilitate traffic of equipment used for pruning. Due to the low stand basal area and volumes per tree currently observed in the plots planted with bareroot seedlings at 302 trees acre<sup>-1</sup>, there will likely be less material harvested in the first thinning relative to the container plots. If so, the return rates for planting bareroot material at wide spacing may be lower than that of planting container seedlings at the same spacing.

## CONCLUSIONS

On this well-drained site, planting container seedlings dramatically increased pine growth relative to planting bareroot seedlings. The long-term survival and growth benefits of container seedlings highlight the importance of planting seedlings with a good ability to gather moisture and nutrients on an adverse site. As such, planting container seedlings may be preferable to planting bareroot seedlings on a well-drained site.

Using herbicide mixtures that provided broad-spectrum control also produced lasting survival and growth benefits on this site, which underscores the value of reallocating moisture and nutrients to crop trees with herbicides on such sites. The hexazinone + sulfometuron and imazapyr + metsulfuron mixtures used in this study have become an industry standard for site preparation since this study's establishment. In fact, pre-mixed granular blends of hexazinone and sulfometuron (which produced the best survival and tree growth in this study) are now available.

The effects of planting density on the productivity and profitability of managing a pine plantation on this site are less clear at this stage of the study, but a more thorough exploration of product quality issues will be pursued as this study progresses.

## LITERATURE CITED

- Barnett, J.P.; Brissette, J.C. 1986. Producing southern pine seedlings in containers. Gen. Tech. Rep. SO-59. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Experiment Station. 71 p.
- Barnett, J.P.; McGilvray, J.M. 1993. Performance of container and bareroot loblolly pine seedlings on bottomlands in South Carolina. Southern Journal of Applied Forestry. 17: 80-83.
- Cain, M.D.; Barnett, J.P. 2002. Effects of early release on natural versus container loblolly pines 12 years after establishment. Southern Journal of Applied Forestry. 26: 173-180.
- Dean, T.J.; Chang, S.J. 2002. Economic rationale for planting less trees in the face of seedling mortality. In: Outcalt, K., ed. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 149-152.
- Dixon, F.L.; Clay, D.V. 2004. Effect of herbicides applied pre- and post-emergence on forestry weeds grown from seed. Crop Protection. 23: 713-721.
- Haywood, J.D.; Barnett, J.P. 1994. Comparing methods of artificially regenerating loblolly and slash pines: Container planting, bareroot planting, and spot seeding. Tree Planter's Notes. 45: 63-67.
- Huang, C.; Kronrad, G.D.; Morton, J.D. 2005. The financially optimum loblolly pine planting density and management regime for nonindustrial private forestland in East Texas. Southern Journal of Applied Forestry. 29: 16-21.
- McDonald, P.M. 1991. Container seedlings outperform bareroot stock: Survival and growth after 10 years. New Forests. 5: 147-156.
- Miller, J.H.; Busby, R.L.; Zutter, B.R. [and others]. 1994. Response of loblolly pine to complete woody and herbaceous control: Projected yields and economic outcomes—the COMP project. In: Edwards, M.B., comp. Proceedings of the eighth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 81-89.
- Muir, R.L., Jr.; Zutter, B.R. 1999. Pre-emergent herbaceous weed control screenings in loblolly pine (*Pinus taeda*) plantations in the Coastal Plain and Piedmont: First-year results. Auburn University, AL: Auburn University Silvicultural Herbicide Cooperative. Research Note 98-5. 10 p.
- Pritchett, W.L.; Fisher, R.F. 1987. Physical properties of forest soils. In: Properties and management of forest soils. New York, NY: John Wiley & Sons, Inc. 114-115.
- Schultz, R.P. 1997. Loblolly pine: The ecology and culture of loblolly pine. Agric. Handb. 713. Washington, DC: U.S. Department of Agriculture, Forest Service. 514 p.
- South, D.B.; Barnett, J.P. 1986. Herbicides and planting date affect early performance of container-grown and bare-root loblolly pine seedlings in Alabama. New Forests. 1: 17-27.
- United States Department of Agriculture, Soil Conservation Service (USDA SCS). 1989. Soil survey of Claiborne Parish, Louisiana. 147 p.
- Van Deusen, P.C.; Sullivan, A.D.; Matney, T.G. 1981. A prediction system for cubic foot volume of loblolly pine applicable through much of its range. Southern Journal of Applied Forestry. 5: 186-189.
- Yeiser, J.L.; Temple Chair, T.L.L.; Ezell, A.W. 2004. Oustar herbicide for efficient herbaceous weed control and enhanced loblolly pine seedling performance in the Southeastern U.S. Forest Ecology and Management. 192: 207-215.
- Zutter, B.R.; Glover, G.R.; Gjerstad, D.H. 1987. Vegetation response to intensity of herbaceous weed control in a newly planted loblolly pine plantation. New Forests. 4: 257-271.
- Zutter, B.R.; Edwards, M.B.; Newbold, R.A. [and others]. 1999. Fascicle nutrient and biomass responses of young loblolly pine to control of woody and herbaceous competitors. Canadian Journal of Forest Research. 29: 917-925.

# HARDWOOD VIGOR AND SURVIVAL FOLLOWING APPLICATIONS OF IMAZAPYR IN MID-ROTATION PINE PLANTATIONS

Prabudhda Dahal, Hal O. Liechty, Bryan Rugar, Conner Fristoe, and Eric Heitzman<sup>1</sup>

**Abstract**—Tree vigor, live crown ratios, dieback, and survival of hardwood competition were monitored for 2 years following a fall application (16 ounces per acre) of imazapyr on 4 stands of loblolly pine (*Pinus taeda* L.) in the Gulf Coastal Plain of Louisiana and Arkansas. Assessments during the first growing season following application indicated that 87 to 98 percent of the hardwood stems were completely defoliated or had 80 percent or more crown dieback. The lowest levels of defoliation and dieback occurred in the densest stands. Typically, the crowns of the recovered hardwoods had some level of dieback, but live crown ratios of these trees were similar to those found in control areas. Differences in mortality and recovery were evident among species.

## INTRODUCTION

Herbicides are extensively used to operationally control brush and hardwood competition in loblolly pine stands (Schultz 1997). Brush and hardwoods compete aggressively for available site resources and thus may reduce crop tree growth and survival. Weed management is most critical during stand initiation to ensure high survival rates and successful establishment of loblolly pine seedlings (Will and others 2002, Zutter and others 1999). As the stand reaches canopy closure, the degree to which further control of competition within or below the stand canopy benefits pine crop tree growth and productivity is poorly documented. As part of a study investigating the effect of competition control and fertilization on mid-rotation pine stands, we are monitoring the response of hardwood and brush to herbicide application following initial thinning. The objectives of this part of the study are to (1) evaluate the impact of herbicide application on hardwood vigor and crown characteristics, (2) determine the extent of hardwood mortality and the timing of mortality from herbicide application, and (3) examine the variation in responses of the various hardwood species found in these stands.

## METHODS

The study was established in four stands within the Gulf Coastal Plain of Arkansas and Louisiana at least 1 year after an initial thinning operation. Sites were established in the years 2001 and 2002. Two sites, Marion and Crossroads, were located in Union Parish, LA, while the other two sites, South Crossett and West Crossett, were located in Ashley County, AR.

Soils in all four sites were either classified as Alfisols or Ultisols and were somewhat poorly- to poorly-drained. Loblolly pine was the most dominant overstory species in these stands accounting for approximately 89 percent of the total basal area measured in the sites. Sweetgum (*Liquidambar styraciflua* L.), red maple (*Acer rubrum* L.), blackgum (*Nyssa sylvatica* Marsh.), and water oak (*Quercus nigra* L.) represented 67 percent of the basal area of the hardwood and brush species greater than 1 inch d.b.h. These four hardwood species also accounted for 64 percent of the hardwoods and

shrubs. The two Louisiana sites had the lowest pine and highest hardwood basal area. The total basal area ranged from a low of 66.3 square feet per acre at the Marion site to 124.4 square feet per acre at the West Crossett site. The proportion of hardwood and shrub to pine basal area ranged from approximately 6.5 percent to 20.1 percent. Thus the four sites comprised a wide range of stand densities as well as diversity in stand composition.

A total of 12 plots were established in each stand. Plots were 0.08 to 0.24 acre in size. Imazapyr was operationally applied to 6 plots within each stand by aircraft at a rate of 16 ounces with 3.2 ounces of surfactant per acre in September or October. All trees > 1 inch d.b.h. were annually measured during the dormant season. Herbicide application occurred just prior to the first tree measurements and leaf fall. Crown vigor, percent live crown, percent dieback, and percent normal foliage were determined in early summer during the next two growing seasons following herbicide application for each non-conifer species. These measurements were based on the U.S. Department of Agriculture forest health measurement guidelines (USDA Forest Service 1999). Crown vigor was quantified using four classes. The crown vigor was assigned class 1 if the live crown ratio was  $\geq 40$  percent,  $\geq 80$  percent of the foliage was normal, and there was  $\leq 10$  percent tree dieback. Foliage was considered normal if 50 percent of leaf was not damaged or missing. Similarly, the trees that did not meet the criteria for class 1 or 3 but had  $\geq 30$  percent normal foliage and  $\leq 70$  percent dieback was categorized as class 2. Species with any live crown ratio, 0 to 20 percent normal foliage, and any amount of dieback was classified as class 3. Trees with no visible live foliage or buds were classified as class 4.

## RESULTS AND DISCUSSION

### Crown Vigor and Defoliation

A drastic reduction of crown vigor was apparent as a result of herbicide application. In addition, the majority of the hardwood trees in the herbicide plot were defoliated following herbicide application (fig. 1). A total of 77 percent of the hardwood trees

<sup>1</sup> Program Technician, Associate Professor, and Graduate Research Assistant, respectively, School of Forest Resources, University of Arkansas at Monticello, Monticello, AR 71656; Silviculture Coordinator, Southwest Region, Plum Creek Timber Company, Crossett, AR 71635; and Assistant Professor, Division of Forestry, West Virginia University, Morgantown, WV 26506.

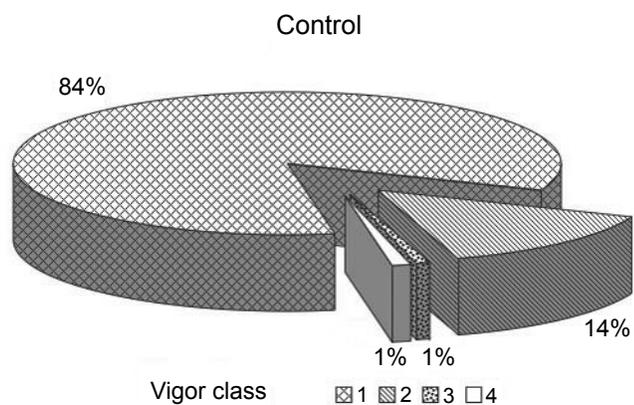


Figure 1—Hardwood crown vigor during the growing season following herbicide application.

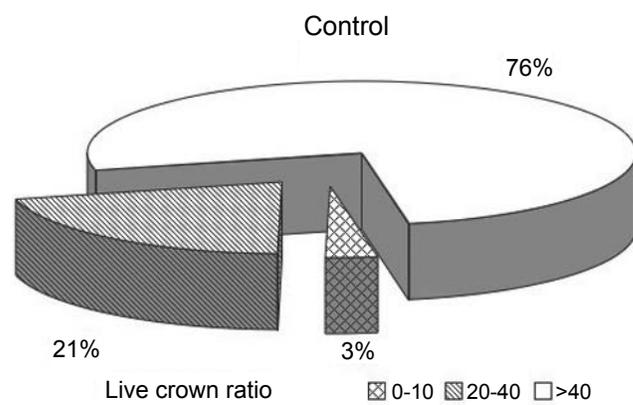


Figure 2—Hardwood live crown ratio during the growing season following herbicide application.

in the herbicide plots (crown vigor class 3 and 4) were entirely defoliated or contained only sporadic deformed leaves early in the growing season following herbicide application. In the control treatment, the majority of the hardwood stems had live crown ratios > 40 percent (fig. 2). In the herbicide treatment, 60 percent of the trees had live crown ratios of ≤ 10 percent.

### Mortality

Hardwood mortality differed among sites (table 1). Mortality at the end of the first growing season following herbicide application was greater in the two Louisiana sites (40 to 50 percent) than in the two Arkansas sites (26 to 27 percent). Prior to imazapyr application, hardwood and shrubs comprised a greater proportion of the basal area at the Louisiana sites (15 to 17 percent) than the Arkansas sites (4 to 6 percent).

**Table 1—Hardwood mortality as a proportion of standing basal area and density at the end of the first growing season following herbicide application**

Site	Control		Herbicide	
	Trees	BA	Trees	BA
----- % per acre -----				
Crossroads	0.2	0.1	41.5	49.9
Marion	0.0	0.0	50.0	56.7
S Crossett	0.0	0.0	26.9	23.8
W Crossett	0.4	0.1	26.1	32.7

Since imazapyr is a foliar active herbicide, it is probable that less imazapyr was intercepted by the pine and more by the hardwood and shrub foliage in Louisiana than in Arkansas. This resulted in a higher rate of mortality at the Louisiana sites. Although many of the trees initially defoliated by the herbicide application did not die, the majority of these trees had low vigor and small live crown ratios during the second growing season following herbicide application. Only 8.6 percent of the trees that were classified with a vigor rating of 4 during the growing season following herbicide application and received a 1 or 2 vigor rating the next year. It seems unlikely that the majority of the stems that were initially severely defoliated will fully recover.

### Responses of Different Hardwood/Brush Species

The composition of the dominant hardwood and shrub competitors within the sites was typical of the Upper Coastal Plain in Arkansas and Louisiana. First-year mortality was relatively low for ash (*Fraxinus* spp), red maple, and most oak species (table 2). Although these species were often defoliated by the herbicide, they refloresced the following year. Vigor of these trees was low during the second growing season following herbicide application. Winged elm (*Ulmus alata* Michx.), and some other minor species such as holly (*Ilex opaca* Sol.), showed little if any defoliation by the imazapyr and also had low mortality rates. Sweetgum, persimmon (*Diospyros virginiana* L.), black cherry (*Prunus serotina* Ehrh.), and blackgum suffered high levels of mortality. Further mortality can be expected to occur in remaining living stems as pine grow and more aggressively compete for site resources.

**Table 2—Importance values (IV)<sup>a</sup> prior to herbicide application and the percent stem<sup>b</sup> mortality and basal area mortality of the 10 most dominant hardwood species at the end of the first growing season following herbicide application**

Species	Pre-herbicide IV	Post-herbicide mortality (control)		Post-herbicide mortality (herbicide treatment)	
		Stems	BA/acre	Stems	BA/acre
		----- % -----			
<i>P. taeda</i>	143.8	—	—	—	—
<i>L. styraciflua</i>	26.7	0.3	0.1	51.7	53.5
<i>N. sylvatica</i>	15.1	0.0	0.0	58.5	64.0
<i>A. rubrum</i>	14.0	0.0	0.0	7.7	6.5
<i>Q. nigra</i>	12.5	0.0	0.0	14.7	18.0
<i>U. alata</i>	6.4	0.0	0.0	3.9	5.2
<i>Q. alba</i>	6.4	0.0	0.0	28.8	29.3
<i>P. serotina</i>	6.1	0.0	0.0	59.1	59.1
Miscellaneous <sup>c</sup>	5.9	0.0	0.0	19.5	26.3
<i>D. virginiana</i>	5.3	2.6	1.4	64.7	64.5
<i>Fraxinus spp</i>	5.3	0.0	0.0	15.0	6.2
<i>Q. pagoda</i>	5.0	0.0	0.0	5.3	1.0

<sup>a</sup> Importance value (IV) = relative density + relative dominance + relative frequency.

Calculated by taking into account all species present in the 4 sites.

<sup>b</sup> Percent of the pre-herbicide stems and basal area per acre.

<sup>c</sup> Species such as *Aralia spinosa*, *Ligustrum spp.*, *Zanthoxylum clava-herculis*.

## CONCLUSIONS

Imazapyr was effective in reducing the crown vigor and live crown ratio of the majority of hardwood and shrub species commonly found in Arkansas and Louisiana. Mortality rates varied among species as well as among sites. Generally, mortality was greater in stands with lower densities of over-story pine trees. Continued monitoring of these stands will provide further insight on how hardwood and shrubs species respond to mid-rotation applications of herbicide.

## LITERATURE CITED

- Schultz, R.P. 1997. Loblolly pine: the ecology and culture of loblolly pine (*Pinus taeda* L.). Agric. Handb. 713. Washington, DC: U.S. Department of Agriculture, Forest Service: 8.1-8.36.
- USDA Forest Service. 1999. Forest health and monitoring 1999 field methods guide. Research Triangle Park, NC: U.S. Department of Agriculture, Forest Service, National Forest Health Monitoring Program. 354 p.
- Will, R.E.; Munger, G.T.; Zang, Y.; Borders, B.E. 2002. Effects of annual fertilization and complete competition control on current annual increment, foliar development, and growth efficiency of different aged *Pinus taeda* stands. Canadian Journal of Forest Resources. 32: 728-740.
- Zutter, B.R.; Miller, J.H.; Allen, H.L. [and others]. 1999. Fascicle nutrient and biomass responses of young loblolly pine to control of woody and herbaceous competitors. Canadian Journal Forest Resources. 29: 917-925.



## **Site Preparation**

*Moderator:*

**HARRY QUICKE**  
BASF Corporation



# BIOMASS OF FIRST AND SECOND ROTATION LOBLOLLY PINE PLANTATIONS IN THE SOUTH CAROLINA COASTAL PLAIN

Charles A. Gresham<sup>1</sup>

**Abstract**—In the South Carolina Coastal Plain, intensive loblolly pine (*Pinus taeda* L.) plantation management, without fertilization, was sustainable through two rotations as measured by biomass accumulation. Fixed plot tree inventories and destructive tree sampling of first and second rotation sections of the same plantations were used to produce area based estimates of aboveground, oven-dry tree biomass. First rotation plots in two plantations produced 289 and 242 tonnes/ha at 34 and 36 years after establishment respectively. Second rotation plots of these same stands produced 127 to 152 tonnes/ha at 15 years after establishment. Second rotation crown biomass was 67 to 87 percent of the crown biomass of the first rotation plots at 42 to 44 percent of the age of the first rotation trees. Total aboveground biomass of second rotation plots was 44 to 61 percent of the total aboveground biomass of the first at 42 to 44 percent of the age. Biomass accumulation is at least proportional to age from the first to second rotation; thus these management procedures appear to be sustainable.

## INTRODUCTION

Sustainable resource management has come to the forefront in the last decade and underlies management decisions of all natural resources. For example, the Ecological Society of America issued an analysis of research needs for resource sustainability for the last decade of the 20<sup>th</sup> century (Lubchenco and others 1991). Recently, the U.S. Forest Service issued an analysis of the condition of forests in the United States relative to sustainable forest management (Guldin and Kaiser 2004). The July/August and December 2003 issues of the *Journal of Forestry* were dedicated to sustainable development and certification.

In 1985, Clemson University expanded a site preparation study being established by then-Westvaco Corporation to focus on quantitatively determining the sustainability of intensive loblolly pine (*Pinus taeda* L.) plantation management. For the purposes of the project, sustainability was defined as non-declining biomass accumulation from the first rotation plantation to the second and as preservation of the pools of N and P at the end of the second rotation. Although this definition ignores many aspects of sustainability, such as biodiversity, forest health, water, and socio-economic benefits (Guldin and Kaiser 2004), it does allow reasonably straightforward quantification.

The research reported in this paper is a part of this larger effort and is limited to the accumulation of aboveground tree biomass. The objective of this research was to compare tree biomass in first and second rotation plantations and to compare biomass accumulation by tree component and site preparation method.

## SITES

Two loblolly pine plantations were established in South Carolina's Coastal Plain following clearcut harvesting of hardwood flatwood forests. Both stands were site prepared by shearing residual trees and stumps, raking the debris into windrows, and planting improved coastal loblolly pine on beds. At planting, 56 kg elemental P/ha was applied. The Greeleyville plantation was established on a somewhat poorly drained Lynchburg

fine sandy loam soil in 1967 and the Snow Mill plantation on a poorly drained Bladen loam soil in 1969. Twenty four 61 m x 61 m treatment plots were established in the first rotation Snow Mill stand in 1985, and most of the stand was clearcut in June 1986, 17 years after establishment. Likewise 16, 61 m x 61 m treatment plots were established in the first rotation Greeleyville stand in 1987, and most of the stand was clearcut harvested later that year, 20 years after establishment. Three treatment plots in each plantation were designated as control plots and were not harvested.

In both stands, the treatment plots were reestablished after harvest and a debris burn. Four site preparation methods were replicated in each of three blocks of plots. Blocks of plots were grouped by average codominant first rotation tree height, and unused plots were not measured. Site preparation methods tested were: (1) three pass shear, rake, and bed; (2) rebed only; (3) herbicide residual trees and plant on old beds; and (4) disk only. Both stands were site prepared and the second rotation planted in 1987. Each treatment plot was split, and the planted seedlings in one half were released from competition by periodic spot herbicide application for the first growing season only.

## PROCEDURES

In each second rotation plantation, the following site preparation and release treatment plots were selected for study: (1) three pass site preparation, unreleased half; (2) rebed only site preparation, unreleased half; (3) herbicide site preparation, released and unreleased halves; and (4) the first rotation control plots. In each of these treatment combinations for each of the tree blocks in each stand, we established a 20 m x 20 m measurement plot within the planted area and another measurement plot 20 m long and with a variable width that contained the windrow created during the first rotation plantation establishment.

All standing stems 2.5 cm d.b.h. and larger were tallied by recording species d.b.h. and status (as alive or dead). Every fourth live tree tallied was tagged with a sequentially numbered punch tag. Total height to terminal bud was measured

<sup>1</sup> Associate Professor, The Belle W. Baruch Institute of Coastal Ecology and Forest Science of Clemson University, Georgetown, SC 29442.

on all tagged trees in the Snow Mill stand. Because the Greeleyville stand had a higher density of volunteer pines and understory hardwoods, total heights were measured on up to 10 tagged, planted pines, up to 10 tagged, volunteer pines, and up to 15 tagged hardwoods per measurement plot. Total height was measured with a telescoping fiberglass measuring rod with the beginning of a 30 m fiberglass tape attached to the tip. The rod was raised against the tree bole until a distant observer indicated that the tip of the rod was adjacent to and level with the terminal bud. The fiberglass tape was then read at groundline.

Twenty-six pine and 12 hardwood trees located in each second rotation plantation were destructively sampled to determine biomass. Likewise, 10 pines and 12 hardwood trees were destructively sampled in each first rotation plantation. For each combination of first and second rotation plantations and pine and hardwood species groups, three to five diameter classes were established such that each class contributed equally to estimated stand biomass. Then equal numbers of trees were destructively sampled in each diameter class with standard methods.

Biomass equations were developed, separately by stand, for seven tree components [bole, foliage, twigs, unfoliated branches, deadwood, crown (as the sum of foliage, twigs, unfoliated branches, and deadwood), and total aboveground biomass (as the sum of crown and bole)] for pines and hardwoods (separately) in the second rotation section and pines and hardwoods (separately) in the first rotation section. All equations used  $\log \text{dbh}^2$  to predict the log of the biomass component of interest. Biomass equations were used to predict area based aboveground biomass estimates from the live stem inventories. To facilitate data analysis and presentation, inventoried stems were assigned to a product class based on d.b.h. and species. Pine stems < 9.5 cm d.b.h. were considered precommercial as were hardwood stems < 18 cm d.b.h. Pine stems > 9.4 cm d.b.h. and < 17.8 cm d.b.h. were classified as pulpwood as were hardwood stems at least 18 cm d.b.h. Pine chip and saw stems were > 17.7 cm d.b.h. and < 30.5 cm d.b.h. Pine stems > 30.5 cm d.b.h. were considered saw-timber. Bonferroni pairwise mean comparison tests with  $P=0.05$  were used to determine significant differences.

## RESULTS AND DISCUSSION

The first rotation portion of the Snow Mill stand had accumulated almost 290 tonnes/ha 34 years after establishment, and the second rotation portion had accumulated 128 to 152 tonnes/ha 15 years after establishment (table 1). For the Greeleyville stand, the first rotation section accumulated 242 tonnes/ha, and the second rotation section accumulated 118 to 148 tonnes/ha. The total biomass of the second rotation was 44 to 53 percent of the total biomass of the first rotation for Snow Mill and 49 to 61 percent for Greeleyville. However, second rotation tree crown biomass was 68 to 86 percent of the crown biomass for first rotation trees for Snow Mill and 67 to 82 percent for Greeleyville. This higher percent of crown biomass compared to total biomass indicates that crown biomass accumulation of the second rotation trees is more rapid than bole biomass accumulation. As indicated in table 1, in both stands the crown biomass for the second rotation treatments are not significantly different for the crown biomass for the first rotation trees. In contrast, total biomass and bole biomass are significantly different between the two rotations.

For both the Snow Mill and Greeleyville stands, the total aboveground tree biomass of the second rotation as a percent of the total aboveground tree biomass of the first rotation is > the same percents of their ages. The second rotation trees of the Snow Mill stand are 44 percent of the age of the first rotation trees, but total aboveground biomass is 44 to 53 percent of the first rotation trees. Likewise, the age of the second rotation trees in the Greeleyville stand is 42 percent of the age of the first rotation trees, but the total aboveground biomass is 49 to 61 percent of the first rotation trees. The second rotation trees are accumulating biomass faster than a linear prediction from age alone.

The distribution of biomass among product classes showed differences among site preparation methods (tables 2 and 3). At Snow Mill, the herbicide and herbicide/release plots had windrows that were not site prepared and thus contained much hardwood biomass. In contrast, the rebed only and shear, rake, and bed plots had site prepared windrows and thus had much less hardwood biomass. In the Greeleyville plantation, there was not as strong a difference in hardwood biomass. Most of the pine biomass in both stands was in the chip and saw product class followed by the pine pulpwood class. Chip

**Table 1—Bole, crown, and total aboveground, oven dry tree biomass estimates for the first and second rotation portions of the Snow Mill and Greeleyville plantations. Second rotation estimates are presented by site preparation treatments used to establish the second rotation trees. Values within a column followed by the same letter are not significantly different (P = 0.05)**

Site preparation treatment	Snow Mill Plantation			Greeleyville Plantation		
	Bole	Crown	Total	Bole	Crown	Total
----- tonnes/ha -----						
Herbicide	113.4b	23.6a	137.1b	98.8b	19.0a	117.8b
Herbicide & release	105.7b	22.2a	127.9b	118.4b	23.2ab	141.6b
Rebed only	125.8b	26.2a	152.0b	124.4b	23.6ab	148.0b
Shear, rake, bed	109.6b	20.7a	130.2b	123.5b	23.0ab	146.5b
First rotation	258.7a	30.3a	289.0a	213.6a	28.3b	241.9a

**Table 2—Total aboveground tree biomass estimates of the first and second rotation sections of the Snow Mill plantation by product classes. Second rotation biomass estimates are presented by site preparation treatment**

Site preparation treatment	Pine sawlogs	Pine chip & saw	Pine pulp wood	Pine precommercial	Hardwood pulpwood	Hardwood precommercial
----- tonnes/ha -----						
Herbicide	10.5	84.0	29.2	2.8	3.3	13.9
Herbicide and release	5.2	90.2	23.3	2.0	1.0	8.3
Rebed only	11.6	108.0	26.0	2.2	1.5	5.3
Shear, rake, bed	0.0	86.2	41.6	2.7	0.0	0.9
First rotation	149.1	75.4	0.0	0.0	11.9	21.9

**Table 3—Total aboveground tree biomass estimates of the first and second rotation sections of the Greeleyville plantation by product classes. Second rotation biomass estimates are presented by site preparation treatment**

Site preparation treatment	Pine sawlogs	Pine chip & saw	Pine pulpwood	Pine precommercial	Hardwood pulpwood	Hardwood precommercial
----- tonnes/ha -----						
Herbicide	4.6	62.2	39.3	4.0	2.7	9.5
Herbicide and release	2.7	104.5	27.4	3.0	0.8	6.5
Rebed only	0.0	92.4	44.4	2.4	0.0	10.4
Shear, rake, bed	0.0	80.2	53.4	5.7	0.0	8.6
First rotation	147.2	69.2	4.9	0.4	2.8	19.4

and saw differences within treatments between the two stands are not consistent nor are treatment differences in the pulpwood class.

Three conclusions can be drawn from this research. First, the area based crown biomass of the second rotation trees at age 15 was not significantly different from the crown biomass of 34- or 36-year-old first rotation trees. In contrast, the bole biomass of the second rotation trees was much less than that of the first rotation trees. Second, at 15 growing seasons after planting, site preparation methods did not seem to affect aboveground biomass accumulation. The herbicide and release plots in Greeleyville had the most chip and saw biomass, and in the Snow Mill plantation, the rebed only plots had the most chip and saw biomass. In both stands, the shear, rake, and bed plots had the most pine pulpwood biomass. Finally, the total aboveground biomass of the second rotation plots as a percent of the total aboveground biomass of the first rotation plots was greater than the percent of the ages. This means that the second rotation plantation is accreting biomass faster than the linear increase in age. Assuming that both the first and second rotation trees accumulate area-based biomass in a sigmoid curve pattern and that the first rotation trees have a small annual increment, then the second rotation trees would accumulate biomass much less the linear percent of age,

because they are younger than the 50 percent break point of a sigmoid curve. Only if the second rotation trees were older than 50 percent of the age of the first would one expect growth faster than the linear percent of age. The fact that the second rotation trees at 40 to 45 percent of the age of the first have 44 to 60 percent of the biomass of the first indicates that there is no sign of a lessening of growth rate from one rotation to another. Thus these data indicated that these management practices on these sites are sustainable as measured by biomass accumulation.

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#### LITERATURE CITED

- Guldin, R.W.; Kaiser, H.F. 2004. National report on sustainable forests – 2003. FS-766. Washington, DC: U.S. Department of Agriculture, Forest Service. 139 p.
- Lubchenco, J.; Olson, A.M.; Brubaker, L.B. [and others] 1991. The sustainable biosphere initiative: an ecological research agenda. *Ecology*. 72: 371-412.

# WESTERN GULF CULTURE-DENSITY STUDY—EARLY RESULTS

Mohd S. Rahman, Michael G. Messina,<sup>1</sup> Richard F. Fisher,<sup>2</sup> Alan B. Wilson,<sup>3</sup>  
Nick Chappell,<sup>4</sup> Conner Fristoe,<sup>5</sup> and Larry Anderson<sup>6</sup>

**Abstract**—The Western Gulf Culture-Density Study is a collaborative research effort between Texas A&M University and five forest products companies to examine the effects of early silvicultural treatment intensity and a wide range of both densities and soil types on performance of loblolly pine. The study tests 2 silvicultural intensities, 5 planting densities (200 to 1,200 trees per acre), and 4 soil types classified by drainage class and depth to a restrictive layer. Eighteen sites were established between 2001 and 2003 in four states. The final product of this research will be an estimate of the best combination of early silvicultural practices for a given soil type and location and the production of data for growth and yield modeling of loblolly pine stands in the West Gulf. This paper presents current survival and growth data for the study sites and discusses trends in response to density, culture, and soil type.

## INTRODUCTION

Planting density is one of the most important factors regulating every stage of forest stand development. Productivity in a forest ecosystem is normally limited by resource availability; therefore, stand density management is vital to sustaining maximum productivity. In fact, forestry has been described as the 'science of density optimization' (Zeide 2004). Stand density determines such ecosystem processes as time to canopy closure, suppression of understory vegetation through overstory shading, inter- and intra-specific competition, crown recession, lateral growth, mortality (Nyland 2002), faunal diversity associated with snags, litter production (Ferguson and Archibald 2002), and carbon sequestration (Zhou 2001). Natural stand characteristics, such as wood quality at final harvest and risks from pathogens, are also heavily influenced by stand density (Nyland 2002). Stand density impacts forest management decisions such as the objectives of planting, frequency of thinning, planting methods including equipment choice, and degree of likely mechanization of future operations (Nyland 2002). Intensive forest management is currently practiced on more than 34.5 million acres in the southern United States. The application of intensive management has sometimes tripled aboveground biomass accumulation when compared to lower inputs, although results have varied widely among soil-site conditions. Due to its ability to reproduce and grow rapidly on a wide range of site conditions (Schultz 1997), loblolly pine (*Pinus taeda* L.) has become 'the' southern pine species for nearly a century. Several spacing trials with loblolly pine (Burkes and others 2003, Harms and others 2000, Lin and Morse 1975) have been implemented in the last few decades. Some studies (Harms and others 2000, Lin and Morse 1975) did not include intensive forest management in their design whereas others include one level of intensive management (Burkes and others 2003). Therefore, the need is obvious for a study involving planting densities and levels of intensive forest management. In addition, such a study should be replicated on a range of soil-site conditions to cover a wide region. Therefore, the objective of the Western Gulf

Culture-Density Study (WGCDS) is to test the effect of planting density and cultural treatments on loblolly pine growth and survival on a wide range of soil-site conditions.

## MATERIALS AND METHODS

A soil classification based on drainage and depth to a restrictive layer (fragipan or argillic horizon) was developed (table 1). On each of these soil types, a study involving planting density and cultural treatments was established with several replications. Five levels of planting density (table 2) and two levels of silvicultural intensity (table 3) were used. At each study site location, only one soil type was present, and hence the replications were across locations; i.e., each site location had 1 replication of 16 plots, 10 of which represented the core study (5 densities x 2 cultural intensities) and 6 which were designated for a thinning study (3 thinning regimes x 2 cultural treatments). The thinning regimes are: (1) initial planting density of 700 trees per acre (TPA) thinned to 450 TPA; (2) 700 TPA thinned to 200 TPA; and (3) 450 TPA thinned to 200 TPA. The thinning trigger chosen for the WGCDS is 55 percent of the maximum Reineke's stand density index for loblolly pine,

**Table 1—Western Gulf Culture-Density Study soil groups based on site drainage and depth to subsurface restrictive layer**

WGCDS soil group	Drainage class	Depth to subsurface restrictive layer <i>inches</i>
A	Poorly - somewhat poorly	< 20
B	Poorly - somewhat poorly	> 20
C	Moderately well – well	< 20
D	Moderately well – well	> 20

<sup>1</sup> Research Associate and Professor, respectively, Texas A&M University, Department of Forest Science, College Station, TX 77843-2135.

<sup>2</sup> Operation Leader, Applied Research and Development, Temple-Inland Forest, Diboll, TX 75941.

<sup>3</sup> Silviculture Research Manager, Rayonier, Inc., Yulee, FL 32041-0819.

<sup>4</sup> Manager, Forest Productivity and Nutrition, Potlatch Corporation, Warren, AR 71671.

<sup>5</sup> Region Silviculturist, Plum Creek Timber Company, Crossett, AR 71635.

<sup>6</sup> Research Forester, Weyerhaeuser Company, Hot Springs, AR 71902.

**Table 2—Five planting densities, associated tree spacings, and plot sizes in the Western Gulf Culture-Density Study**

Density	Spacing	Trees per measurement plot	Measurement plot	Gross plot
<i>trees/acre</i>	<i>ft x ft</i>		----- acres -----	
1,200	4.5 x 8	120	0.1 15 trees x 8 rows	0.23 23 trees x 12 rows
950	5.7 x 8	96	0.1 12 trees x 8 rows	0.25 20 trees x 12 rows
700	6.2 x 10	72	0.1 9 trees x 8 rows	0.26 15 trees x 12 rows
450	9.7 x 10	48	0.1 6 trees x 8 rows	0.27 10 trees x 12 rows
200	15.6 x 14	42	0.2 7 trees x 6 rows	0.55 11 trees x 10 rows

**Table 3—Silvicultural treatments (LO and HI) for the Western Gulf Culture-Density Study**

Treatment	LO	HI
Site preparation	No difference between LO and HI, but differs among soil types: soil type 'A': bedding and ripping; soil type 'B': bedding only; soil type 'C': ripping only; soil type 'D': none	
Fertilization	250 lb DAP/ac in year 1 only	Year 1: 250 lb DAP/ac Year 2: N/P/K/B mix Year 4+: as per biennial foliar analyses
Herbicide	Year 1 only	Until canopy closure
Insecticide	First 2 years for tip moth; no difference between LO and HI	

assumed to be 450 TPA at quadratic mean diameter of 10 inches (Reineke 1933). Currently, no plot across the entire WGCDS has reached the thinning trigger and, as such, data from thinning plots are reported with data from core plots.

The study sites were established during 3 years on 19 locations in Texas, Arkansas, Louisiana, and Mississippi (table 4). The oldest sites were established in early 2001 and completed their fourth growing season in the summer of 2004. The youngest sites were 2 years old at the end of 2004.

**Site Establishment**

Sites were mechanically prepared according to the soil type (table 3). Since there was only one soil type at any location, mechanical site preparation did not vary within sites regardless of planting density or cultural intensity. All sites were planted with loblolly pine. No genetic control was maintained across site locations; i.e., each site was planted with the best open-pollinated genetic family for that location. Each planting spot was double planted to ensure good survival, with one of the seedlings clipped off in the first September or October where two survived.

**Post-Planting Treatments**

All sites were fertilized according to the two levels of cultural treatments (table 3). The entire study was fertilized with 250 pounds of diammonium phosphate (DAP) per acre in year 1.

**Table 4—Western Gulf Culture-Density Study site matrix by soil type and establishment year**

Establishment year	Soil type				Total
	A	B	C	D	
2001	3	3	1	3	10
2002	—	3	—	1	4
2003	1	—	4	—	5
Total	4	6	5	4	19

In year 2, the HI plots were treated with 100 pounds of elemental N, 10 pounds of elemental P, 40 pounds of elemental K, and 0.5 pound of elemental B per acre. On the sites planted in 2001, foliar samples were collected from the HI plots in the winter of 2003-2004 and analyzed for fertilizer recommendation. Following analyses, HI plots on these sites were fertilized with 120 pounds of elemental N (using DAP and urea), 10 pounds of elemental P (using DAP), and 50 pounds of elemental Mg (using SulPoMag) per acre in year 4.

All study sites were sprayed for herbaceous competition in year 1, regardless of the level of cultural treatments (HI and LO). Beginning in year 2 and continuing until year 4, only HI plots were treated for undesirable vegetation control. The choice of chemical was not uniform across sites as the objective was to suppress competition to <20 percent ground cover.

On soil types 'A' and 'B', chemicals were broadcast for complete control, whereas on soil types 'C' and 'D', a 2-foot radius around each tree was spot sprayed to minimize erosion.

The entire study site was treated for Nantucket pine tip moth (*Rhyacionia frustrana*) for the first 2 years using MIMIC® (tebufenozide) and Pounce® (permethrine) either by spraying one of the two or alternating between them, spraying monthly between March and October.

### Height and Diameter Measurements

Height and diameter were measured at the end of each growing season between the months of December and January. Height was measured for each tree in the measurement plot (table 2). Diameter was measured at the groundline (GLD) following year 1 on a subsample of trees (frequency varied among densities with 33+ percent of all trees measured on any plot). After the trees developed a diameter at breast height (d.b.h.), they were measured for GLD and d.b.h. for that year and then only d.b.h. on all trees in the following years. Height was measured to the nearest 0.1 foot and diameter to the nearest 0.1 inch.

### Statistical Analyses

Data for any growing year were combined for all sites, regardless of their establishment year. This provided all 19 sites for height and diameter data after 1 and 2 years of growth, 14 sites (established in 2001 and 2002) for data after 3 years of growth, and 10 sites (established in 2001) for data after 4 years. Data were analyzed using a split-split plot design where soil type was considered as the main plot, planting density as the subplot, and cultural treatment as the sub-subplot. Treatment means were separated using Tukey's procedure. All statistical significance was tested at  $\alpha = 0.05$ . To avoid redundancy throughout the text, statistical significance level has been

omitted to reflect values at 0.05 unless otherwise mentioned. Single degree-of-freedom linear contrasts were used to compare soil groups. All data were analyzed using SAS version 8.0 (SAS Institute Inc., Cary, NC, USA 2000).

## RESULTS AND DISCUSSION

### Survival

Survival at the end of year 4 was not affected by soil type, cultural treatment, or planting density. Average survival for all trees across all study site locations was 94.3 percent. The high survival is likely due to the double planting. Survival for all seedlings at the end of year 1, following clipping of additional seedlings from each planting spot, was 96.9 percent. The fact that survival has not been affected by density suggests that density-dependent mortality had not yet occurred after 4 years of growth.

### Height and Diameter

Height and GLD were not affected by cultural treatment in year 1, but beginning in year 2, height and d.b.h. were consistently higher for seedlings in the HI treatments than in the LO treatments (table 5). At the end of year 4, height and d.b.h. for HI trees were 9 and 22 percent greater, respectively, than those for LO trees. Cultural treatments for HI and LO treatments were the same in year 1, and the difference between these two treatments began in year 2. Therefore, the pattern of delayed differences in height and diameter for these two cultural treatments is expected.

Height was not affected by planting density for any measurement except for year 3, when tree height for the 700-TPA was greatest and that for the 200-TPA was lowest (table 6). Planting density significantly affected d.b.h. beginning in year 3 and continuing to year 4. D.b.h. started to show a density response

**Table 5—Average loblolly pine height and dbh by cultural treatment at the end of each of four growing seasons in the WGCDS**

Cultural treatment	Year							
	1		2		3		4	
	Height <i>ft</i>	GLD <i>in</i>	Height <i>ft</i>	dbh <i>in</i>	Height <i>ft</i>	dbh <i>in</i>	Height <i>ft</i>	dbh <i>in</i>
LO	2.2 a	0.7 a	5.8 b	0.7 b	10.5 b	1.5 b	15.4 b	2.7 b
HI	2.2 a	0.7 a	6.2 a	0.8 a	11.3 a	1.8 a	16.8 a	3.3 a

**Table 6—Average loblolly pine height and dbh by planting density at the end of each of four growing seasons in the WGCDS**

Density (TPA)	Year							
	1		2		3		4	
	Height <i>ft</i>	GLD <i>in</i>	Height <i>ft</i>	dbh <i>in</i>	Height <i>ft</i>	dbh <i>in</i>	Height <i>ft</i>	dbh <i>in</i>
200	2.1 a	0.7 a	5.7 a	0.7 a	10.4 b	1.7 a	15.5 a	3.4 a
450	2.2 a	0.7 a	5.8 a	0.7 a	10.7 ab	1.7 a	16.0 a	3.2 a
700	2.3 a	0.7 a	6.1 a	0.8 a	11.1 a	1.7 a	16.4 a	3.0 ab
950	2.2 a	0.7 a	6.0 a	0.8 a	10.9 ab	1.6 b	16.1 a	2.9 b
1,200	2.2 a	0.7 a	6.0 a	0.8 a	10.8 ab	1.6 b	15.8 a	2.6 c

in year 3, when it decreased with increasing density. The decrease in diameter with increasing density was consistent across densities at the end of year 4 (table 6), when trees of the 200-TPA had 31 percent greater d.b.h. than those of the 1,200-TPA.

Soil type significantly affected height and diameter in all measurement years. Soil type 'A', which is poorly- to somewhat poorly-drained with a shallow (<20 inches) subsurface restrictive layer (table 1), had consistently greater height and diameter than the remaining soil types, whereas soil type 'D', which is moderately well- to well-drained with a deep (>20 inches) subsurface restrictive layer had the lowest height and diameter (table 7). After year 4, tree height and d.b.h. for soil type 'C' were comparable to those of soil type 'A'. In other words, soils with <20 inches depth to a subsurface restrictive layer ('A' and 'C') had taller trees and bigger diameters than soils with deep subsurface restrictive layers ('B' and 'D') at the end of all measurement years (table 8). Tree height and d.b.h. on soils with shallow, restrictive layers averaged 22 and 18 percent, respectively, greater than those on soils with deep restrictive layers. The effect of site drainage on tree height and diameter was also present until year 3, when tree height and d.b.h. were greater on 'poorly- to somewhat poorly-drained' sites than on 'moderately well- to well'-drained sites. However, this response was not present in year 4 (table 8). This is because growth between year 3 and year 4 was lowest for soil type 'B' (poorly- to somewhat poorly-drained and >20 inches to the restrictive layer).

There was an interaction between cultural intensity and planting density in year 1; however, this treatment interaction effect was absent in the following years, and the pattern of growth between trees of HI and LO treatments has been very consistent among all densities. There was also an interaction

between planting density and soil type for both height and d.b.h. during all measurement years. This was due to poor growth observed for trees on 'D' sites (table 7) which responded to density differently from trees on 'A' sites wherein the density influence on d.b.h. was strong. We expect that such interactions will be absent in the future years, when slow-growing sites will also begin to show density effects on height and diameter growth.

### SUMMARY

Survival has been excellent across the entire study (>94 percent), which is attributed largely to double planting of seedlings and lack of density-dependent mortality over the first four growing seasons. High inputs of silvicultural treatments resulted in taller and larger diameter trees. Planting density affects early diameter growth more than it affects height; trees in 200-TPA plots had 31 percent greater d.b.h. than trees in 1,200-TPA after four growing seasons. There was no interaction of cultural treatment and planting density present in any measurement year, except for height in year 1.

Soil type significantly affected height and diameter across all measurement years for all sites. Both drainage and depth to the restrictive layer significantly affected early growth; however, depth to the restrictive layer had a stronger effect. Soil types with a shallow depth to restrictive layer had greater growth compared to deeper soils. A drainage effect on height and diameter was absent after year 4.

Of all treatments tested in this study (silvicultural intensity, planting density, and soil type), soil type had the greatest effect on growth. The effect of silvicultural treatment intensity on height and d.b.h. was consistent across soil types; however, pattern of density response to tree height and diameter was not consistent among soil types.

**Table 7—Average loblolly pine height and dbh by soil type at the end of each of four growing seasons in the WGCDs**

Soil type	Year							
	1		2		3		4	
	Height <i>ft</i>	GLD <i>in</i>	Height <i>ft</i>	dbh <i>in</i>	Height <i>ft</i>	dbh <i>in</i>	Height <i>ft</i>	dbh <i>in</i>
A	2.8 a	0.9 a	7.6 a	1.0 a	12.5 a	1.9 a	18.6 a	3.2 a
B	2.0 b	0.6 b	5.6 c	0.7 b	10.5 c	1.6 b	14.5 b	2.9 b
C	2.6 a	0.9 a	6.6 b	0.8 b	11.5 b	1.8 b	17.8 a	3.4 a
D	1.8 c	0.6 b	5.2 d	0.6 c	10.1 c	1.5 c	15.3 b	2.7 b

**Table 8—Significance value of linear contrasts to compare soil groups by drainage and depth to subsoil restrictive layer**

Linear contrast	Year							
	1		2		3		4	
	Height	GLD	Height	dbh	Height	dbh	Height	dbh
Poorly drained (A+B) vs. well drained (C+D)	0.001	0.05	0.0001	< 0.0001	0.001	0.001	0.51	0.45
Shallow subsoil (A+C) vs. deep subsoil (B+D)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

## LITERATURE CITED

- Burkes, E.C.; Will, R.E.; Barron-Gafford, G.A. [and others]. 2003. Biomass partitioning and growth efficiency of intensively managed *Pinus taeda* and *Pinus elliottii* stands of different planting densities. *Forest Science*. 49(2): 224-234.
- Ferguson, S.H.; Archibald, D.J. 2002. The 3/4 power law in forest management: how to grow dead trees. *Forest Ecology and Management*. 169(3): 283-292.
- Harms, W.R.; Whitesell, C.D.; DeBell, D.S. 2000. Growth and development of loblolly pine in a spacing trial planted in Hawaii. *Forest Ecology and Management*. 126(1): 13-24.
- Lin, C.; Morse, P.M. 1975. A compact design for spacing experiments. *Biometrics*. 31: 661-671.
- Nyland, R.D. 2002. *Silviculture: concepts and applications*. New York, NY: McGraw-Hill. 682 p.
- Reineke, L.H. 1933. Perfecting a stand density index for even-aged forests. *Journal of Agricultural Research*. 46(7): 627-638.
- Schultz, R.P. 1997. Loblolly pine: the ecology and culture of loblolly pine (*Pinus taeda* L.). *Agric. Handb.* 713. Washington, DC: U.S. Department of Agriculture, Forest Service. 1-1 to 12-27 p.
- Zeide, B. 2004. Optimal stand density: a solution. *Canadian Journal of Forest Research*. 34(4): 846-854.
- Zhou, W. 2001. Effects of forest carbon sequestration on optimum planting density. *Journal of Forest Economics*. 7(3): 187-201.

# EIGHTEEN-YEAR RESPONSE OF SLASH PINE TO WET-WEATHER HARVESTING AND SITE PREPARATION ON A POORLY DRAINED SILT LOAM SOIL IN LOUISIANA

D. Andrew Scott and Allan E. Tiarks<sup>1</sup>

**Abstract**—Physical disturbances to soil resulting from forest management operations may reduce tree survival and growth, but responses are soil-, species-, and disturbance-specific. We studied wet-weather harvesting, shearing, root-raking, disking, and phosphorus fertilization on a poorly drained flatwoods site in Louisiana. Slash pine survival was improved by wet-weather harvesting, but 18-year growth responses were not affected by any physical disturbances due to the inherently poor physical properties of soils on the site. Fertilization increased volume at age 18 by 47 percent, and the effect was still increasing.

## INTRODUCTION

Foresters and others have been concerned for decades about potential risks to long-term soil productivity caused by mechanized equipment-based soil physical disturbances. Many short-term and some long-term studies have been conducted in the South over the past 40 years, and negative harvesting impacts on soil properties have been well documented (Miller and others 2004, Miwa and others 2004).

Few studies of severe soil disturbance have resulted in clear, well-documented losses in soil productivity as measured by tree-growth reductions. Some studies have been confounded with other effects, such as weed competition or adequate experimental control (Morris and Miller 1994). Some recent studies that have controlled for many of these factors have not found growth losses following soil compaction (Scott and others 2004) or wet-weather logging (Eisenbies and others 2004).

Responses to soil disturbances can be partially explained in terms of soil properties and processes. Soil physical disturbances (compaction, rutting, churning) may cause increased soil strength, reduced porosity, reduced infiltration and aeration, and reduced root growth (Miller and others 2004, Miwa and others 2004). The most severe disturbances occur not when a soil is at the water content most conducive to compaction but at water contents at or above the liquid limit, which is the water content at which soil becomes fluid. At soil water contents above the liquid limit, static and shear forces cause the soil to become viscous and flow. In this state, soil porosity is not lost due to the incompressibility of saturated soil, although pore size distributions may change (Miwa and others 2004).

Tree root growth may be reduced by loss of aeration, increased soil strength, or altered hydrology. The relative impact of soil disturbance on any given soil depends on the specific soil properties and the type of disturbance. In soils with adequate internal drainage, the loss of soil porosity and structure may increase soil strength and reduce aeration, causing reduced root growth. Soils with well-graded textures may be especially prone to damage by puddling, which causes crusting and cementation. In imperfectly drained

soils, however, the loss of soil structure caused by rutting and churning may not have discernible effects on drainage and tree growth. Thus, some soil deleterious compaction effects can be avoided by logging during dry times when soil strengths are high enough to support machinery or during wet times when the soil will flow; but we do not yet know which sites will respond negatively to each type of disturbance. Physical soil preparation, such as disking, ripping, and bedding, may help restore soil physical properties, but the efficacy of each method on each soil type is not known.

An additional problem with determining whether soil disturbances and site preparation practices have lasting effects on productivity is that early results are not always indicative of later results (Tiarks and others 1998). Tree growth responds to soil treatments quite differently in some cases before canopy closure, when intraspecific competition and each tree must establish roots in a small area, and after canopy closure, when individual trees are better established and competition becomes more interspecific.

We designed this study to determine if severe soil disturbances would reduce long-term soil productivity on a poorly drained flatwoods soil in southwest Louisiana, what level of mechanical site preparation would be needed to restore productivity, and if fertilization had an interactive effect with soil physical disturbance. We also wanted to determine how responses have changed or not changed over 18 years of stand development.

## MATERIALS AND METHODS

### Study Sites

The study site is located in the West Bay Management Area in Allen Parish, LA, which is on the West Gulf Coastal Plain and in the flatwoods physiographic region. The soil is a poorly drained Caddo silt loam (fine-silty, siliceous, active, thermic Typic Glossaqualfs) interspersed by about 10 percent moderately well drained Messer silt loam (coarse-silty, siliceous, superactive, thermic Haplic Glossudalfs) pimple mounds.

The preharvest stand was a 40-year-old slash pine (*Pinus elliotti* Engelm.) plantation with little understory vegetation.

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<sup>1</sup> Research Soil Scientist, USDA Forest Service, Southern Research Station, 2500 Shreveport Highway, Pineville, LA 71360; and Emeritus Soil Scientist, USDA Forest Service, Southern Research Station, 25352 McPherson Ave., Council Bluffs, IA 51501.

## Treatments

The experimental design was a split-plot randomized complete block design with four blocks. The main-effects plots were rectangular, 0.45-ha in size, and split into two equal halves. The measurement plots were the interior 0.05-ha of each half. We installed six main-effects treatments, which comprised two soil conditions at the time of harvest and four site preparation treatments in different combinations. The treatments were:

1. Dry weather logging (DRYH-ONLY). The plots were logged in the summer of 1979 when the soil was dry enough to support logging equipment with little compaction or surface disturbance. The woody residue on these plots was burned.
2. Dry weather logging followed by shearing (DRYH-SHEAR). Logging was done at the same time as Treatment 1. The plots were sheared in the fall of 1979.
3. Wet-weather logging (WETH-ONLY). The plots were logged in January-March 1979 when the soil water content ranged from above field capacity to nearly saturated, so compaction and rutting effects by the skidders were maximized. The woody residue on these plots was burned.
4. Wet weather logging followed by shearing (WETH-SHEAR). Logging was done at the same time as Treatment 3. The plots were sheared in the fall of 1979.
5. Wet weather logging followed by shearing and rootraking (WETH-RAKE). This treatment was the same as Treatment 4, except the areas were rootraked following shearing.
6. Wet weather logging followed by shearing, rootraking, and flat disking (WETH-DISK). After logging, shearing, and rootraking (same as Treatment 5), the plots were flat disked.

The split-plot treatments were fertilizer applications of 0 and 56 kg ha<sup>-1</sup> of phosphorus (P) applied as triple superphosphate (0-46-0) in a small circle around each tree. The rate of fertilizer was 0.154 kg tree<sup>-1</sup> and was applied in May 1980.

All woody vegetation 6.4 cm or larger in diameter remaining on the plots was injected with Tordon 101 (picloram and 2,4-D) in the summers of 1980 and 1981.

## Planting

Uniform grades 1 and 2 slash pine seedlings were hand planted at 2- by 3-m spacing February 11-13, 1980. Because overall survival at the end of the first growing season was only 61 percent, all missing and dead trees were replaced.

## Measurements

Total height of each tree in the measurement plot was measured at 1, 3, 5, 9, and 13 years following treatment, and the height of every 10<sup>th</sup> tree was measured at 18 years following treatment. Diameter at breast height of each tree in the measurement plot was measured at 5, 9, 13, and 18 years following treatment. At age 18 years, tree heights were estimated by height-diameter relationships developed from the sampled heights. Individual tree volumes were determined by equations developed by Lohrey (1985) and summed by measurement plot for stand volume estimates.

## Data Analysis

Initial survival was analyzed with analysis of variance and orthogonal contrasts. The stand volume data were analyzed

with a repeated measures analysis of variance and orthogonal contrasts to elucidate the individual effects over time. For all comparisons,  $\alpha = 0.05$  was used. When the F-test indicated significant treatment differences, the Student-Newman-Keuls multiple comparisons test was used to separate the means. All statistical analysis was performed on SAS (SAS Institute 2000).

## RESULTS

### Survival

Initial survival was low across all treatments and averaged only 61 percent after one full growing season. When all treatments were compared, only the WETH-SHEAR and WETH-RAKE treatments had significantly greater first-year survival than the DRYH-ONLY treatment (fig. 1). All other treatments were similar, and the fertilizer treatment and the fertilizer by treatment interaction had no significant effect. Because of this poor survival, all dead and missing trees were replanted after the first growing season. At age 3 years, the overall survival had improved to 86 percent. All treatments were similar at age 3 years.

Orthogonal contrasts were used to elucidate the various effects at ages 1 and 3 years. At age 1 year, the time of logging had the only significant effect (table 1). Wet-weather harvesting improved initial survival from 53.7 percent on the dry-harvested plots to 64.9 percent. Shearing, rootraking, disking, and fertilization had no effect, and there were no significant interactions between the time of logging and shearing and between physical treatments and fertilization. At age 3 years, after the poor survival was supplemented by replanting, the time of logging had no significant influence on survival, but shearing improved survival from 82.8 to 87.8 percent (table 1). No other treatment or interaction was significant.

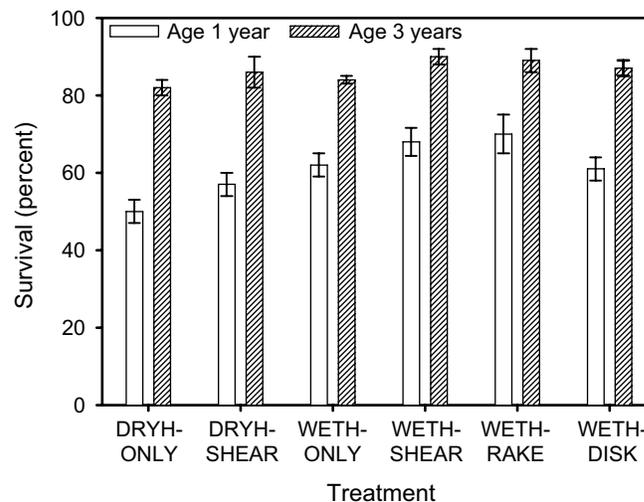


Figure 1—Early survival of slash pine in soils impacted by harvesting and site preparation on a flatwoods site in Louisiana. Age 3 years results include trees replanted after the first growing season. The treatment abbreviations indicate the type of harvest (dry vs. wet) and site preparation (only = no mechanical site preparation, shear = shearing site preparation, rake = rootraking following shearing, and disk = flat disking following shearing and rootraking).

**Table 1—Early survival of slash pine (percent) in soils impacted by harvesting and site preparation on a flatwoods site in Louisiana**

Treatment comparison	First-year survival (%)			Third-year survival (%)		
	A <sup>a</sup>	B	P>F <sup>b</sup>	A <sup>a</sup>	B	P>F <sup>b</sup>
Dry (A) vs. wet logging (B)	53.7	64.9	0.01	83.8	86.9	0.16
No shearing (A) vs. shearing (B)	56.1	62.5	0.12	82.8	87.8	0.03
No rotraking (A) vs. rotraking (B)	59.3	65.5	0.08	85.3	88.1	0.14
No disking (A) vs. disking (B)	69.8	61.2	0.14	89.2	87.0	0.46
Not fertilized (A) vs. fertilized (B)	61.7	60.9	0.78	84.9	87.6	0.17

<sup>a</sup> Within each year numbers in the A column represent survival for the A treatments and numbers in the B column represent survival for the B treatments.

<sup>b</sup> The P-values were determined from preplanned orthogonal contrasts for the physical site treatments and from the type III F-test for the fertilizer treatments.

### Volume Growth

At age 18 years, stand volume averaged 213 m<sup>3</sup> ha<sup>-1</sup>. Stand volumes were similar for all soil physical treatments (fig. 2). Fertilization increased volume production by 47 percent and was a significant factor at every age sampled. The unfertilized plots averaged 172.3 m<sup>3</sup> ha<sup>-1</sup>, while the fertilized plots averaged 253.8 m<sup>3</sup> ha<sup>-1</sup>. The interaction between the physical treatments and fertilization was not significant.

Orthogonal contrasts revealed that at age 18 none of the individual or interaction effects (wet or dry logging, shearing, rotraking, disking, and the logging and shearing interaction) were significant at  $\alpha = 0.05$  (table 2). Shearing increased volume by 13 percent but was not significant at  $\alpha = 0.05$ .

Because the treatments imposed variable survival after the first year and therefore different numbers of trees were replanted, we analyzed the volume of the original trees at age 18 years to ensure that the replanting did not affect our interpretations. The only difference in treatment effect between the total stand volume (original + replanted trees) and the original trees only was the shearing effect. Shearing improved growth of the original trees significantly ( $P < 0.0234$ ), while only marginally ( $P < 0.0524$ ) for all trees. Otherwise, the interpretations were not different for any effect.

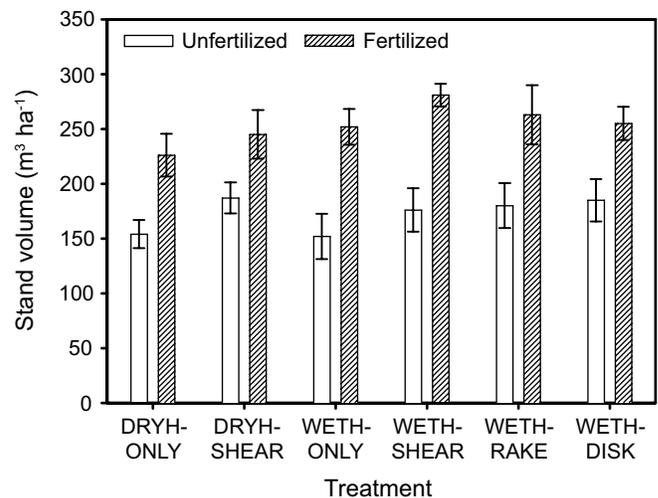


Figure 2—Eighteen-year slash pine volume response to soil physical disturbances and fertilization on a flatwoods site in Louisiana. Error bars represent one standard error. The treatment abbreviations indicate the type of harvest (dry vs. wet) and site preparation (only = no mechanical site preparation, shear = shearing site preparation, rake = rotraking following shearing, and disk = flat disking following shearing and rotraking).

**Table 2—Eighteen-year volume production of slash pine in soils impacted by harvesting and site preparation on a flatwoods site in Louisiana**

Treatment comparison	Volume		P>F <sup>b</sup>
	A <sup>a</sup>	B	
	---- m <sup>3</sup> /ha ----		
Dry (A) vs wet logging (B)	203.1	215.2	0.3421
No shearing (A) vs. shearing (B)	196.1	222.2	0.0524
No rotraking (A) vs. rotraking (B)	209.3	220.9	0.2931
No disking (A) vs. disking (B)	221.7	219.9	0.9200
Not fertilized (A) vs. fertilized (B)	172.3	253.8	0.0001

<sup>a</sup> Numbers in the A column represent volume for the A treatments and numbers in the B column represent volume for the B treatments.

<sup>b</sup> The P-values were determined from preplanned orthogonal contrasts for the physical site treatments and from the type III F-test for the fertilizer treatment.

Similarly, the soil physical treatments had little effect on volume growth throughout the development of the stand. The time of logging (wet vs. dry logging) had no effect on volume at any age (fig. 3). Shearing marginally increased (as defined by  $\alpha = 0.10$ ) volume at ages 5, 13, and 18 (fig. 4). Rootraking increased volume growth by 47 percent at age 5 years, but this effect was absent at age 8 and thereafter (fig. 5). Disking had no effect on volume growth at any age (fig. 6). Fertilization increased volume production significantly at every age measured (fig. 7).

The repeated measures analysis revealed that the soil physical treatment effects were not different through time, although the fertilization effect was significantly different ( $P < 0.0001$ ) through time. Fertilization continued to increase the growth rates through age 18 (fig. 7). The fertilization x soil physical treatment x age interaction was not significant. The individual effects, as estimated by contrasts, changed little through time. The time of logging x age, disking x age, and time of logging x shearing x age interactions were not significant. The shearing x age ( $P < 0.0765$ ) and rootraking x age ( $P < 0.0834$ ) interactions were marginally significant.

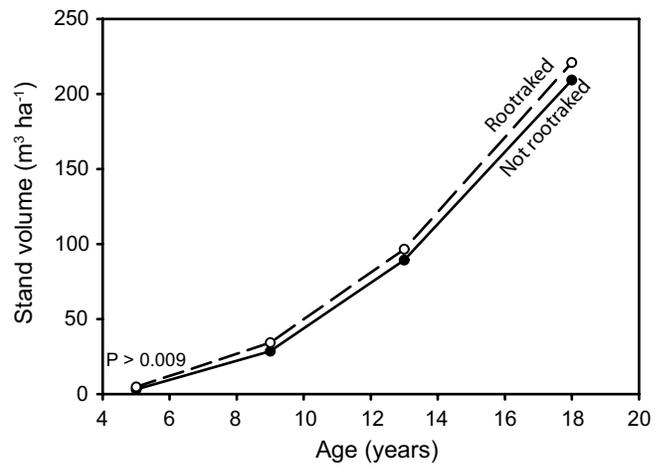


Figure 5—Slash pine volume response to rootraking following shearing on a flatwoods site in Louisiana.  $P$  values were determined from preplanned orthogonal contrasts.

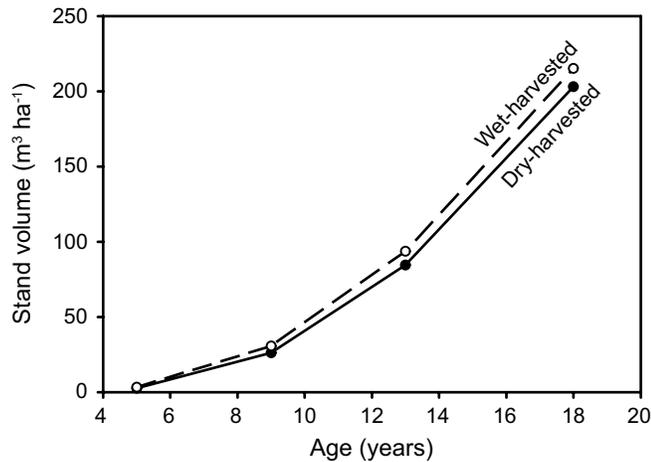


Figure 3—Slash pine volume response to wet and dry soil conditions at harvest on a flatwoods site in Louisiana.

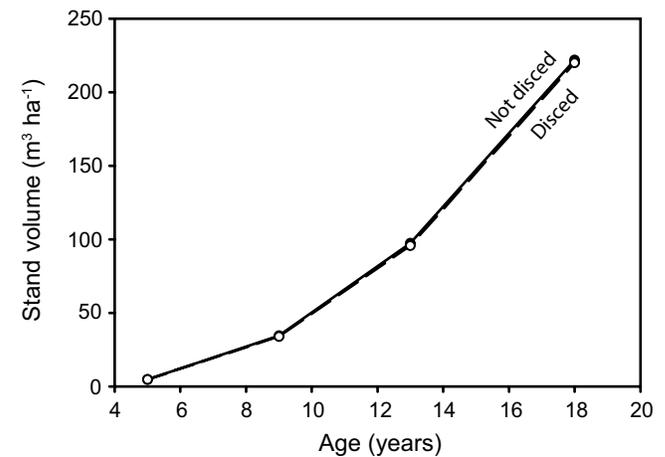


Figure 6—Slash pine volume response to disking following shearing and rootraking on a flatwoods site in Louisiana.

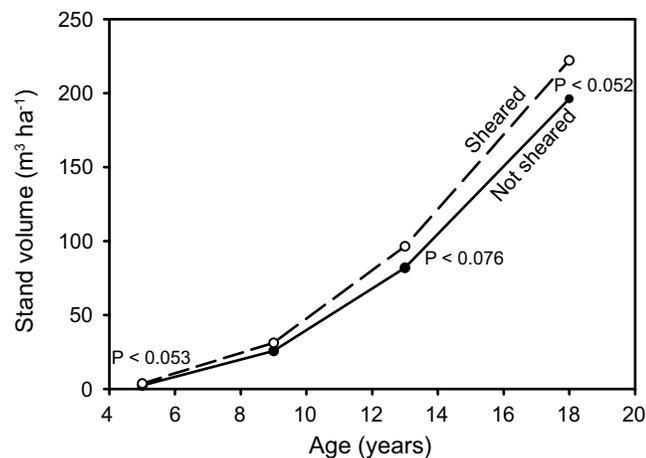


Figure 4—Slash pine volume response to burning vs. shearing site preparation on a flatwoods site in Louisiana.  $P$  values were determined from preplanned orthogonal contrasts.

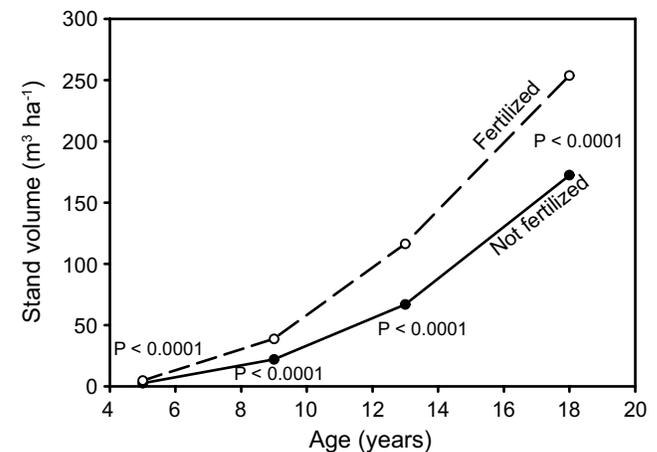


Figure 7—Slash pine volume response to fertilization on a flatwoods site in Louisiana.

## DISCUSSION

Many studies on soil compaction and wet-weather logging have focused on skid trails and logging decks but have not reported whether an overall area has been negatively impacted, e.g., Lockaby and Vidrine (1988) and Hatchell (1981). In this study we assessed the entire plot. Only 2.7 percent of the area of wet-weather logged plots remained undisturbed, while > 50 percent was characterized by moderate or severe compaction and rutting (Tiarks 1990). The dry-weather logged plots had no visually detected soil disturbance. Therefore, this study was a good test of the overall effects of harvest-induced soil physical disturbance on site productivity.

## Survival

Initial survival was poor across all plots, partly due to a mild to severe drought in the area from July 1980 through July 1982, which averaged -2.74 on the Palmer Drought Severity Index (National Climatic Data Center 2005). The only significant treatment effect in the first year was higher survival in the wet-weather harvested plots. The dry-weather harvesting did not take place until July, which increased the probability of insect damage (Tiarks 1990). After replanting, the survival at age 3 years was affected only by shearing, which improved survival. Although woody competition was controlled by injected herbicides, brushy competition was reduced by shearing better than the burning on the nonsheared plots. These results are in contrast to those of several other studies (Miwa and others 2004) in which survival was reduced by compaction, rutting, and other soil disturbances. However, those studies were conducted on coarse-textured or adequately drained soils. This study was conducted on a medium-textured (silt loam) soil with little internal drainage but dry soil conditions during late summers.

## Volume

Volume growth was unaffected by both soil disturbance caused by harvesting and site preparation method. Wet-weather logging had no impact on volume growth at any age through age 18 years. The growth patterns were not diverging, even after canopy closure. Mechanical site preparation (shearing, shearing + root raking, shearing + root raking + disking) had no effect on volume growth compared to burning. Shearing had marginal impacts at ages 5, 13, and 18 years, but this effect was likely due to its control of brush competition.

The lack of response to any soil physical disturbance indicates that for this soil, which had little internal drainage and little macroporosity prior to harvest, soil physical disturbances during very wet conditions did not impact soil productivity. Further, the site preparation treatments had little impact, largely because they did not affect soil properties limiting growth. These results are similar to those found in other studies. Aust and others (1995) found that soils with inherently low soil physical quality had less impact from wet-weather logging than soils with better initial soil properties.

Other site preparation treatments may have been beneficial, such as bedding, although bedding studies in the West Gulf Coastal Plain have not shown similar improvements in growth as in the Atlantic Coastal Plain (Derr and Mann 1977, Haywood 1980), or with slash pine compared to loblolly pine (*P. taeda* L.) (Cain 1978). Heavier surface textures in the West Gulf Coastal Plain reduce the ability of bedding to increase aeration, because wet conditions are maintained in the surface

through capillary action. Further, early increases in growth due to bedding in this region have not been maintained, possibly due to low soil fertility (Tiarks and Haywood 1996).

Volume growth was significantly improved by P fertilization, which was not surprising. Several studies in similar soils have found P fertilization to be required on the moderately to severely P-deficient soils in the West Gulf Coastal Plain (Haywood and Burton 1990, McKee 1973, Tiarks 1983). The fertilizer effect was no more significant on the wet-weather logged plots, indicating the soil physical disturbance did not restrict rooting volume.

## CONCLUSIONS

Soil physical disturbances caused by wet-weather logging and mechanical site preparation had no negative effects on early survival and no effect on 18-year volume growth of slash pine on a poorly drained flatwoods site in southwestern Louisiana. The lack of effect was not due to a lack of disturbance; the wet-weather-logged plots were moderately to severely disturbed across the majority of the area. However, the soils were medium-textured, had little inherent macroporosity or drainage, and were inherently infertile. Soil physical disturbance did not likely change these factors, so slash pine growth was unaffected. Similarly, mechanical site preparation had little effect, because the forms of site preparation, i.e., shearing, root-raking, and disking, did not improve the soil physical characteristics. Tree growth was substantially improved by P fertilization on this inherently infertile site. This study indicates that while soil physical disturbances may reduce the long-term productivity of some sites, moderate to severe physical disturbances may not negatively impact soils with inherently poor soil physical properties.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Aust, W.M.; Tippett, M.D.; Burger, J.A.; McKee, W.H., Jr. 1995. Compaction and rutting during harvesting affect better drained soils more than poorly drained soils on wet pine flats. *Southern Journal of Applied Forestry*. 19: 72-77.
- Cain, M.D. 1978. Planted loblolly and slash pine response to bedding and flat disking on a poorly drained site—an update. Res. Note 237. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 6 p.
- Derr, H.J.; Mann, W.F., Jr. 1977. Bedding poorly drained sites for planting loblolly and slash pines in southwest Louisiana. Res. Pap. SO-134. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 5 p.
- Eisenbies, E.H.; Burger, J.A.; Aust, W.M.; Patterson, S.C. 2004. Loblolly pine response to wet-weather harvesting on wet flats after 5 years. *Water, Air, & Soil Pollution*. 4: 217-233.
- Hatchell, G.E. 1981. Site preparation and fertilizer increase pine growth on soils compacted in logging. *Southern Journal of Applied Forestry*. 5: 71-83.
- Haywood, J.D. 1980. Planted pines do not respond to bedding on an Acadia-Beauregard-Kolin silt loam site. Res. Note SO-259. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 4 p.
- Haywood, J.D.; Burton, J.D. 1990. Phosphorus fertilizer, soils, and site preparation influence loblolly pine productivity. *New Forests*. 3: 275-287.

- Lockaby, B.G.; Vidrine, C.G. 1988. Effect of logging equipment traffic on soil density and growth and survival of young loblolly pine. *Southern Journal of Applied Forestry*. 8: 109-112.
- Lohrey, R.E. 1985. Stem volume, volume ratio, and taper equations for slash pine in the west gulf region. In: Shoulders, E., ed. *Proceedings of the third biennial southern silvicultural research conference*. Gen. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 451-459.
- McKee, W.H., Jr. 1973. Slash pine response to nitrogen and phosphorus on imperfectly drained soil of the west Gulf coastal plain. *Soil Science Society of America Proceedings*. 37: 784-788.
- Miller, R.E.; Colbert, S.R.; Morris, L.A. 2004. Effects of heavy equipment on physical properties of soils and on long-term productivity: a review of literature and current research. *Tech. Bull.* 887. Research Triangle Park, NC. National Council for Air and Stream Improvement. 76 p.
- Miwa, M.; Aust, W.M.; Burger, J.A. [and others]. 2004. Wet-weather harvesting and site preparation effects on coastal plain sites: a review. *Southern Journal of Applied Forestry*. 28: 137-151.
- Morris, L.A.; Miller, R.E. 1994. Evidence for long-term productivity change as provided by field trials. In: Dyck, W.J.; Cole, D.W.; Comerford, N.B., eds. *Impacts of forest harvesting on long-term site productivity*. London: Chapman and Hall: 41-80.
- National Climatic Data Center. 2005. <http://www.ncdc.noaa.gov/oa/ncdc.html> [Date accessed unknown].
- SAS Institute. 2000. *SAS/STAT user's guide*. Version 8. Cary, NC: SAS Institute.
- Scott, D.A.; Tiarks, A.E.; Sanchez, F.G. [and others]. 2004. Forest soil productivity on the southern long-term soil productivity sites at age 5. In: Connor, K.F., ed. *Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 372-377.
- Tiarks, A.E. 1983. Effect of site preparation and fertilization on slash pine growing on a good site. In: Jones, E.P., Jr., ed. *Proceedings of the second biennial southern silvicultural research conference*. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 34-39.
- Tiarks, A.E. 1990. Growth of slash pine planted in soil disturbed by wet-weather logging. *Journal of Soil and Water Conservation*. 45: 405-407.
- Tiarks, A.E.; Haywood, J.D. 1996. Site preparation and fertilization effects on growth of slash pine for two rotations. *Soil Science Society of America Journal*. 60: 1654-1663.
- Tiarks, A.E.; Meier, C.E.; Baldwin, V.C.; Haywood, J.D. 1998. Value of tree measurements made at age 5 years for predicting the height and diameter growth at age 25 years in loblolly pine plantations. In: Waldrop, T.A., ed. *Proceedings of the ninth biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 537-541.

# RELATIONSHIP BETWEEN TILLAGE INTENSITY AND INITIAL GROWTH OF LOBLOLLY PINE SEEDLINGS

M. Chad Lincoln, Rodney E. Will, Emily A. Carter, John R. Britt, and Lawrence A. Morris<sup>1</sup>

**Abstract**—To determine the relationship between changes in soil attributes associated with differing tillage intensities and growth of loblolly pine seedlings, we measured soil moisture, nitrogen (N) availability, and soil strength across a range of tillage treatments on an Orangeburg soil series near Cuthbert, GA (four replications). We then correlated these measurements to the growth of individual seedlings. The five tillage treatments were: no-till (NT), coultter only (C), coultter + subsoil (CS), coultter + bed (CB), and coultter + bed + subsoil (CSB). Adjacent to 3 trees per plot (60 trees total), soil moisture was measured every 2 weeks using TDR, soil N availability was measured monthly by KCl extractions, and soil strength was measured 2 times during the year using a cone penetrometer beginning in May, 2003. In December of 2003, the 60 trees were excavated to determine tree biomass. Average soil moisture in the upper 60 cm decreased from 28 percent in the NT treatment to 22 percent in the CB and CSB treatments. Nitrate concentrations increased by 33 percent in the bedded treatments (CB and CSB) compared to the NT, C, and CS treatments. From 0 to 200 mm, bedding decreased the average soil strength by 46 percent compared to the other treatments. Subsoiling decreased soil strength at depths > 200 mm. Tillage positively affected relative height growth ( $p = 0.0005$ ), and all the tillage treatments increased relative height growth compared to the NT treatment. Soil strength between 0 and 100 mm ( $P=0.002$ ,  $r^2=0.41$ ) was positively correlated with seedling relative height growth. Soil moisture from 0 to 300 mm ( $P=0.0016$ ,  $r^2=0.44$ ) was negatively correlated with seedling relative height growth. In contrast, N availability was not correlated to seedling growth. These results indicate tillage increases rootability by decreasing soil strength and increasing porosity, and that these changes are associated with increased seedling growth.

## INTRODUCTION

Intensive site preparation has become a standard practice for the establishment of pine plantations (Outcalt 1983). Mechanical site preparation methods, such as bedding and subsoiling, can improve water status and structure of many soils, and facilitate planting (Berry 1979). The beneficial effects of bedding or subsoiling can be attributed to improved drainage, improved microsite environment (nutrients, aeration, temperature, and moisture) for root development, increased moisture availability, and reduced competition (Haines and others 1975). Operations that increase the ability of a seedling to exploit the existing resources in the soil or increase the quantities of the resources in the soil will increase seedling growth (Wheeler and others 2002).

However, the high cost of mechanical site preparation techniques and inconsistent results have caused many forest managers to reconsider the benefits of these practices. Lower-cost treatments such as fertilization and herbicide application may reduce the need for tillage if the positive effects of tillage are largely due to increased resource availability. However, if the positive effects of soil tillage are related to changes in soil physical properties and the ability of roots to exploit the soil volume, then tillage is useful to increase seedling growth. The goals of this study were to (1) quantify the effects of soil tillage on soil strength (SS), soil moisture, and soil nitrogen (N) availability and (2) determine the relationship between tillage-mediated changes in soil attributes and growth of loblolly pine seedlings. Different levels of soil tillage (coultter only, bedding, subsoiling, and bedding and subsoiling combined) were employed to generate a range of responses and to determine the minimum amount of tillage necessary to obtain the desired changes in soil attributes.

## PROCEDURES

This study was established on a tract of land owed by Mead-Westvaco, located in the Upper Coastal Plain of southwest Georgia. The site has an Orangeburg (Typic Kandiudult) soil type with 1 to 6 inches of sandy loam topsoil over a clay loam B-horizon. Five treatments were evaluated, no-till (NT), coultter (C), coultter + bed (CB), coultter + subsoil (CS), and coultter + subsoil + bed (CSB). Prior to tillage treatments, all plots received an aerial herbicide treatment of 6 quarts of Accord SP and 1 ounce of Escort in a total aqueous solution of 15 gallons per acre on July 3, 2002. The plots were operationally hand-planted on January 7, 2003, with a first-generation open-pollinated Atlantic Coast loblolly pine family. The rows were 12 feet apart, and the seedlings were planted at a 6-foot spacing along the rows. A broadcast herbaceous weed control treatment of 12 ounces per acre of Oustar<sup>®</sup> was aerially applied on March 8, 2003, at 10 gallons per acre. To ensure uniform and complete weed control, mop-up spraying using glyphosate was done throughout the year to control herbaceous and woody competition.

The randomized complete block design consisted of four blocks each containing five randomly placed treatment plots. The plots are 7 rows wide with 30 trees per row (0.37 acre). Tillage treatments were implemented on November 17, 2002, using a Savannah Forestry Equipment, LLC model 420 two-disk heavy-duty subsoil plow pulled by a Caterpillar D-7R tractor. This plow consists of a linear arrangement of a 1.2 m coultter wheel, followed by a 7.5-cm-wide subsoil shank and then 2 80-cm-diameter opposed notched disk blades. The plow creates a continuous bed up to 50 cm in height, 1.7 m wide, and subsoils at a depth up to 60 cm. To install the non-bedded tillage treatments, the disks were elevated to avoid

<sup>1</sup> Graduate Research Assistant and Associate Professor, respectively, University of Georgia, Warnell School of Forest Resources, Athens, GA 30602; Research Soil Scientist, USDA Forest Service, Southern Research Station, Auburn, AL 36849; Site Preparation Forester, Mead Westvaco, Phenix City, AL 36868; and Professor, University of Georgia, Warnell School of Forest Resources, Athens, GA 30602.

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soil contact. To install the non-subsoiled tillage treatments, the subsoil shank was removed from the plow. The no-till treatments were hand-planted at the same spacing as the tillage treatments.

Before the first growing season (2003), 3 trees of differing size were chosen in each plot (60 trees total) to be observed all year and intensively measured. Seedling height and ground line diameter were measured at regular intervals. Near each of 60 trees, exchangeable N in the form of ammonium and nitrate, volumetric soil moisture, and SS were periodically measured. We measured KCl-extractable ammonium and nitrate concentration once per month (Mulvaney 1996). Soil moisture was measured via time domain reflectometry from 0 to 300 and 0 to 600 mm every 2 weeks from early April until September and monthly from September until December. SS was measured with a Rimik CP 20 Cone Penetrometer in May and August. Nine insertions were made to a depth of 600 mm and recorded in 25 mm increments in an area of 1 m<sup>2</sup> around each tree. At the end of the first growing season, all 60 measurement trees were excavated to measure stem, foliar, and root biomass.

We tested the effects of tillage type on SS, soil moisture, and N availability with analysis of variance (ANOVA), using a split plot analysis when appropriate, i.e., when soil depth (SS) and date (soil moisture) were included in the analysis. We then tested the relationship between the tillage-mediated differences in these soil attributes on seedling relative height growth (absolute height growth/initial height) using linear regression. The responses of the three seedlings per plot were averaged before analyses as the plot served as the experimental unit.

## RESULTS

### Soil Strength

SS changed with soil depth (depth effect  $P < 0.0001$ ). In the NT plots, SS increased between 100 to 200 mm and then decreased at deeper depths, probably reflecting a root restrictive layer in the soil profile across the site (fig.1). Overall, the tillage treatments reduced SS (tillage effect  $P < 0.0001$ ), but depth to which the different tillage treatments was effective

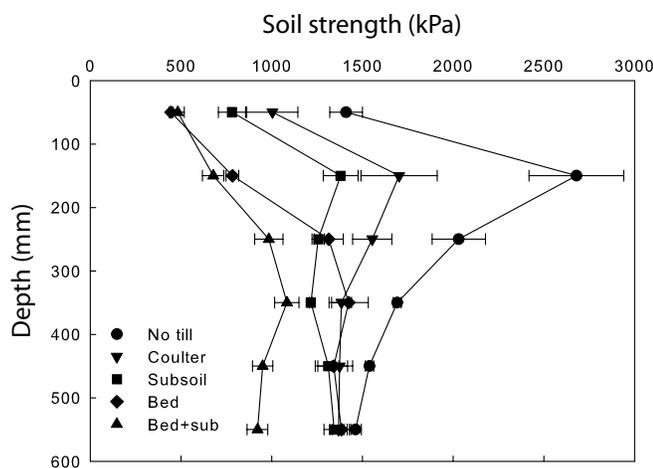


Figure 1—The response of soil strength to soil depth and tillage treatment for a 1-year-old loblolly pine stand in southwest Georgia measured in May, 2003.

depended on tillage type (tillage x depth interaction  $P < 0.0001$ ). The bedding treatments (CB and CSB) were reduced in average SS from 1,411 kPa in the NT treatment to 463 kPa in the beds between 0 and 100 mm. At greater soil depths, the subsoil treatments became more effective at reducing SS. Between 500 to 600 mm, the CSB treatment was most effective, with an average SS of 922 kPa compared to 1,462 kPa of the NT. The C treatment was less effective than the more intensive tillage treatments at reducing SS, but this treatment reduced SS at all depths compared to the NT treatment. The results for August, 2003, were similar to May with tillage treatment, depth, and tillage x depth significant ( $P < 0.0001$ ).

### Soil Moisture

Volumetric soil moisture varied throughout the growing season with generally reduced moisture in summer due to lower precipitation and greater evapotranspiration (date effect  $P < 0.0001$ ) (fig. 2). Between 0 to 600 mm, the volumetric moisture content of the soils in the NT treatment was consistently higher than in the tillage treatments, with the bedded (CB and CSB) treatments having the lowest moisture content (tillage effect  $P = 0.0002$ ). Tillage effects were generally consistent throughout the year (date x tillage treatment,  $P = 0.11$ ). Average volumetric soil moisture content ranged from 28 percent in the NT treatment to 22 percent in the CSB treatment (fig. 2). Moisture content from 0 to 300 mm was similar to 0 to 600 mm with treatment and date significant, but there was a date x tillage interaction ( $P < 0.0001$ ) probably due to less consistent moisture contents of the tillage treatments resulting from greater variation in periodic wetting and drying.

### Soil Nitrogen Concentration

Tillage treatment ( $P = 0.006$ ) and date ( $P < 0.0001$ ) significantly affected soil Nitrate N concentration (fig. 3). Average nitrate N levels throughout the year ranged from a high of 3.2  $\mu\text{g/g}$  in the CB treatment to 1.8  $\mu\text{g/g}$  in the CS treatment. The higher nitrate N levels in the bedded treatments was most likely due to increased organic matter and top soil that are localized around the seedlings and a soil surface that was more rapidly warmed (Morris and Lowery 1988). Higher

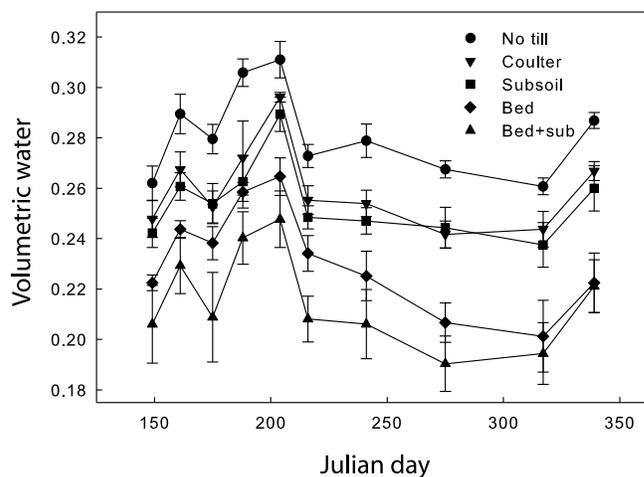


Figure 2—Average volumetric water content from 0 to 600 mm of the tillage treatments for a 1-year-old loblolly pine stand in southwest Georgia measured in 2003.

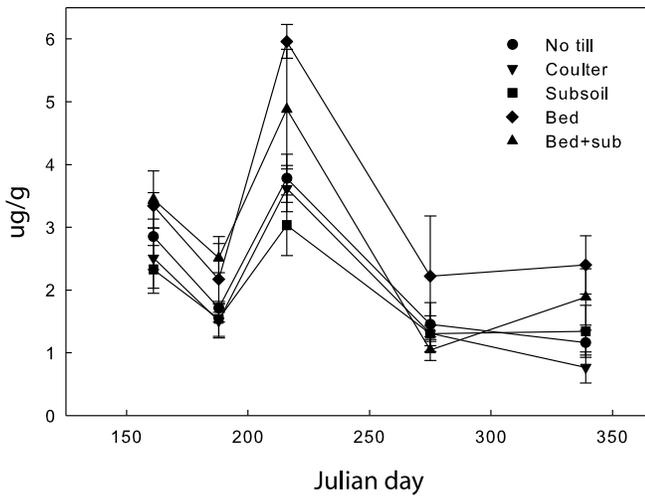


Figure 3—Nitrate concentration of the tillage treatments for a 1-year-old loblolly pine stand in southwest Georgia measured in 2003.

nitrate levels in mid-summer were expected because of higher temperatures. Tillage treatments did not significantly affect ammonium N concentration ( $P = 0.60$ ).

### Seedling Growth

Seedling height after the first growing season was correlated to seedling biomass. Across tillage treatments, a positive relationship existed between seedling height and root biomass ( $P < 0.0001$  and  $r^2 = 0.46$ ) and seedling height and stem biomass ( $P < 0.0001$  and  $r^2 = 0.60$ ). The regression equations are  $\text{height} = 46.089 + 0.3851 * (\text{root biomass})$  and  $\text{height} = 43.139 + 0.6495 * (\text{stem biomass})$  where height is seedling height in cm and biomass is in grams. During the 2003 growing season, the seedlings in the tilled treatments grew taller than the seedlings in the NT treatment resulting in a significant date x treatment interaction ( $P < 0.0001$ ) (fig. 4). Seedling height increased from 22.5 to 52.3 cm in the NT treatment and from 19.1 to 69.5 cm on the CSB treatment. Planting depth differences caused a difference in initial heights between

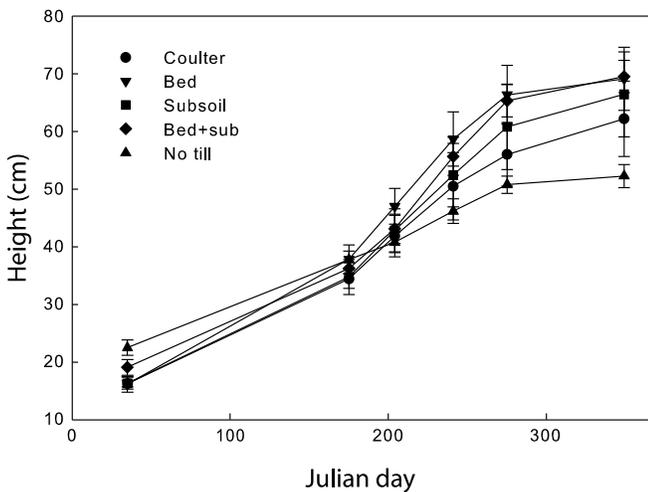


Figure 4—Height growth of loblolly pine seedlings by tillage treatment for a 1-year-old loblolly pine stand in southwest Georgia measured in 2003.

treatments of up to 6 cm. Because of the differences among the initial heights of seedlings within treatments (from 16 cm in the CB treatment to 23 cm in the NT) and due to the small differences in initial heights between tillage treatments, we used relative height growth (seedling height growth/initial height) as our estimate of seedling response. Relative height growth increased as a result of tillage ( $P = 0.0005$ ) (NT = 1.4; C = 2.9; CS = 3.1; CB = 3.5; CSB = 2.9).

Relative height growth increased as SS decreased in the upper portion of the soil profile (0 to 400 mm). From 400 to 600 mm, the relationship between SS and relative height growth was not significant. As SS in the 0 to 100 mm zone decreased from 1,900 to 500 kPa, relative height growth increased from 1.6 to 3.5 with 41 percent of the variation in relative height predicted by SS (fig. 5). This relationship was also significant ( $P < 0.05$ ) from 100 to 200 mm ( $r^2 = 0.37$ ), 200 to 300 mm ( $r^2 = 0.31$ ), and 300 to 400 mm ( $r^2 = 0.22$ ). When average volumetric water content between 0 to 300 mm decreased from 29 percent to 19 percent, relative height growth increased from 1.6 to 3.5 ( $P = 0.002$ ,  $r^2 = 0.44$ ) (fig. 6). The relationship at 0 to 600 mm was not as strong ( $P = 0.01$ ,  $r^2 = 0.29$ ). Nitrate N, both ammonium ( $P = 0.72$ ) and nitrate ( $P = 0.26$ ) (fig. 7), were not significantly related to relative height growth.

### DISCUSSION

The purpose of soil tillage in forest site preparation is to improve soil physical attributes and to facilitate seedling establishment and growth. The data in this study indicate a positive correlation between SS and seedling growth. This positive correlation was most likely due to improved soil physical conditions that enabled roots to better capture and exploit soil resources (Will and others 2002). Subsoiling was successful at reducing SS at depths  $> 400$  mm, but as other studies have shown, adding subsoiling to other tillage treatments did not increase growth (Wheeler and others 2002). The reason decreased SS deeper in the soil profile did not increase growth is most likely due to concentration of roots near the surface soil (Nambiar and Sands 1993).

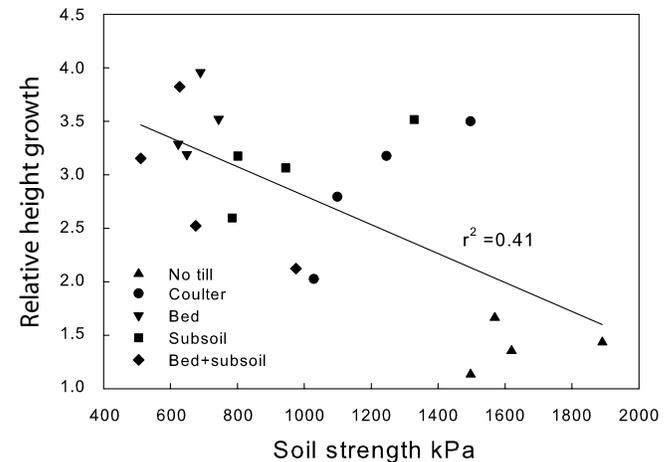


Figure 5—Regression of soil strength from 0 to 100 mm as related to relative height growth for a 1-year-old loblolly pine stand in southwest Georgia measured in 2003.

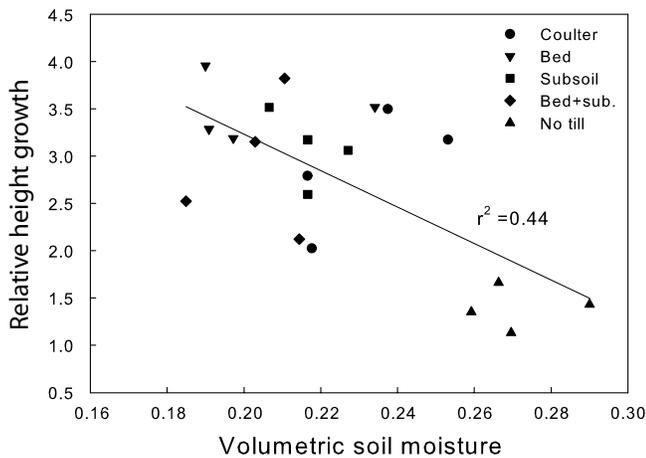


Figure 6—Regression of average soil moisture from 0 to 300 mm as related to relative height growth for a 1-year-old loblolly pine stand in southwest Georgia measured in 2003.

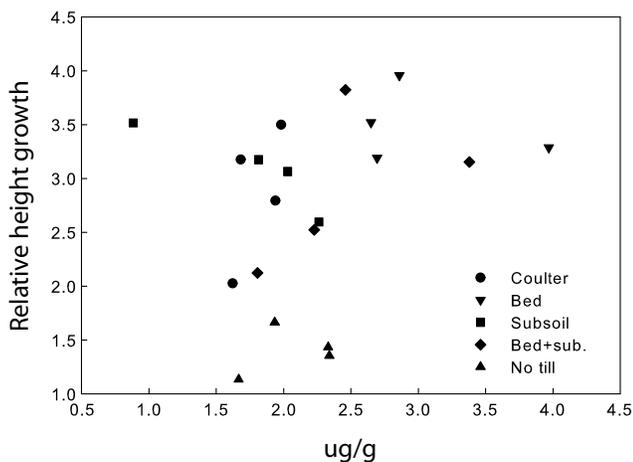


Figure 7—Regression of nitrate N levels of individual tillage treatments as related to relative height growth for a 1-year-old loblolly pine stand in southwest Georgia measured in 2003.

As volumetric water content decreased, relative height growth increased. The decrease in volumetric water content in the tilled treatments did not necessarily translate into less available water for the seedlings; the amount of soil water available to plants is a function of rooting volume as well as water infiltration and retention characteristics of the soil (Morris and Lowery 1988). The decrease in volumetric water content in this study was most likely caused by an increase in large voids in the soil and increased macro-porosity created by the tillage treatments (Harrison and others 1994). Increased macro-porosity probably allowed the roots to more fully utilize the site, and this may have translated into improved relative height growth (Shiver and Fortson 1979, Will and others 2002).

Although tillage increased Nitrate N, this increase did not relate to increased relative height growth. Increased levels of N in the soil may not always be necessary to improve early seedling growth. Morris and Lowery (1988) stated that increased N mineralization may not be important in young

stands because over 100 pounds per acre of N may be mineralized in the first 2 years after site preparation while pine seedlings accumulate only 3 to 5 pounds per acre when planted at normal densities. These increased levels of nitrate N may be useful to the trees when they grow larger and the site becomes more fully exploited. Also, in this case weed control eliminated any vegetation competing for available N that could be expected to have an adverse effect on seedling growth (Burger and Pritchett 1988).

The results obtained in this study indicate that tillage treatments decreased SS, decreased volumetric soil moisture, and increased N availability. The change in SS resulting from tillage is probably the most meaningful predictor of seedling response to tillage intensity. In areas with high SS, particularly in the upper portion of the soil profile, tillage will increase seedling growth. On this soil, adding subsoiling to bedding did not cause any additional benefit, and minimal tillage, i.e., the coultter only, provided almost as much benefit as the more intensive treatments. The effects of tillage will probably provide an additive benefit to weed control since we found a tillage response in the absence of competing vegetation.

## LITERATURE CITED

- Berry, C.R. 1979. Subsoiling improves growth of pine on a Georgia Piedmont site. Res. Note SE-284. Asheville, NC: U.S. Department of Agriculture Forest Service. 3 p.
- Burger, J.A.; Pritchett, W.L. 1988. Site preparation effects on soil moisture and available nutrients in a pine plantation in the Florida flatwoods. *Forest Science*. 34(1): 77-87.
- Haines, L.W.; Maki, T.E.; Sanderford, S.G. 1975. The effect of mechanical site preparation treatments on soil productivity and tree (*Pinus taeda* L. and *P. elliotii* Engelm. var. *elliottii*) growth. In: Bernier, B.; Winget, C.H., eds. *Forest soils and forest land management*. Quebec, Canada: Les Presses de l'University Laval: 379-395.
- Harrison, D.F.; Cameron, K.C.; McLaren, R.G. 1994. Effects of subsoil loosening on soil physical properties, plant growth, and pasture yield. *New Zealand Journal of Agricultural Research*. 37: 559-567.
- Morris, L.A.; Lowery, R.F. 1988. Influence of site preparation on soil conditions affecting stand establishment and tree growth. *Southern Journal Applied Forestry*. 12(3): 170-178.
- Mulvaney, R.L. 1996. Extraction of exchangeable ammonium and nitrate. In: Sparks, D.L., ed. *Methods of soil analysis*, part 3. Chemical methods. Soil Science Society of America Book Series Number 5. Madison, WI: American Society of Agronomy: 1129-1131.
- Nambiar, E.K.S.; Sands, R. 1993. Competition for water and nutrients in forests. *Canadian Journal of Forest Resources*. 23: 1955-1968.
- Outcalt, K.W. 1983. Mechanical site preparation improves growth of genetically improved and unimproved slash pine on a Florida flatwoods site. In: Jones, Jr., E.P., comp. *Proceedings of the second biennial southern silvicultural research conference*. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 11-13.
- Shiver, B.D.; Fortson, J.C. 1979. Effect of soil type and site-preparation method on growth and yield of flatwoods slash pine plantations. *Southern Journal Applied Forestry*. 3(3): 95-100.
- Wheeler, M.J.; Will, R.E.; Markewitz, D. [and others]. 2002. Early loblolly pine stand response to tillage on the piedmont and upper coastal plain of Georgia: mortality, stand uniformity, and second and third year growth. *Southern Journal Applied Forestry*. 26(4): 181-189.
- Will, R.E.; Wheeler, M.J.; Markewitz, D. [and others]. 2002. Early loblolly pine stand response to tillage on the piedmont and upper coastal plain of Georgia: tree allometry, foliar nitrogen concentration, soil bulk density, soil moisture, and soil nitrogen status. *Southern Journal Applied Forestry*. 26(4): 190-196.

# A 16-YEAR EVALUATION OF EFFECTS OF RIPPING ON SHORTLEAF PINE ON A MISSOURI OZARKS SITE

David Gwaze, Carl Hauser, and Mark Johanson<sup>1</sup>

**Abstract**—A shortleaf pine (*Pinus echinata* Mill.) ripping study was established by the Missouri Department of Conservation in March 1988 at the Logan Creek Conservation Area. The objective of the study was to evaluate the effects of ripping on survival, height, diameter, volume, crown spread, and free-to-grow status of planted shortleaf pine seedlings. Ripping improved survival by 4 percent during the first 3 growing seasons, and at age 16 the improvement in survival was 7.1 percent. It improved crown spread by 13.6 percent and free-to-grow status by 3.8 percent after 2 growing seasons. Ripping improved height, diameter, and volume by 14.2, 14.0, and 41.2 percent, respectively, after 2 growing seasons. However, at age 16, ripping had no effect on height, and it reduced diameter and volume by 5.3 percent and 10.2 percent, respectively. The results suggest that benefits of ripping are minor and short-term.

## INTRODUCTION

Restoration of shortleaf pine (*Pinus echinata* Mill.) in its former natural range can be accomplished through natural and/or artificial regeneration. Artificial regeneration is preferred where (1) no seed trees exist, (2) harvesting does not coincide with a good seed crop, (3) more precise stocking goals are required, and (4) genetic composition of the new forest needs to be altered to achieve certain management objectives (e.g. better production, greater genetic diversity, etc.). In the Missouri Ozarks, most of the forests have been high graded and good seed crops are difficult to predict, making artificial regeneration attractive. Furthermore, genetically improved seed is available, providing an opportunity to improve forest productivity.

Artificial regeneration of shortleaf pine in the Missouri Ozarks presents numerous challenges. Summer droughts are common, soils are rocky and contain hardpans, and hardwood vegetation competes with the planted seedlings. Some form of site preparation is essential for successfully establishing shortleaf pine on these sites. Ripping or subsoiling is an alternative mechanical site preparation method for regenerating shortleaf pine on these harsh sites. Ripping has been reported to improve survival and growth of planted shortleaf pine by breaking up the hardpans or impervious subsoil layers and thus encouraging deeper root development and increased root growth area (Wittwer and others 1986). It has also been reported to reduce hardwood competition around the seedling during the first few years after planting, eliminating the need for follow-up release treatment from competing hardwoods (Wittwer and others 1986). Ripping provides a catchment area for any precipitation and allows the seedling's roots to extend further into the soil profile where more moisture may be available. The result is an increase in moisture for the seedling, and ultimately, improved survival and growth. Ripping has also been used as a site preparation method in the U.S.A. (e.g. Wittwer and others 1986) and in other countries such as New Zealand (Guild 1971) and Australia (Lacey and others 2001). There are few reports that quantify ripping benefits on shortleaf pine in the U.S.A. In Georgia, ripping increased height growth by 17 percent, root-collar diameter by 15 percent, and tree volume by 38 percent 5 years after planting

(Berry 1979). In Arkansas, ripping improved survival by 20 to 25 percent, and competition from weeds and other vegetation was reduced (McClure 1984). In Missouri, ripping increased height growth by 53.8 percent after 5 growing seasons at Mark Twain National Forest (McClure 1989).

Interest in ripping for shortleaf regeneration in Missouri was stimulated by the excellent results in Arkansas (McClure 1984). Ripping was started in Missouri in 1984 at the Mark Twain National Forest, Salem District. The Missouri Department of Conservation (MDC) and Mark Twain National Forest began the trial use of ripping for shortleaf pine site preparation in the late 1980s. By the early 1990s, about 300 acres of public land were ripped and planted with shortleaf pine trees. Initial results in Missouri indicated that increased growth and survival might be expected using this practice (McClure 1989), but benefits of ripping at mature ages had not been quantified. In 1987, a project was initiated to evaluate the efficacy of ripping as a site preparation method in Missouri Ozarks. The objectives were to determine the effects of ripping on survival, height, diameter, volume, crown spread, and free-to-grow status of planted shortleaf pine seedlings.

## MATERIALS AND METHODS

### Study Site

The study site is located on Logan Creek Conservation Area in the Ozark Highlands of Reynolds County, MO (NE ¼ of Sec 7, T. 30 N., R. 1 W.; fig. 1). The study site is classified by the ecological classification system for Missouri (ECS) within the Current River Pine-Oak Woodland Dissected Plain Landtype Association (LTA) (Nigh and Schroeder 2002). This LTA is located along the periphery of the Current River Valley and is characterized by a moderately dissected upland plain associated with the Roubidoux Formation. Relief over large areas is generally < 100 feet. Historically, this area was dominated by pine and pine-oak woodland complexes. Sinkholes and other karst features are common within this LTA.

The study location is on a ridge and upper west facing slope of up to 10 percent. Soils on the ridge tops are Captina series

<sup>1</sup> Resource Scientist, Missouri Department of Conservation, Columbia, MO 65201; Former Silviculturist, Missouri Department of Conservation, Jefferson City, MO 65102; and Resource Science Assistant, Missouri Department of Conservation, Ellington, MO 63638, respectively.

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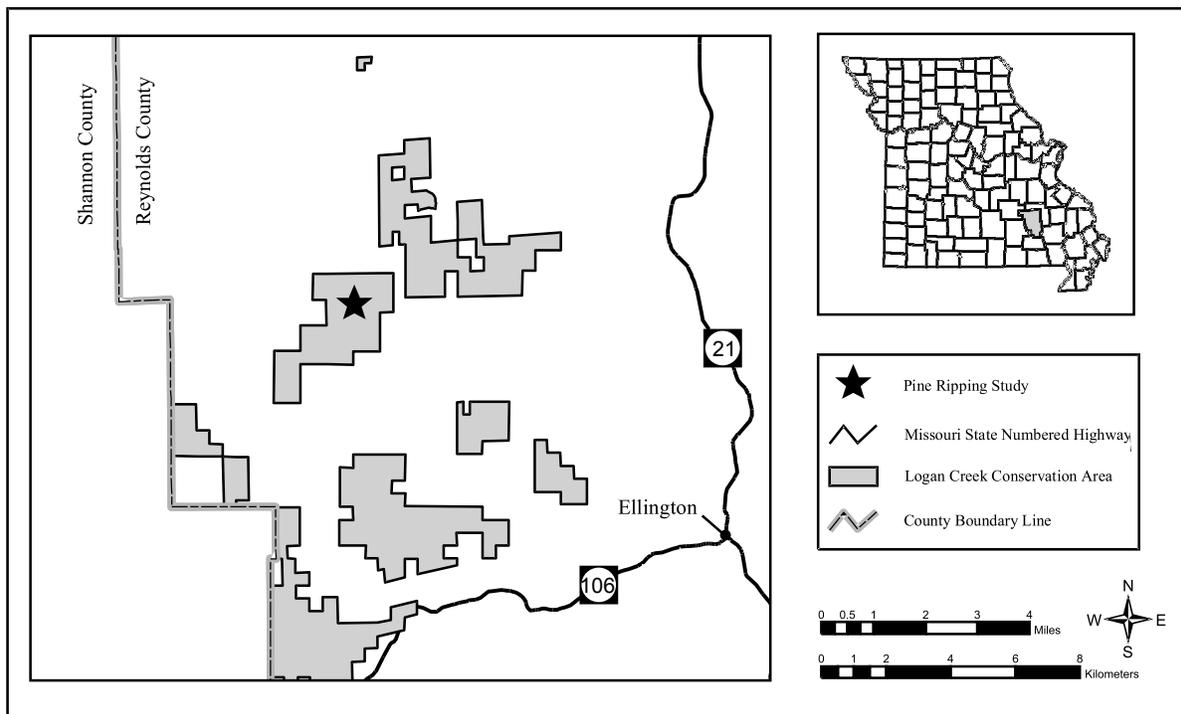


Figure 1—Location of ripping study.

which characteristically have a fragipan at a depth around 18 inches. Clarksville soils are generally found on the side slopes. The original stand, dominated by black oak (*Quercus velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), white oak (*Q. alba* L.), and shortleaf pine (*Pinus echinata*), was destroyed by a tornado in 1985. A salvage harvest was done prior to initiating this study.

### Site Preparation, Planting, and Assessment

The site was bulldozed, and remaining stems and debris were windrowed on the contour. Ripping was done with a bulldozer and two-toothed ripper during winter of 1987. Genetically improved 1-0 shortleaf pine seedlings were planted on a spacing of 7 x 7 feet in March 1988. Total height (HT), crown spread, basal diameter (BD) at 1 inch above ground, and survival were measured December 1988 and September 1989. All assessments were repeated in September 1990, except for basal diameter. Height and crown spread were measured with a meter stick, and basal diameter was measured with an electronic caliper. Vegetation was considered competing with shortleaf pine seedlings if a leaf or branch of competing vegetation was located within an imaginary inverted cone of 45° each side of vertical above the terminal bud or competing vegetation covered the pine's terminal leader. Otherwise, the shortleaf pine seedlings were judged as free-to-grow. The study was re-measured at age 16 in April 2004 for height using a clinometer and for diameter at breast height (d.b.h.), using a diameter tape. Volume at ages 1 and 2 were estimated using a volume index:  $HT \times BD^2$ . Volume at 16 years was estimated using volume of a cone:

$$\text{volume (dm}^3\text{)} = HT \cdot \text{dbh}^2 \cdot 0.02618 \quad (1)$$

### Study Design and Statistical Analysis

A randomized block design was used, with 2 treatments in a total of 10 blocks (fig. 2). The treatments were: (1) ripping to a depth of 46 to 61 cms (18 to 24 inches) on a 2.14 m (seven foot) spacing, and (2) control, with no ripping. Ripping was done to break up the fragipan and to remove competing vegetation. Each plot was 4 rows x 10 seedlings with a buffer of 2 rows on each side and 2 seedlings on each end. Because of varying space between windrows and the need to avoid residual stumps, not all plots resulted in 40 measured seedlings per plot. The actual number varied from 37 to 66 measured seedlings per plot, with only 2 plots with less than 40.

Plot means were used for all analyses. Analyses were carried out for survival, height, diameter, volume, crown spread, and free-to-grow status for each age separately. Using the PROC GLM procedure in SAS, analyses of variance (ANOVAs) were used to test for significant differences among blocks and

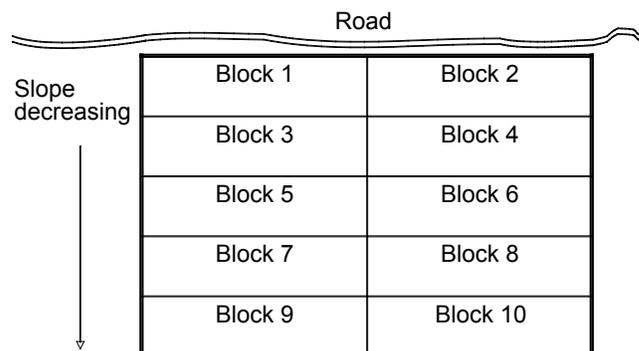


Figure 2—Schematic diagram of the field layout. The ripping and control treatments were randomly assigned to each block.

treatments for height, diameter, volume, and crown spread. The following linear model was used for the analysis:

$$Y_{ij} = \mu + B_i + T_j + e_{ij} \quad (2)$$

where

$Y_{ij}$  = the observation on the  $j^{\text{th}}$  treatment in the  $i^{\text{th}}$  block

$\mu$  = the population mean

$B_i$  = the random variable for block

$T_j$  = the fixed effect of treatment (ripping and control)

$e_{ij}$  = the error term. Survival and free-to-grow were analyzed using chi-squared test.

## RESULTS AND DISCUSSION

### Survival

Seedlings in the ripping treatment had significantly higher survival than those in the control treatment at all ages ( $P < 0.05$ ). Survival at ages 1 to 3 was above 90 percent for both treatments (fig. 3). At age 16, survival in the control treatment

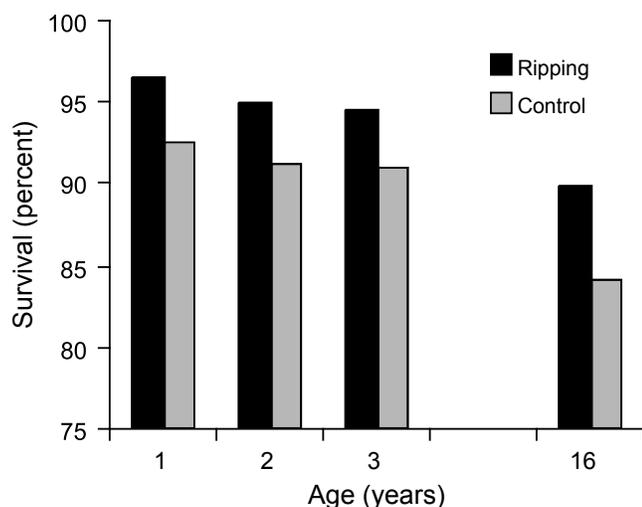


Figure 3—Mean survival of two treatments at four ages.

dropped to 84.2 percent while that in ripping treatments remained above 90 percent (survival = 90.2 percent). The differences between ripping and control treatments were probably not operationally meaningful as survival of 84.2 percent after 16 growing seasons is well within acceptable limits for the region. The high survival rates for both treatments were a surprise given that the region experienced a dry summer in 1988. Results from this study are consistent with other studies in the U.S.A. which showed that ripping improved survival of shortleaf pine (Berry 1979, McClure 1989).

### Growth at Ages 1 to 3

Seedlings in the ripping treatment had significantly greater height, diameter, volume, and crown spread than those in the control treatment for all ages, except height after the first growing season (table 1). Ripping increased crown spread, height, basal diameter, and volume by 13.6, 14.1, 14.0, and 41.2 percent, respectively, after 2 growing seasons (table 1). Although root systems were not assessed, a larger basal diameter should be correlated with larger root systems. After 3 growing seasons, height growth in the ripping treatment was 146.9 cm and that in the control treatment was 130.8 cm, an increase of 12.3 percent (table 1). The advantage of ripping appears to decline with age for crown spread, and the trend is less clear for height.

The increased growth in the ripping treatment may have been the result of improved soil physical properties and/or improved soil-water extraction. Ripping may have resulted in increased water infiltration from snowmelt, which may have increased soil moisture within the ripped treatment during planting in comparison to the control treatment.

There appeared to be a greater advantage of ripping near the ridge, and the advantage diminished down the slope (fig. 4). Ripping improved volume by 161.2 percent and 132.9 percent in the 2 blocks (1 and 2) located near the ridge, respectively. The response to ripping near the ridge might be expected, because the Captina soils are found on the ridges and Clarksville soils on the side slopes. The Captina soils are deep, moderately well-drained soils with a fragipan at 18 to 24 inches.

**Table 1—Treatment effects on height, diameter, volume and crown spread at 1 to 3 and 16 years for a shortleaf pine ripping study**

	Age	Ripping	Control	Increase <sup>a</sup>	P-value
	years			%	
Height (cm)	1	25.1	22.7	10.6	0.065
Height (cm)	2	73.5	64.4	14.1	0.020
Height (cm)	3	146.9	130.8	12.3	0.010
Height (m)	16	10.7	10.6	1.3	0.360
Basal diameter (mm)	1	4.8	4.4	9.1	0.010
Basal diameter (mm)	2	13.0	11.4	14.0	0.019
Diameter (cm)	16	14.9	15.8	-5.3	0.005
Volume (cm <sup>3</sup> )	1	6.8	5.0	36.0	0.021
Volume (cm <sup>3</sup> )	2	148.7	105.3	41.2	0.018
Volume (dm <sup>3</sup> )	16	66.7	74.3	-10.2	0.016
Crown spread (cm)	1	14.3	11.4	25.4	0.004
Crown spread (cm)	2	44.2	38.8	13.6	0.028
Crown spread (cm)	3	75.4	67.6	11.7	0.007

<sup>a</sup> Increase due to ripping

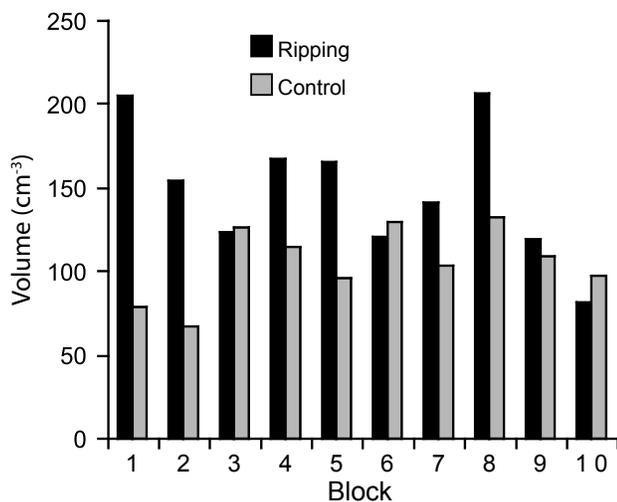


Figure 4—Volume growth for two treatments across the different blocks after the two growing seasons.

This study appears to indicate that ripping in the absence of a fragipan, such as in the mid-slopes, is of little benefit to growth.

Early results from this study are consistent with findings from other research on ripping effects on survival and growth of shortleaf pine in the U.S.A. In Missouri, a ripping study at Salem District of Mark Twain National Forest showed that shortleaf pine trees planted in a burned and ripped site were 53.8 percent taller than controls after 5 years (McClure 1989). Also, Berry (1979) reported that volume of shortleaf pine was improved 38 percent by ripping at 5 years of age in a Piedmont site in Georgia. In Oklahoma, ripping increased basal diameter of loblolly pine by 20 percent after 2 growing seasons (Wittwer and others 1986). In contrast, early results from studies at 5 years or younger in Australia revealed that ripping had no significant effect on growth of *Pinus elliotii* (Francis and others 1984) or of *Eucalyptus*, *Melaleuca*, and *Callitris* species (Knight and others 1998). These differences probably reflect different soil physical properties or different requirements for the species involved.

### Growth at Age 16

There was no significant difference between height of trees in the ripping and the control treatments at 16 years of age, but trees in the ripping treatment had significantly lower diameter and volume than those in the control treatment (table 1). While ripping increased volume by 41.2 percent after 2 growing seasons, the trees in the control treatment caught up; at 16 years the trees in the control treatment averaged 10.2 percent more volume and 5.3 percent greater diameter than trees in the ripping treatment. Trees in the ripping treatment had lower average volume than those in the control treatment in all blocks except block 1 (fig. 5). Thus, the advantage of ripping near the ridge was still maintained at age 16 years in block 1 but not in block 2.

Results at 16 years indicate that, while ripping at this site was beneficial at young ages, it was not at older ages. Therefore, early assessments may not be reliable for measuring the benefits of ripping at older ages. It is important to verify the effects of ripping over time, especially on studies where inferences

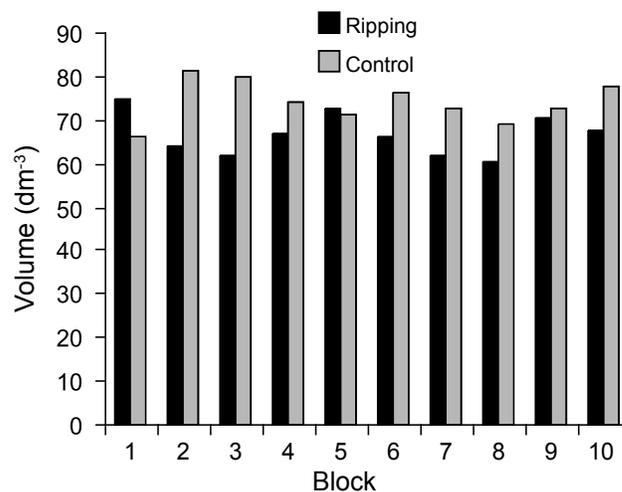


Figure 5—Volume growth for 2 treatments across the different blocks at age 16.

about benefits of ripping were based on early growth assessments. It may be that the fragipan re-forms, the ripping depth was not sufficient to break the fragipan, or that there are other limiting factors below the fragipan that restrict tree growth in the ripping treatment. It is difficult to relate the results to soil properties, because information on soil properties is absent. More research is required to understand the relationship between soil properties and effect of ripping. There is need for addition research on effect of ripping on different soils and the need to find the most appropriate ripping depth for each particular soil type.

The success of ripping as a site preparation method depends on the long-term benefits of ripping out-weighing the costs. The costs of ripping should be offset by the savings in planting time and improved survival and growth generated by ripping. The study showed that ripping benefited trees in the short-term. Trees in control treatments had a slower start, but they eventually out-performed the trees in the ripping treatment at 16 years at this site.

### Competition

There was no significant difference in free-to-grow status between trees in the ripping treatment and those in the control treatment after the first and third growing seasons; but free-to-grow seedlings were significantly higher in ripping treatment than in the control treatment after the second growing season (fig. 6,  $P = 0.024$ ).

The number of surviving seedlings in the free-to-grow status was > 93 percent in both treatments across all the 3 first growing seasons. The lack of competition was consistent with high survival during the first three growing seasons. Although seedlings in the ripping treatment have a statistically significant better competitive advantage in the second growing season, the competitive advantage is too small to be of practical significance (< 4 percent).

In Missouri, herbicide release was normally applied during the 1980s at 3 to 5 years to maintain a minimum of 400 shortleaf pine seedlings per acre in a free-to-grow condition. According to McClure (1984), the biggest advantage of ripping is that

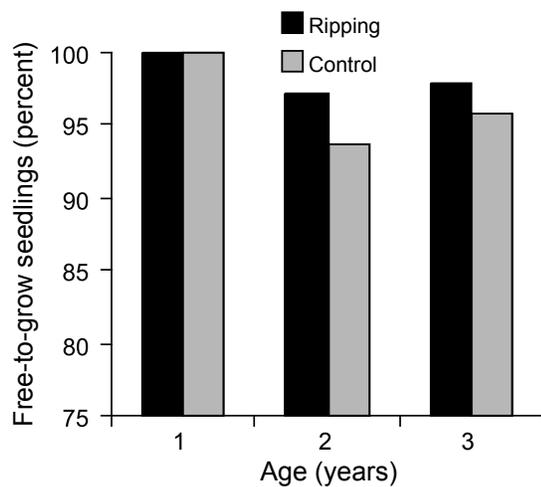


Figure 6—Free-to-grow seedlings for two treatments at three ages.

release herbicide will not be needed. This study does not support this assertion. Prior burning or bulldozing is a prerequisite for controlling slash and vegetation before ripping. Fire or bulldozing would remove slash that would otherwise collect under the draw bar, forcing it out of the ground. In the absence of slash, the operator can avoid stumps and large rocks. Herbicides are restricted on federal lands. Thus, fire or bulldozing used alone or in combination with ripping are the only site preparation methods likely to negate the use of herbicide. Our study shows that herbicide release is not required after 3 years on both the ripped and control treatments. The study indicates that there were 871 and 851 seedlings per acre in free-to grow status after 3 growing seasons in rip and control treatments, respectively. Thus release herbicide will not be needed on the control treatments (bull dozed and not ripped). Because the number of seedlings in free-to-grow status is high in both treatments, fewer seedlings need to be planted to achieve 400 free-to-grow seedlings. Given the number of free-to-grow seedlings after 3 growing seasons, only 409 and 418 seedlings need to be planted in ripped and non-ripped sites, respectively, to achieve the 400 free-to-grow seedlings at this site. Such low planting densities could be recommended when artificially regenerating shortleaf pine to achieve a pine-oak mix in which pine would still be dominant.

## CONCLUSION

Restoration of shortleaf pine depends on an effective low-cost site preparation method. The results presented here provide baseline data for future studies that will investigate effects of different site preparation methods on survival and growth of shortleaf pine in Missouri. This study has shown that conclusions regarding advantages of ripping based on evaluation at a young age do not reflect results at more mature ages. This study showed that while ripping was beneficial at ages 3 and younger, it was not at age 16.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Berry, C.R. 1979. Subsoiling improves growth of pine on a Georgia Piedmont site. Res. Note SE-284. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 3 p.
- Francis, P.J.; Bacon, G.J.; Gordon, P. 1984. Effects of ripping and nitrogen fertilizer on the growth and windfirmness of slash pine on a shallow soil on the Queensland coastal lowlands. *Australian Forestry*. 47 (2): 90-94.
- Guild, D.W. 1971. Windrowing and ripping, a comparative study with other site preparation techniques. *New Zealand Journal of Forestry*. 16: 88-97.
- Knight, A.J.P.; Beale, P.E.; Dalton, G.S. 1998. Direct seeding of native trees and shrubs in low rainfall areas and on non-wetting sands in South Australia. *Agroforestry Systems*. 39: 225-239.
- Lacey, S.T.; Brennan, P.D.; Parekh, J. 2001. Deep may not be meaningful: Cost and effectiveness of various ripping tine configurations in a plantation cultivation trial in eastern Australia. *New Forests*. 21(3): 231-248.
- McClure, L. 1984. Mechanical site preparation. In: *Artificial reforestation of shortleaf pine: a Missouri seminar*. Salem, MO: U.S. Department of Agriculture, Forest Service, Mark Twain National Forest: 50-60.
- McClure, L. 1989. Alternatives for stand in management area 4.1: analysis and choice in forest project level planning. Salem, MO: U.S. Department of Agriculture, Forest Service, Mark Twain National Forest. 52 p.
- Nigh, T.A.; Schroeder, W.A. 2002. *Atlas of Missouri ecoregions*. Jefferson City, MO: Missouri Department of Conservation. 212 p.
- Wittwer, R.F.; Dougherty, P.M.; Cosby, D. 1986. Effects of ripping and herbicide site preparation treatments on loblolly pine seedling growth and survival. *Southern Journal of Applied Forestry*. 10: 253-257.

# FIRST-YEAR SURVIVAL AND GROWTH OF THREE SPECIES ASSEMBLAGES PLANTED ON RECLAIMED MINE LAND AS AFFECTED BY THREE LEVELS OF SILVICULTURAL INTENSITY

Chad N. Casselman, Thomas R. Fox, and James A. Burger<sup>1</sup>

**Abstract**—Surface mined land in the Appalachian coal-producing region have been found to exhibit growing conditions that are unfavorable for the establishment of productive forests including dense ground covers, compacted soil materials, and unfavorable soil chemical properties. To address these concerns, a 3 x 3 x 3 factor random complete block experiment was used to investigate the survival and height growth differences associated with three species assemblages across three levels of silvicultural intensity at three separate study sites. Hardwood survival was superior to both of the other species groups (69 percent versus 42 and 50 percent for white pine and hybrid poplar, respectively). Hybrid poplar grew far more in height (126.6 cm) over 1 year than either of the other species. Additionally, sites with sandstone-derived soils were found to have superior survival and growth compared to soils derived from shale or siltstone overburden. Hybrid poplar appears to have the greatest potential to revert reclaimed mine land to forest after it has already been reclaimed to grass cover.

## INTRODUCTION

The Appalachian coal-producing region of the Eastern United States is predominantly forested prior to mining. The process of surface mining removes these forests and the native soils that support them. Current reclamation practices create adverse conditions for reclamation with trees, and consequently reforestation of surface mined lands has decreased since the passage of Surface Mining Control and Reclamation Act (SMCRA) of 1977 (Ashby 1991). These adverse conditions include: (1) excessive competing vegetation, (2) soil compaction, and (3) unfavorable soil chemical properties.

Competing vegetation is a direct result of ground covers sown to prevent soil erosion on newly reclaimed surfaces. Several studies have shown that these dense ground covers are detrimental to good survival and growth of tree species. For example, on a surface mine in Indiana, Andersen and others (1989) found that black walnut (*Juglans nigra* L.) and northern red oak (*Quercus rubra* L.) survival after 7 growing seasons increased from 4 and 1 percent, respectively, when planted into an existing dense ground cover to 66 and 48 percent, respectively, when planted after ground cover was controlled. Ashby (1997) found that the height of 16 different tree species combined were significantly taller with chemical weed control after 5 years.

Soil compaction on post-SMCRA reclaimed mined lands is also widespread. Compaction in mine soils is usually caused by the passage of large equipment over the soil in an effort to stabilize the soil when returning it to its approximate original contour as required by SMCRA. Tillage treatments have been shown to ameliorate the detrimental effects of compaction. Ashby (1997) found that the mean height of 16 different tree species was significantly greater 5 years after ripping the mine soil to a depth of 1.2 m. Black walnut seedlings growing on a surface mine in southern Illinois were found to have tap-root lengths which were 92 and 75 percent greater in their first and second years of growth, respectively, in ripped versus unripped plots (Philo and others 1982). This same study

found overall rooting depth to be 81 and 58 percent greater in their first and second years in the ripped versus the unripped plots. Radial root growth was found to be 89 percent greater in the ripped plots in the second year.

Chemical properties of mine soils are related to the overburden rock type from which these soils were created. In a study of the effect of overburden rock type on survival and growth of pitch x loblolly pine hybrids (*Pinus rigitaeda*), an inverse relationship between soil pH and the amount of oxidized sandstone in the growth medium was found (Torbert and others 1990). The rock types evaluated in this study consisted of pure sandstone, pure siltstone, and mixtures containing various proportions of each type. It is noteworthy that as pH decreased, stem volume increased to the extent that the pure sandstone plots (lowest pH) had five times more stem volume than in the pure siltstone plots (highest pH). Mine soils commonly have insufficient levels of N and P. Two separate studies of southwest Virginia mine soils have shown such deficiencies. In one, mine soils were found to have less total N than native soils and, of the total N, most was unavailable to plants (Li and Daniels 1994). In the other, spoils were found to have P-fixing capacities to the extent that P supply would still limit plant growth even after fertilization (Howard and others 1988).

Good survival and growth of trees is largely dependent on selecting the appropriate trees for a specific site based on site conditions and silvical characteristics. For this reason, survival and growth have been found to be extremely variable both between species and within the same species across different sites. For example, a study in southwest Virginia found white pine (*Pinus strobus* L.) survival after 11 years of growth to be 58 percent (Torbert and others 2000), whereas in a study in southeastern Ohio, no white pine survived after 3 years (Larson and others 1995). Several commercial hardwood species were found to have excellent survival after 2 years on a mountain-top-removal mine in West Virginia treated with weed control and tillage (Gorman and Skousen 2003). Conversely, Torbert and Burger (1996) found only 3 percent

<sup>1</sup> Graduate Research Assistant, Associate Professor, and Professor, respectively, Virginia Polytechnic Institute and State University, Department of Forestry, Blacksburg, VA 24061.

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survival for yellow poplar (*Liriodendron tulipifera* L.) in areas where no ripping or weed control had been employed.

The objective of this investigation was to evaluate the first-year survival and growth of three species assemblages under three levels of silvicultural intensity intended to alleviate the three common limiting conditions for tree establishment and growth on reclaimed mine land. Assemblages were installed at three sites, each with different site characteristics.

## METHODS

The study used a 3 x 3 x 3 random complete block design to evaluate: (1) the effects of site conditions at each of three sites, (2) the three levels of silvicultural intensity, and (3) the effects of the three species assemblages on first-year survival and height growth. Study sites were located in Lawrence County, OH, Nicholas County, WV, and Wise County, VA. Species assemblages included: (1) hybrid poplar [*Populus trichocarpa* L. (Torr. and Gray ex. Hook) x *Populus deltoids* (Bartr. ex Marsh.) hybrid 52-225]; (2) white pine; and (3) native hardwood mix intended to mimic the premining forest composition at each site based on species composition of adjacent unmined forests. The treatments included: (1) weed control only (WC); (2) weed control plus tillage (WC+T); and (3) weed control plus tillage plus fertilization (WC+T+F). All trees were planted at 2.4 m x 3.0 m spacing for a final planting density of 1,345 trees ha<sup>-1</sup>. Plots were blocked within each site based on soil properties. Nine 0.25-ha plots were established in each of the three blocks at each site. Plots were laid out to be as contiguous as possible within each block, while still maintaining uniform soil properties. Slopes in all plots were < 15 percent.

The weed control treatment consisted of 9.351 ha<sup>-1</sup> of glyphosate broadcast over each site in August, 2003. After planting in April, 2004, pendimethalin was broadcast at a rate of 4.921 ha<sup>-1</sup> for pre-emergence control of weeds. Spot applications of glyphosate were made to each tree in June, 2004, to provide additional competition control. Seedlings were shielded from drift during this application.

The tillage treatment employed was ripping. Depth of ripping was set between 61 and 91 cm. The equipment used to install the tillage treatment varied based on local equipment variability but was consistent within blocks and included: single shank only, single shank with coulters creating beds, and multiple shanks resulting in tillage of the entire site. Tillage was carried out prior to planting in April, 2004.

Fertilizer was applied to the designated plots in late May, 2004. A banded application of 272 kg ha<sup>-1</sup> of diammonium phosphate added 49.0 kg ha<sup>-1</sup> N and 55.1 kg ha<sup>-1</sup> P. Muriate of potash and a micronutrient mix were applied around the base of each seedling at the following rates: 91 kg ha<sup>-1</sup> of muriate of potash that added 46.8 kg ha<sup>-1</sup> K and 20 kg ha<sup>-1</sup> of a micronutrient mix that added 1.8 kg ha<sup>-1</sup> S, 0.2 kg ha<sup>-1</sup> B, 0.2 kg ha<sup>-1</sup> Cu, 0.8 kg ha<sup>-1</sup> Mn, and 4.0 kg ha<sup>-1</sup> Zn.

The site in Lawrence County, OH was characterized by fine-textured spoils derived primarily from siltstone. This site had an oxidized topsoil replaced across the site that ranged from 5 to 51 cm deep. The spoil material under the topsoil was near alkaline (pH=6.64 versus 5.38 in the topsoil) and had much higher electrical conductivity than the topsoil (0.47 dS m<sup>-1</sup> versus 0.10 dS m<sup>-1</sup>). This site had been supporting a dense grass cover for at least 10 years. The Nicholas County, WV

site was characterized by a coarse-textured soil with a high coarse fragment percentage (50 to 60 percent). These soils were derived from shale overburden. The site had been used for grazing prior to study establishment and had been supporting grass cover for at least 10 years. The Wise County, VA site also had coarse-textured spoils and high coarse fragment content; however, this site had oxidized sandstone topsoil replaced to depths ranging from 0 to 47 cm across the site. This site had been supporting grasses for < 10 years.

A 20 m x 20 m measurement plot was established in the center of each 0.25-ha treatment plot within which all trees were assessed for survival and height growth. Initial height (to the estimated base of the terminal bud) was assessed in May, 2004, shortly after bud break. First-year survival and growth were determined following measurement in late August, 2004.

Analysis of covariance was used to analyze white pine and hardwood data using initial height as a covariate. Hybrid poplar were planted from woody cuttings and had no initial height; consequently analysis of variance was used to analyze data for this species. Hardwood species used in the analysis included red oak, sugar maple (*Acer saccharum* L.), and yellow poplar, as these species were common to all three sites. Survival data was transformed using the arcsine transformation and height growth data using the natural log transformation prior to analysis of variance/covariance to satisfy the assumptions associated with those procedures (Gomez and Gomez 1984). Analysis was done by species due to the different analysis procedures used. Additionally, analysis was done by site and by treatment if the site x treatment interaction was significant after analysis by species. Mean separation was conducted using Tukey's HSD with significance set at P<0.05 for all comparisons. If interaction terms were not significant, only main effect means were compared. SAS version 8.2 (SAS Institute 2001) was used for all statistical analyses.

## RESULTS

### Survival

In general, hardwoods had the best survival across sites and treatments (69 percent) followed by hybrid poplar at 50 percent with white pine having only 42 percent survival across sites and treatments. Site effects on survival showed that the site in Virginia (VA) had the highest mean survival for all species and that the Ohio site (OH) had the lowest (fig.1). For hybrid poplar, survival at the VA site (72 percent) was significantly higher than that at either of the other sites (37 and 41 percent for OH and WV, respectively). For hardwood, survival in VA was significantly higher than that in OH (82 versus 48 percent respectively). The site x treatment interaction was significant for white pine (P=0.0428).

Treatment effects on survival revealed that WC+T gave the highest mean survival across sites for each species while WC+T+F resulted in the lowest mean survival. This difference was significant for both hardwood and hybrid poplar (81 and 59 percent for hardwood versus 54 and 37 percent for hybrid poplar for these treatments, respectively; fig. 2). Examination of the site x treatment interaction for white pine revealed that in OH, survival decreased as the level of silvicultural intensity increased, whereas in VA and WV survival was increased as a result of WC+T (fig.3).

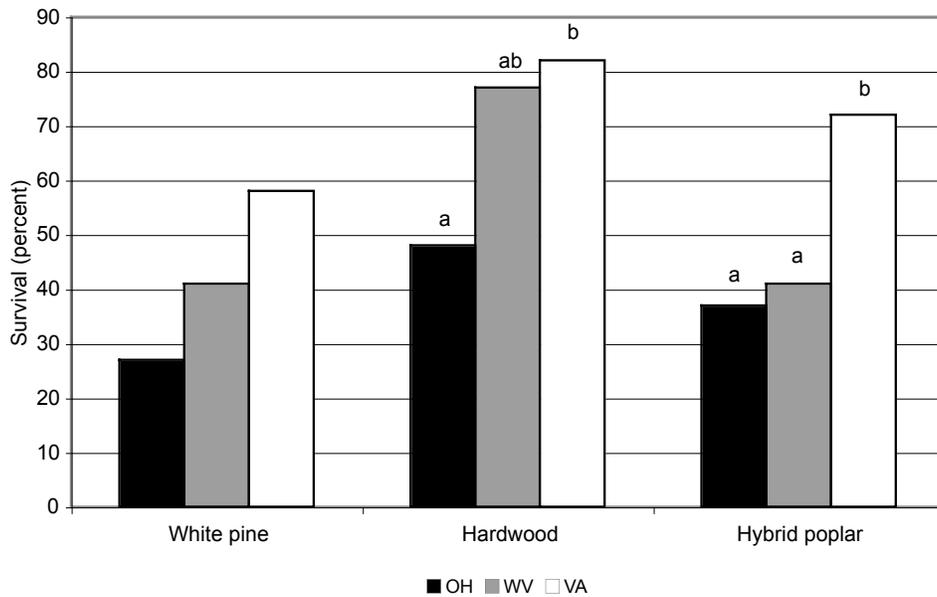


Figure 1—Site effects by species on survival of three species assemblages planted on reclaimed surface mines in Lawrence County, OH, Nicholas County, WV, and Wise County, VA under three levels of silvicultural intensity. For each species, bars with the same letter are no different at  $P < 0.05$ .

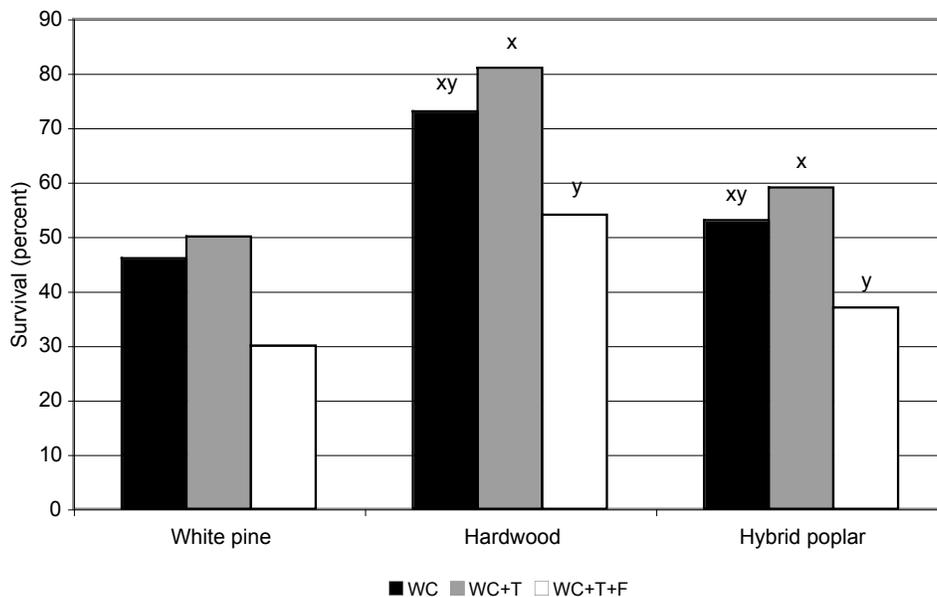


Figure 2—Treatment effects by species on survival of three species assemblages planted on reclaimed surface mines in Lawrence County, OH, Nicholas County, WV, and Wise County, VA under three levels of silvicultural intensity. For each species, bars with the same letter are no different at  $P < 0.05$ .

### Height Growth

Hybrid poplar grew far more in height than hardwoods or white pine. Average height growth for hybrid poplar across sites and treatments was 56.7 cm compared to 6.2 cm for white pine and -2.0 cm for hardwood. Hardwood species often died back to heights shorter than their initial height after planting, resulting in negative height growth. Height growth of white pine was no different between sites and ranged from 5.8 to 6.7 cm (fig.4). For hardwood, height growth ranged from -6.3 cm in OH to 1.3 cm in VA; the difference between these two sites was significant. There was significant site x treatment interaction for hybrid poplar ( $P=0.0308$ ).

There were no treatment effects for hardwood or white pine with height growth of white pine ranging from 5.6 cm in WC to 6.7 cm in WC+T to 6.2 cm in WC+T+F (fig.5). Hardwood height growth ranged from -2.1 cm in WC to -4.4 cm in WC+T to 0.4 cm in WC+T+F. The site x treatment interaction for hybrid poplar revealed a synergistic effect of WC+T+F on height growth of this species in VA, where height growth averaged 126.6 cm (fig.6). This was nearly double the height growth of the second-highest response, which was also in VA for the WC+T treatment (65.4 cm). In WV, WC+T and WC+T+F both resulted in significantly more height growth than WC (60.2 cm

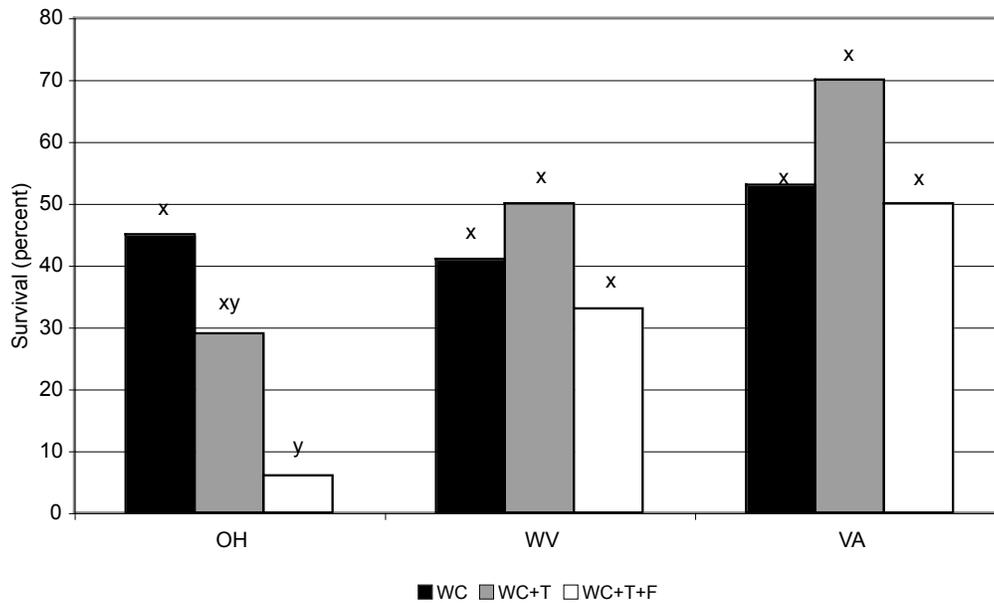


Figure 3—White pine survival percentage site by treatment interaction for trees planted on reclaimed surface mines in Lawrence County, OH, Nicholas County, WV, and Wise County, VA under three levels of silvicultural intensity. For each site, bars with the same letter are no different with respect to treatment at  $P < 0.05$ .

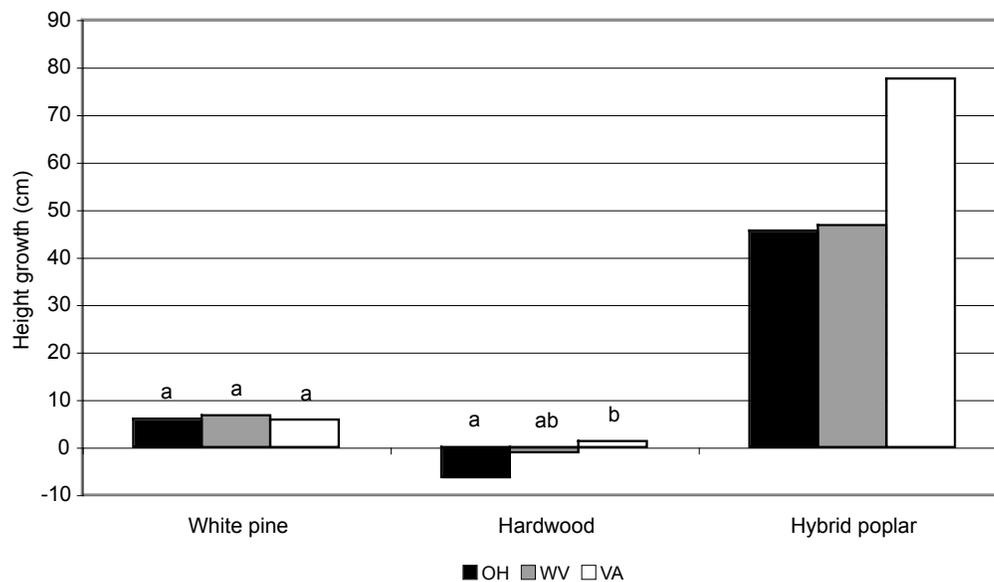


Figure 4—Site effects by species for height growth of three species assemblages planted on reclaimed surface mines in Lawrence County, OH, Nicholas County, WV, and Wise County, VA under three levels of silvicultural intensity. For each species, bars with the same letter are no different at  $P < 0.05$ .

and 57.6 cm versus 22.4 cm respectively). There was no treatment response for hybrid poplar in OH where heights ranged from 35.8 cm in WC to 50.8 cm in WC+T+F.

## DISCUSSION

The results of this study indicate that there is likely no universal prescription for good establishment and first year growth of the species used in this study, since numerous interactions existed between the sites, treatments, and species assemblages. The results of this study fit well with other studies using similar species and treatments on post-SMCRA reclaimed

mined lands. For example, a study was conducted on three surface mines in West Virginia using species similar to those in this study. McGill and others (2004) found that in plots receiving similar treatments to the WC+T+F treatment, the same hybrid poplar clone averaged 1.0 m in total height after 1 year, and average first-year survival for the hybrid was 79 percent across all 3 sites. In this study, we found overall survival was lowest in OH; white pine had the lowest survival of the three species assemblages at this site. Larson and others (1995) found that white pine survived and grew poorly on sites in this geographic area with the near alkaline and fine-texture

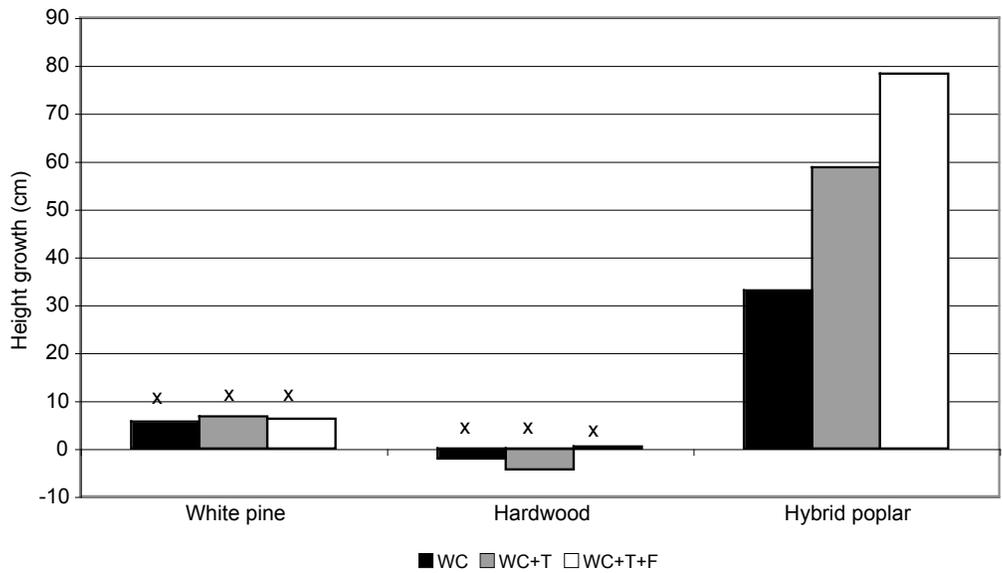


Figure 5—Treatment effects by species for height growth of three species assemblages planted on reclaimed surface mines in Lawrence County, OH, Nicholas County, WV, and Wise County, VA under three levels of silvicultural intensity. For each species, bars with the same letter are no different at  $P < 0.05$ .

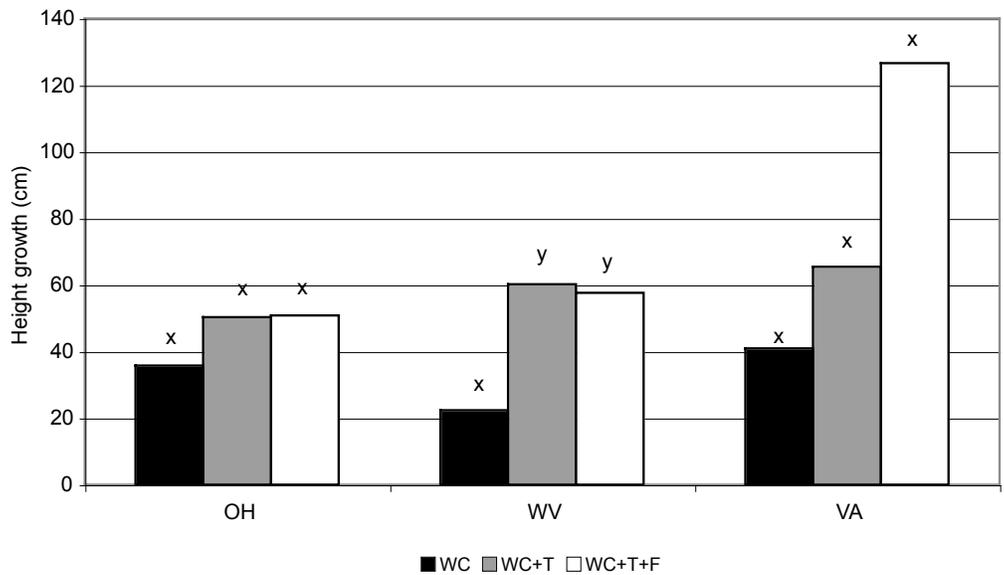


Figure 6—Hybrid poplar height growth site by treatment interaction for trees planted on reclaimed surface mines in Lawrence County, OH, Nicholas County, WV, and Wise County, VA under three levels of silvicultural intensity. For each site, bars with the same letter are no different with respect to treatment at  $P < 0.05$ .

spoil materials common to the area. One explanation for poor survival and growth of white pine in OH would be that white pine performs best on well-drained soils within its native range (Wendel and Smith 1990), and the soils in OH had fine textures, no soil structure, and many areas with hydrophytic vegetation, indicating anaerobic conditions and poor drainage.

For all species, WC+T+F decreased survival below that of the WC treatment and significantly below that in WC+T. Two hypotheses exist for decreased survival in the WC+T+F treatment: (1) Fertilization stimulated the competing vegetation (Ramsey and others 2001). Despite uniform herbicide applications to all sites, competing vegetation was greater in OH

than at the other sites and notably greater in the tree rows where fertilizer was banded. (2) A salt effect was created by the fertilizer, leading to moisture stress in the trees. Diammonium phosphate and muriate of potash fertilizers are considered to pose moderate and high salt hazards, respectively (Brady and Weil 2002). In OH, a combination of these two factors would be likely; tillage at this site would have brought the siltstone spoil, which has been shown to negatively affect pine growth (Torbert and others 1990), close to the surface. The salt levels of this spoil ( $0.47 \text{ dS m}^{-1}$ ) are close to levels suggested by Torbert and others (1994) ( $0.05 \text{ dS m}^{-1}$ ) as negatively affecting tree growth. This salt effect would be compounded by adding fertilizer to the spoil; the soil has

poor drainage, and therefore excess salts could not be readily leached out of the rooting zone.

Tillage has been shown to improve tree survival and growth through reduction of bulk density on surface mines (Ashby 1996, Torbert and Burger 1996). Tillage produced mixed results in terms of survival and growth response in this study. There was no response to tillage in OH for any species in terms of height growth nor was there a survival difference associated WC+T when compared to WC. This could be due to an ineffective tillage treatment resulting from tilling these fine-textured soils when they were saturated. Shukla and others (2004) found that on mine soils in southeastern OH similar to the ones in our study, bulk density was an important variable in determining site quality and failure to improve bulk density would logically be associated with failure to improve survival or height growth. In WV, WC+T failed to significantly improve survival, though mean survival was higher in WC+T than in WC for all species. Alternatively, height growth of hybrid poplar at this site nearly tripled compared to the WC treatment, indicating that soil compaction was a major limitation for good growth at this site. An inverse relationship between soil density and several plant growth measures has been found by researchers. For example, Foil and Ralston (1967) found such a relationship between bulk density and root length and weight for loblolly pine (*Pinus taeda* L.), and Hatchell (1970) found a similar relationship between bulk density with shoot and root weights for loblolly pine. Zisa and others (1980) found an inverse relationship between bulk density and depth of root penetration for three conifer species. Although soil physical properties in VA were similar to those in WV, there was no significant response to WC+T at this site compared to the WC treatment. This could be due to the increased water-holding capacity of the loam-textured soil and the lower coarse fragment percentage of the sandstone spoil at the VA site compared to the sandy loam texture and higher coarse fragment content at the WV site. Torbert and others (1990) found that whole soil water-holding capacity was greater in pure sandstone spoil with lower coarse fragment contents than in finer-textured siltstone spoils.

Comparing the effects of WC+T+F between WV and VA, it is important to consider that the site in WV was likely fertilized to maintain the lush grass cover for grazing cattle, as indicated by much higher N and P levels in the soils from this site. For this reason, trees at this site likely had all the nutrients they needed prior to the fertilization treatment. The synergistic response to WC+T+F for hybrid poplar on the sandstone spoils in VA is logical given that these soils are inherently low in N and P (Howard and others 1988, Li and Daniels 1994) and that hybrid poplar have been shown to respond favorably to fertilization (van den Driessche 1999).

## CONCLUSIONS

Hardwood species had the highest survival across sites and treatments, with white pine having the lowest survival. Both of these species were unresponsive to treatment in terms of first-year height growth. This lack of height growth could translate into continued weed control to ensure these species aren't out-competed by the weeds at these sites.

For hardwood and white pine, WC+T would likely be the optimum treatment. This treatment gave the highest mean survival for all species, and any increased height growth as a

result of WC+T+F may not offset the decreased survival that resulted from this treatment.

Sites with oxidized sandstone soil materials appear to be the most favorable for tree establishment and growth given the species and treatments used in this study. Shale-derived soils appear to be less suitable and, on fine-textured siltstone-derived spoils, other species and/or treatments may be needed to ensure an adequately stocked productive stand develops.

Hybrid poplar is likely the best alternative of the tree species used. This species attained heights in excess of 50 cm at all sites within 1 year and as such decreased the chances of these trees succumbing to the competing vegetation. The best combination of species, treatments, and site characteristics occurred in VA where hybrid poplar, in combination with the WC+T+F treatment and oxidized sandstone spoils, attained an average height of 126.6 cm in 1 year.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Andersen, C.P.; Bussler, B.H.; Chaney, W.R. [and others]. 1989. Concurrent establishment of ground cover and hardwood trees on reclaimed mined land and unmined reference sites. *Forest Ecology and Management*. 28: 81-99.
- Ashby, W.C. 1991. Surface mine tree planting in the Midwest pre- and post-Public Law 95-87. In: Oaks, W.; Bowden, J., eds. *Technologies for success. Proceedings of the annual meeting of the American society for surface mining and reclamation*. Vol. 2. Lexington, KY: American Society for Surface Mining and Reclamation: 617-623.
- Ashby, W.C. 1996. Red oak and black walnut growth increased with mine soil ripping. *International Journal of Surface Mining and Reclamation*. 10(3): 113-116.
- Ashby, W.C. 1997. Soil ripping and herbicides enhance tree and shrub restoration on stripmines. *Restoration Ecology*. 5(2): 169-177.
- Brady, N.C.; Weil, R.R. 2002. *The nature and properties of soils*. 13<sup>th</sup> ed. Upper Saddle River, NJ: Prentice Hall. 960 p.
- Foil, R.R.; Ralston, C.W. 1967. The establishment and growth of loblolly pine seedlings on compacted soils. *Soil Science Society of America Proceedings*. 31: 565-568.
- Gomez, K.A.; Gomez, A.A. 1984. *Statistical procedures for agricultural research*. New York, NY: John Wiley & Sons. 680 p.
- Gorman, J.; Skousen, J. 2003. Second year survival of commercial hardwoods on reclaimed minesoils in West Virginia. In: *Proceedings of the American society for surface mining and reclamation*. Lexington, KY: American Society for Surface Mining and Reclamation: 279-291.
- Hatchell, G.E. 1970. Soil compaction and loosening treatments affect loblolly pine growth in pots. Res. Pap. SE-72. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 9 p.
- Howard, J.L.; Amos, D.F.; Daniels, W.L. 1988. Phosphorus and potassium relationships in southwestern Virginia coal-mine spoils. *Journal of Environmental Quality*. 17: 695-700.
- Larson, M.M.; Kost, D.A.; Vimmerstedt, J.P. 1995. Establishment of trees on minesoils during drought and wet years. *International Journal of Surface Mining and Reclamation*. 9(3): 99-103.

- Li, R.S.; Daniels, W.L. 1994. Nitrogen accumulation and form over time in young mine soils. *Journal of Environmental Quality*. 23: 166-172.
- McGill, D.W.; Ford, V.L.; McNeel, J.F. 2004. Early development of a species test established on surface mines thirty years post-reclamation. In: Proceedings of the national meeting of the American society for surface mining and reclamation. Lexington, KY: American Society for Surface Mining and Reclamation: 1227-1238.
- Philo, G.R.; Kolar, C.A.; Ashby, W.C. 1982. Effects of ripping on mine soil compaction and black walnut establishment. Symposium on surface mining hydrology, sedimentation and reclamation. Lexington, KY: University of Kentucky: 511-557.
- Ramsey, C.L.; Jose, S.; Brecke, B.J.; Merritt, S. 2001. Growth response of longleaf pine (*Pinus palustris* Mill.) seedlings to fertilization and herbaceous weed control in an old field in southern USA. *Forest Ecology and Management*. 172: 281-289.
- SAS Institute. 2001. SAS System for Windows. Version 8. Cary, NC: SAS Institute Inc.
- Shukla, M.K.; Lal, R.; Ebinger, M. 2004. Soil quality indicators for reclaimed minesoils in southeastern Ohio. *Soil Science*. 169: 133-142.
- Torbert, J.L.; Burger, J.A. 1996. Influence of grading intensity on herbaceous ground cover, erosion, and tree establishment in the southern Appalachians. In: Daniels, W.L.; Burger, J.A.; Zipper, C.E., eds. Proceedings of the 13<sup>th</sup> annual meeting of the American society for mining and reclamation. Success and failures: applying research results to insure reclamation successes. Lexington, KY: 637-646.
- Torbert, J.L.; Burger, J.A.; Daniels, W.L. 1990. Pine growth variation associated with overburden rock type on a reclaimed surface mine in Virginia. *Journal of Environmental Quality*. 19: 88-92.
- Torbert, J.L.; Burger, J.A.; Johnson, J.E.; Andrews, J.A. 1994. Final report: indices for indirect estimates of productivity of tree crops. OSM cooperative agreement GR996511. Blacksburg, VA: Virginia Polytechnic Institute and State University. 22 p.
- Torbert, J.L.; Burger, J.A.; Schoenholtz, S.H.; Kreh, R.E. 2000. Growth of three pine species after eleven years on reclaimed minesoils in Virginia. *Northern Journal of Applied Forestry*. 17(3): 95-99.
- van den Driessche, R. 1999. First-year growth response of four *Populus trichocarpa* x *Populus deltoides* clones to fertilizer placement and level. *Canadian Journal of Forest Research*. 29: 554-562.
- Wendel, G.W.; Smith, H.C. 1990. Eastern white pine. In: Burns, R.M.; Honkala, B.H., tech. coords. *Silvics of North America: 1. Conifers*. Vol. 2. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service. 877 p.
- Zisa, R.P.; Halverson, H.G.; Stout, B.B. 1980. Establishment and early growth of conifers on compact soils in urban areas. Res. Pap. NE-451. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

## **Hardwoods: Artificial Regeneration**

*Moderator:*

**ANDY EZELL**

Mississippi State University



# FIRST-YEAR SURVIVAL AND GROWTH OF BOTTOMLAND OAK SPECIES FOLLOWING INTENSIVE ESTABLISHMENT PROCEDURES

Andrew B. Self, Andrew W. Ezell, and Michael R. Guttery<sup>1</sup>

**Abstract**—Oak seedlings are annually planted on thousands of acres in the South. While the majority of these seedlings are planted for timber production, there is increasing interest in oak establishment for mast production. In this study, seedlings of nine oak species were grown under a protocol developed by Dr. Paul Kormanik designed to produce an “enhanced” seedling of larger above-ground parameters and well-developed roots. These seedlings were planted by non-forestry technicians at seven locations across Mississippi using a 20 feet by 20 feet spacing. Seedlings were planted in augered holes, and a slow-release fertilizer was added at planting. Pre-emergent competition control was applied by Mississippi State University personnel and post-emergent competition control was to be applied during the first growing season by tree planting personnel. Initial above-ground height and groundline diameter (GLD) were recorded prior to the onset of growth and again in November, 2004. Survival and first-year growth results for all species indicated that problems had been encountered during plantation establishment. Further research revealed that seedling handling and some post-emergent competition control had been of undesirable quality. Summary of observations indicate that even the highest-quality seedlings will perform poorly if not handled properly.

## INTRODUCTION

In the South, thousands of acres are artificially regenerated every year using oak (*Quercus* spp.) seedlings. Annual planting acreage is increasing, and the primary focus of these efforts is timber production. However, there has recently been increased interest in mast production for wildlife. The increased attention given to oaks for mast purposes has been noted in both private and public sectors. As a result, the Mississippi Department of Wildlife, Fisheries, and Parks (MDWFP) implemented a program in 2003 entitled, “Acorns for Wildlife”. This program provides private landowners with an opportunity to purchase “enhanced” oak seedlings capable of relatively quick mast production.

During the first growing season after planting, an oak seedling usually does not produce much above-ground growth; survival, not growth, is the primary concern. Several factors affect survival of hardwood plantings. Among these are seedling quality, planting quality, and vegetative competition. Seedling quality should not be a concern with seedlings grown under a protocol developed by Dr. Paul Kormanik (Kormanik and others 1994). Seedlings produced under this protocol are of larger above-ground parameters than normal nursery-grown seedlings and have well-developed root systems. However, planting quality and competing vegetation can still pose a survival threat. Proper planting is a process that includes handling during shipping, storage, and on-site, as well as the actual planting of seedlings. Seedlings should be kept cool and moist during shipping and storage. Once on-site, seedlings should be placed in a portable cooler or in a shaded area. Seedlings removed from shipping containers should be placed in planting bags immediately and handled singularly during planting. Seedling root systems should not be twisted, balled, or bent when placed in soil. Soil should be packed tightly around roots with root collars just below ground level (Allen and others 2001). These procedures have been tested and reported in many pine (*Pinus* spp.) regeneration publications. Corresponding hardwood work has not been published

in quantity, but planting procedures beneficial to pines are generally thought to be beneficial to hardwood species.

Cultural treatments, both mechanical and chemical, can prove effective in establishing oak plantings in areas of prior agricultural use and/or with established herbaceous vegetation. Soil treatments such as augering and subsoiling in compacted areas may increase seedling survival as well as root and subsequent stem growth. These increases result from better nutrient and water absorption (Rathfon and others 1995, Russell and others 1997). Survival can be positively influenced in the first year and afterwards through chemical herbaceous control in many situations (Ezell and Catchot 1997).

## OBJECTIVES

The objectives of the study were (1) to evaluate effects of fertilization, augering, pre-emergent, and post-emergent herbicide applications on first-year growth and survival of oak seedlings under Dr. Kormanik's intensive field management protocol; and (2) to evaluate the economic feasibility of fertilization, augering, initial herbicide application, and follow up herbicide treatments required using this protocol.

## MATERIALS AND METHODS

### Study Sites

Seven sites were selected across Mississippi for this study. Study sites were on State-owned wildlife management areas and ranged from the northeastern corner to the southwestern corner of the State. All sites were retired agricultural row-crop areas with the exception of one retired pasture. Soil series ranged from marginal upland hardwood soils to excellent bottomland hardwood soils. Most were sandy or clay loams, with some pure loam areas.

### Seedlings

All seedlings were grown at the Flint River Nursery in Georgia using acorns collected in Mississippi. These seedlings are

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<sup>1</sup> Graduate Student, Professor, and Graduate Student, respectively, Forest and Wildlife Research Center, Mississippi State University, Mississippi State, MS 39762.

grown under a protocol developed by Dr. Paul Kormanik designed to produce “enhanced” seedlings (Kormanik and others 1994). These seedlings are of large above-ground parameters and possess well-developed root systems with ample first-order lateral roots. This particular nursery was chosen due to prior experience with “enhanced” seedling production. The purpose of Dr. Kormanik’s protocol is to produce seedlings capable of acorn production within 6 to 7 years. Seedling species were selected to match planting sites and included water oak (*Quercus nigra* L.), Nuttall oak (*Q. nuttallii* Palmer), Shumard oak (*Q. shumardii* Buckl.), willow oak (*Q. phellos* L.), swamp chestnut oak (*Q. michauxii* Nutt.), post oak (*Q. stellata* Wangenh.), southern red oak (*Q. falcata* Michx.), cherrybark oak (*Q. pagoda* Raf.), and white oak (*Q. alba* L.).

### Planting

Seedlings were planted mid-March, 2004, at all sites. Seedling transport, handling, and planting were performed by MDWFP personnel at each wildlife management area (WMA). A wide spacing (20 feet by 20 feet) was utilized with each seedling being planted in an augered hole. These holes were approximately 6 inches in diameter and 2 to 3 inches deeper than seedling root systems. Thirty-gram slow-release fertilizer (22-10-7) packets were placed in the bottoms of all holes, which were then backfilled one third and tamped. Seedlings were then placed in the hole with root collars 1.5 to 2.0 inches beneath ground level, and another third of the hole was back-filled. This soil was in turn tamped and the remainder of the hole filled and tamped. All field planting procedures were completed in an attempt to satisfy requirements dictated by Dr. Kormanik’s protocol. Species planted varied by site according to soil/site quality.

### Treatments

Both pre-emergent and post-emergent herbicide applications were to be implemented per Dr. Kormanik’s instructions. A post-plant pre-emergent banded application of sulfometuron methyl [Oust XP® at 2 ounces per acre] was banded at all sites mid-March 2004 prior to seedling bud break. Post-emergent directed glyphosate applications were to be completed as needed, by WMA personnel when herbaceous vegetation emerged in the control bands.

### Study Design

Pin flags were placed beside each sample seedling for easy recognition in anticipation of fall measurements. Individual sites served as replicates, and 15 sample trees of each species deemed suitable for the site were planted at that location.

### Seedling Evaluation

Fifteen trees of each species at a given site were measured for initial GLD and height in mid-March, 2004. Height was recorded in tenths of feet, and GLD was measured to the nearest 0.001 inch. Final height and GLD measurements were taken in November, 2004. Survival of the sample trees was also recorded at that time.

## RESULTS AND DISCUSSION

### Survival

Initial examination of survival data indicated that further investigation would be required to explain response discrepancies. Several problems resulting from improper project establishment were discovered and objective two was aborted due to overall low or erratic survival rates. Survival for water and willow oak, expressed as a percentage, has some discrepancies between sites (table 1). This is apparent when looking at Sites 4 and 7. Both have survival, yet the remaining sites show no survival for these two species. When investigating this inconsistency, seedling handling was found to have differed. Site 4 was planted first and had 86.7 percent survival. Site 7 was planted next and had 26.7 percent survival. Water and willow oak seedlings for the remaining sites were transported separately and remained on a truck for approximately 1 month. Additionally, personnel at these sites reported that these seedlings were held on-site for approximately 3 weeks awaiting arrival of the other seedlings. Mortality of these two species is thought to be attributable to long-term storage without refrigeration and the effects of drying. Results from Site 4 indicate that poor seedling quality was not the deciding factor in water and willow oak mortality.

No sample seedlings survived at Site 5 (table 1). Seedlings were accidentally destroyed before final evaluations could be made in November. Shumard oak displayed the lowest overall survival (Sites 2 and 6). Swamp chestnut and Nuttall oak both displayed excellent survival. In most instances, survival was acceptable for hardwood regeneration. Site 2 had the lowest site index and still maintained acceptable survival levels, indicating that survival is possible when this protocol is followed properly.

**Table 1—Survival percentages of hardwood planting sites**

Site	WAO	WIO	NO	PO	SRO	SHO	SCO	CBO	WO
1	0.00 <sup>a</sup>	c	33.33	c	c	c	c	c	c
2	0.00 <sup>a</sup>	c	c	61.54	73.33	33.33	c	c	c
3	0.00 <sup>a</sup>	0.00 <sup>a</sup>	86.67	c	c	c	80.00	c	c
4	86.67 <sup>b</sup>	c	c	c	c	c	100.00	c	c
5	0.00 <sup>ad</sup>	cd	0.00 <sup>d</sup>	cd	cd	cd	0.00 <sup>d</sup>	0.00 <sup>d</sup>	0.00 <sup>d</sup>
6	0.00 <sup>a</sup>	0.00 <sup>a</sup>	100.00	c	c	40.00	86.68	c	c
7	26.67 <sup>b</sup>	c	93.33	c	c	c	c	c	c

<sup>a</sup> Shipped on separate truck and left on site for 3 weeks.

<sup>b</sup> Sites 4 and 7 shipped separate from other WAO and WIO seedlings.

<sup>c</sup> Species not planted at site.

<sup>d</sup> Site 5 seedlings were destroyed before evaluations could be made.

## Growth

Another problem encountered with establishment was improper soil tamping. In many instances, backfilled soil settled significantly, indicating insufficient tamping at planting. This resulted in GLD measurements of little or no use. Seedling height measurements were also possibly affected by this settling. Another problem with ground level measurements was that planting holes were not completely refilled. These holes exhibited siltation problems affecting height and GLD measurements as well as survival.

Negative or negligible height growth of some species and sites is thought to be attributable to siltation, dieback, and herbivory (table 2). The better sites are easily identified as Sites 3, 4, and 6. These were excellent bottomland hardwood sites, whereas Sites 1, 2, and 7 were lower-quality hardwood sites and had less growth. Since oaks generally do not grow much in the first growing season, these measurements are not outside ordinary expectations for sites of this quality.

## Protocol Problems

While post-plant, pre-bud break Oust® applications were performed properly, the post-emergent directed glyphosate applications were not. The timing of these applications was left to the discretion of WMA personnel who may not have had sufficient training or instructions to properly implement such applications. Application timings should probably have been at 2- to 3-week intervals. However, sites received between zero and three sprayings for the entire growing season. Another deviation from recommended protocol was the mowing, which was completed only at some locations. These problems, while foreseeable to foresters, may not have been anticipated by WMA personnel who were not acquainted with this type of work.

## CONCLUSIONS

Dr. Kormanik has proven “enhanced” oak seedlings are capable of acorn production in periods of time much shorter than that expected when oak seedlings are normally planted.

However, his protocol is a two-part process. The first part is production of “enhanced” seedlings capable of capitalizing on the second portion of the protocol. The second portion is a series of steps that include proper planting, fertilization, and complete weed control. If implemented properly, the second half of the protocol is effective in its design. Problems arise when protocol breaches are encountered. When utilizing Dr. Kormanik’s protocol, all steps must be properly performed. Even the healthiest, most vigorous seedlings will die if improperly handled or if proper planting technique is overlooked. Proper handling and planting technique is critical to growth and survival of hardwood regeneration.

## LITERATURE CITED

- Allen, J.A.; Keeland, B.D.; Stanturf, J.A. [and others]. 2001. A guide to bottomland hardwood restoration. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD/ITR-2000-0011. Gen. Tech. Rep. SRS-40. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 132 p.
- Ezell, A.W.; Catchot, A.L., Jr. 1997. Competition control for hardwood plantation establishment. In: Waldrop, T.A., ed. Proceedings of the ninth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 42-43.
- Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. 1994. Toward a single nursery protocol for oak seedlings. In: Proceedings of the 22nd southern forest tree improvement conference. Atlanta, Georgia. Southern Forest Tree Improvement Centre Publication No. 44: 114-123.
- Rathfon, R.A.; Kaczmarek, D.J.; Pope, P.E. 1995. Site preparation for red oak plantation establishment on old field sites in southern Indiana. In: Proceedings of the 10th central hardwood forest conference. Gen. Tech. Rep. NE-197. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 349-362.
- Russell, D.R., Jr.; Hodges, J.D.; Ezell, A.W. 1997. An evaluation of hardwood reforestation methods on previously farmed lands in central Alabama. In: Waldrop, T.A., ed. Proceedings of the ninth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 272-276.

**Table 2—Average height growth in feet for hardwood planting sites**

Site	WAO	WIO	NO	PO	SRO	SHO	SCO	CBO	WO
1	a	c	-0.200	c	c	c	c	c	c
2	a	c	c	0.013	0.027	-0.140	c	c	c
3	a	a	0.192	c	c	c	0.592	c	c
4	0.217	c	c	c	c	c	0.634	c	c
5	ad	cd	d	cd	cd	cd	d	d	d
6	a	a	0.100	c	c	0.114	0.406	c	c
7	-0.020	c	-0.061	c	c	c	c	c	c

<sup>a</sup> Shipped on separate truck and left on site for 3 weeks, all died.

<sup>b</sup> Sites 4 and 7 shipped separate from other WAO and WIO seedlings.

<sup>c</sup> Species not planted at site.

<sup>d</sup> Site 5 seedlings were destroyed before evaluations could be made.

# DIRECT SEEDING WOODY SPECIES FOR RESTORATION OF BOTTOMLANDS

Daniel J. Twedt<sup>1</sup>

**Abstract**—I direct seeded (broadcast) seeds of 39 species of trees and shrubs using an ATV-mounted rotary spreader to initiate restoration of bottomland forest on retired agricultural sites. Four sites were planted during February, 2000, and 13 additional sites were planted during April and May, 2001. After two growing seasons, stem density of direct-seeded species varied greatly among study plots (range = 0 to 888 stems/ha) but averaged only 110 stems/ha. I recommend that future efforts at direct seeding focus on seven shrub species (*Amorpha fruticosa* L., *Cephalanthus occidentalis* L., *Cornus* spp., *Crataegus* spp., *Ilex decidua* Walt., *Morus rubra* L., and *Prunus* spp.) and seven tree species (*Celtis laevigata* Willd., *Diospyros virginiana* L., *Fraxinus* spp., *Gleditsia triacanthos* L., *Robinia pseudoacacia* L., *Taxodium distichum* (L.) Rich, and *Ulmus* spp.) that successfully established in these trials.

## INTRODUCTION

Forest restoration on bottomland sites is widespread and ongoing throughout the Mississippi Alluvial Valley. An estimated 200,000 ha are expected to be returned to bottomland hardwood forests by 2010 (Stanturf and others 2001). Restoration targets of >800,000 ha by 2020 have been suggested, with a hypothetical restoration potential of >3,000,000 ha (Haynes 2004). Historically, restoration of bottomland hardwood forests has focused on planting heavy-seeded tree species such as oaks (*Quercus* spp.) and pecan [*Carya illinoensis* (Wangenh.) K. Koch]. This focus was intended to ensure reestablishment of species that are relatively poor colonizers but are valuable for wildlife and timber production (Haynes and Moore 1988, King and Keeland 1999). Typically, plantings have been extensive (focused on maximizing area restored) rather than intensive (focused on success within a site; Haynes 2004). This approach usually entailed planting seedlings of 3 to 5 species on a 3.7-m (12-foot) grid (746 planted stems/ha) but with little site preparation or post-planting management. Although most restorations suffer from a lack of clearly-defined objectives, surviving stock of >309 stems/ha has been considered sufficient within some programs (e.g., Wetland Reserve Program; Stanturf and others 2000).

On many sites, natural invasion by colonizing woody species has been retarded by long distances to seed sources and on site allelopathic conditions. The combination of planting relatively few, slower-growing tree species and lack of natural recruitment has resulted in some sites being dominated by grasses and herbs, with a sparse stocking of relatively homogeneous saplings for 10 or more years after planting. The resultant slowly-maturing forests tend to have reduced species diversity with relatively homogeneous structure and uniform canopy. This structure promotes slow colonization by silvicolous wildlife, particularly birds, and inferior bole quality of potentially-merchantable trees.

These conditions are not optimal for management of either timber or wildlife. Indeed, I believe that when restoring bottomland sites, both timber and wildlife benefit from: (1) increased diversity of woody species and structural heterogeneity, (2) increased density of trees and shrubs, (3) restoration methods that are appropriate to site and landscape conditions, and (4) a reduced cost of restoration.

Increased diversity of woody species buffers restored forests from the ravages of insects and diseases. Indeed, combating pestilence in plantation monocultures can require considerable resources. In addition, increased species diversity enhances timber management options by buffering market fluctuations and providing increased flexibility of harvest. A diverse forest benefits wildlife by distributing food and shelter resources. In particular, the seasonality of species-specific fruit (mast) production and peaks in abundance of different insects provide complex and continuous food resources. Additionally, greater diversity in structural niches provides for use by an increased cadre of wildlife species.

On sites with abundant natural regeneration, either from an existing seedbank or colonization from external seed sources, higher densities of trees and shrubs provide benefits to both wildlife and timber production. Increased density of trees enhances timber management by promoting improved timber quality. Bole quality of high-value timber species (e.g., oaks) likely benefits from competition with trees of shorter-stature and shrubs [e.g., dogwood (*Cornus* spp.), hawthorn (*Crataegus* spp.), and plum (*Prunus* spp.)] as well as small-twigged canopy tree species [e.g., sweetgum (*Liquidambar styraciflua* L.)]. These competing species act as “training” or “nurse” trees that result in better bole quality of high-value timber species by encouraging vertical growth and discouraging lateral (epicormic) branches. Increased stature and limb-free boles result in improved timber quality and thereby increase management options. Additionally, increased tree densities provide for increased harvest options, wherein managers can choose among different strategies to achieve target results.

Increased stand densities benefit forest wildlife by more rapidly achieving ‘forest-like’ habitat conditions. Food and cover are provided quickly by shrub-scrub species with many suitable foraging sites for leaf-gleaning birds. Furthermore, shrubby habitats often provide an important food source, in the form of soft, fleshy fruits and small hard seeds, for migrating and wintering songbirds. Some birds of management concern [e.g., Bell’s Vireo (*Vireo bellii*), Orchard Oriole (*Icterus spurius*), and Painted Bunting (*Passerina ciris*)] breed in shrub-shrub habitats provided by “thickets” of invading trees. Many other species of forest-breeding birds use these shrubby areas post-breeding for cover and foraging (Kilgo and others

<sup>1</sup> Wildlife Biologist, U.S. Geological Survey, Patuxent Wildlife Research Center, Vicksburg, MS 39180.

1999). Indeed, for some species, these shrub-scrub habitats may be critical during the development of juvenile birds (Vega-Rivera and others 1999).

If an entire site is planted at high densities, however, the resultant dense canopy cover within the maturing forest will diminish its suitability for many wildlife species; densely-planted areas should be mixed with sparse or unplanted areas. Alternatively, management actions (e.g., patch cuts) should be undertaken to ensure sunlight penetration to the forest floor within parts of the stand. However, retention of some densely-stocked areas well beyond canopy closure (as opposed to thinning the entire stand) promotes dominant or emergent trees within the stand that benefit canopy-dwelling birds.

Historically, it was assumed that natural invasion of light-seeded species would result in restored forests that are diverse and densely stocked. Unfortunately, many reforested sites in the Mississippi Alluvial Valley are isolated within agricultural landscapes. Isolation limits natural invasion by woody species such that colonization cannot be relied upon to produce densely-stocked, mixed-species forests when sites are distant from existing forest edges (Allen 1990, Allen and others 1998, Twedt 2004, Twedt and Wilson 2002). Often lacking on these sites are species that produce soft, fleshy fruits or small seeds that are readily consumed by songbirds. To ensure species diversity on isolated sites, it is essential to plant several species.

Small, isolated forest patches attract few forest breeding birds (Mancke and Gavin 2000, Robbins and other 1989) and support a low reproductive rate for those present (Burke and Nol 2000, Nott 2000). Therefore, an alternative management strategy for these sites may be to plant and maintain these areas in shrubby, early successional habitat. Planting only a select subset of woody species could promote development of a shrubby 'disclimax' community. Long-term continuance of this shrubby habitat will likely require periodic perturbation of vegetation.

Impediments to increasing diversity and density of woody species on restored bottomland sites are primarily logistic and economic. Increasing densities of planted seedlings markedly increases cost of restoration. For example, moving from a 3.7-m (12-foot) spacing to 2.5-m (8-foot) spacing more than doubles the planting stock and labor required for restoration. The rapidly-escalating cost of planting trees at high densities is an impediment to increasing density of woody species using traditional restoration methods. Furthermore, because heavy-seeded oaks and pecans have historically constituted the bulk of planted seedlings, there has been little demand for seedlings of other species. Thus, even if the increased costs of achieving higher densities are accepted, there is a paucity of available seedlings for non-oak species with which to increase stand diversity.

Although relatively few non-oak species are readily available as seedlings, seeds of scores of shrubby and small-seeded tree species are available from commercial seed suppliers. Seeds of woody plants can be obtained at a fraction of the cost of seedlings and can be planted with comparatively little time and expense (Allen and others 2001). Furthermore, Twedt and Wilson (2002) suggested that wildlife (birds) benefit more from direct-seeding acorns than from restorations using planted oak seedlings.

Unfortunately, except for sowing acorns and pecans, little information is available on the methodology or success of directly-sown seeds on bottomland sites (Lof and others 2004). Allen and others (2001) state that direct-seeding of light-seeded species has been unsuccessful in the Mississippi Alluvial Valley, but no data or studies are cited to verify this claim. Twedt and Best (2004) found direct-seeded shrubby species were generally unable to compete with invasive exotic grasses within the Lower Rio Grande Valley. After evaluating 56 direct-seeded woody species in Maryland, Kimmons and others (1980) recommended *Amorpha fruticosa* L. and *Symphoricarpos orbiculatus* Moench. as producing consistently good results. Conversely, Holt (1998a, 1998b) found that directly sowing seeds of woody plants was successful at restoring shrubland in Australia.

I attempted to establish soft, fleshy-fruited, and small-seeded woody species on retired agricultural fields that were being reforested via direct seeding. This restoration study provides baseline empirical data on the rates of establishment and survival of shrub and small-seeded tree species when their seeds are broadcast on bottomland sites. However, because each species has unique environmental requirements for germination and subsequent survival, species-specific pre-planting seed preparation, optimizing season of planting, and matching of species to edaphic and hydrologic conditions will likely increase germination and survival. I chose a generic application method that was easily applied with a minimum of equipment and labor. Treatments were intended to increase the density and diversity of woody species, especially shrubby species, on restored sites to improve wildlife and timber value of restored bottomland hardwood forests.

## SITES

### Year 2000 Study Locations

The three study sites were agricultural fields that had been disked to reduce crop residue and were located at Bayou Cocodrie National Wildlife Refuge (NWR), Ferriday, LA, Mollicy Farms Management Area, Farmerville, LA, and Tallahatchie NWR, Grenada, MS. One additional study site was at Cache River NWR, Augusta, AR. This Arkansas site retained soybean stubble and had been planted with seedlings of 8 tree species (*Q. nuttallii* E.J. Palmer, *Q. nigra* L., *Q. phellos* L., *Q. pagoda* Raf., *Q. michauxii* Nutt., *Carya illinoensis*, *Fraxinus pennsylvanica* Marsh., and *L. styraciflua*) at a density of 750 seedlings/ha approximately 1 month prior to sowing of seeds in this study.

### Year 2001 Study Locations

Thirteen, 0.8- to 1.2-ha sites were seeded during 2001. Most sites had been previously planted with seedlings, but survival was poor, and they were considered "failed plantings." These sites were disked to remove existing vegetation before seeding. I direct-seeded four sites on NWR property [Bayou Cocodrie NWR; Tensas River NWR, Tallulah, LA; and Yazoo NWR Complex (two sites), Hollandale, MS] and nine additional sites on private property within Mississippi that were enrolled in the USDA Wetland Reserve Program (WRP).

## PROCEDURES

Between February 10 and 24, 2000, and April 20 and May 3, 2001, I direct-seeded woody plants using a rotary (cyclone) spreader mounted on the rear of an all-terrain vehicle (ATV). Seeds were mixed with pelletized limestone or gypsum as a

physical carrier for the rotary spreader. Most seeds were obtained from the Louisiana Seed Company, Lecompte, LA, but a few species were obtained from Lovelace Seed Company, Elsberry, MO, or Sheffields Seed Co., Looke, NY. Seeds of four species were locally-collected.

### Year 2000

Soil mycorrhiza (Endo Net Bulk Granular Mycorrhizal Inoculum, Reforestation Technologies International, Salinas, CA, www.reforest.com) were applied to parts of seeded fields, using the same rotary spreader. Seeds were cold stored prior

to planting. On the 3 disked sites, seeds and mycorrhiza were incorporated into existing seedbeds using a wooden drag and/or a small disk pulled behind the ATV.

Using a split-plot experimental design, I applied seeds at 2 rates (whole-plot treatments) at each of the four study sites using four planting mixes (split plot treatments). Planting mixes were: (1) seeds of shrubby plants, (2) seeds of hard and soft mast-producing trees, (3) seeds of shrubby plants combined with seeds of hard and soft mast-producing trees (table 1), and (4) unplanted, non-seeded controls.

**Table 1—Seeds of shrubs and trees direct broadcast at two application rates (high and low) using a cyclone seeder on four bottomland restoration sites during February, 2000**

Species	Seeds/g	\$/kg	Mean seeding rate			
			g/ha		Seeds/ha	
			High	Low	High	Low
<i>Shrubs</i>						
<i>Amorpha fruticosa</i>	9.0	41.80	49	14	441	128
<i>Aralia spinosa</i>	45.2	154.00	43	18	1,957	814
<i>Asimina triloba</i>	0.2	47.30	42	14	10	3
<i>Callicarpa americana</i>	14.1	213.40	13	6	186	78
<i>Cephalanthus occidentalis</i>	56.6	37.40	47	21	2,665	1,202
<i>Cornus amomum</i>	4.5	33.00	44	16	198	71
<i>Cornus florida</i>	2.3	33.00	18	3	41	6
<i>Cornus stricta</i>	5.4	66.00	42	18	228	95
<i>Crataegus aestivalis</i>	9.0	110.00	39	23	348	206
<i>Crataegus marshallii</i>	4.5	132.00	48	23	219	104
<i>Halesia diptera</i>	0.7	41.80	54	32	39	23
<i>Ilex decidua</i>	13.6	41.80	72	29	976	399
<i>Malus angustifolia</i>	2.8	165.00	15	1	42	3
<i>Morus rubra</i>	28.3	165.00	8	3	212	88
<i>Prunus virginiana</i>	3.6	17.60	40	21	146	76
<i>Pyrus communis</i>	2.3	88.00	9	2	21	5
<i>Rhus copallina</i>	24.9	22.00	45	16	1,126	389
<i>Rhus glabra</i>	22.6	33.00	43	17	962	382
<i>Sabal minor</i>	0.9	33.00	51	11	46	10
<i>Sambucus nigra</i>	79.2	37.40	40	21	3,148	1,683
<i>Viburnum rufidulum</i>	1.7	74.80	52	11	88	18
<i>Trees</i>						
<i>Acer rubra</i>	5.88	44.00	37	17	218	99
<i>Albizia julibrissin</i>	2.26	0.00	15	6	34	13
<i>Celtis laevigata</i>	3.85	55.00	54	27	207	105
<i>Diospyros virginiana</i>	0.81	17.60	123	30	100	24
<i>Fraxinum pennsylvanica</i>	11.31	33.00	71	10	799	115
<i>Fraxinus profunda</i>	5.43	41.80	22	14	119	78
<i>Gleditsia triacanthos</i>	1.27	27.50	207	54	262	69
<i>Liquidambar styraciflua</i>	9.05	92.40	66	11	597	102
<i>Liriodendron tulipifera</i>	3.62	22.00	96	13	346	45
<i>Platanus occidentalis</i>	63.35	0.00	355	95	22,489	6,018
<i>Prunus serotina</i>	2.26	26.40	58	31	132	70
<i>Quercus michauxii</i>	0.05	2.20	347	94	16	4
<i>Quercus nigra</i>	0.90	4.40	241	174	218	158
<i>Quercus phellos</i>	0.23	7.15	208	219	47	49
<i>Quercus lyrata</i>	0.06	2.20	325	84	21	5
<i>Robinia pseudoacacia</i>	10.86	66.00	57	25	622	269
<i>Taxodium distichum</i>	1.81	48.40	95	59	172	107
<i>Ulmus crassifolia</i>	29.41	105.60	16	8	478	228
Total			3,207	1,291	39,976	13,341

Within part of direct-seeded treatments (split-split plot), I planted seedlings of hard mast-producing trees (Nuttall oak, *Q. nuttallii*). Seedlings were 1-year-old (1-0) stock, planted at a high rate, 10- x 10-m spacing (100 seedlings/ha), or a low rate, 12- x 15-m spacing (56 seedling/ha). These planting densities were intended to provide ample inter-tree space for direct-seeded, as well as naturally-invading, woody trees and shrubs. Planted seedlings were not included in evaluation of direct seeding.

I applied treatments within 0.5- or 1.0-ha plots to attain desired densities of sown seeds at circa 400 g/ha (low seeding rate) and >1,000 g/ha (high seeding rate). Seeding rates were based on Holt's (1998b) recommendation of 400 to 1,000 g/ha of pure live seed (PLS) and Kimmons and others (1980) stated goal of circa 12,000 woody plants/ha.

### Year 2001

All sites were disked by landowners to prepare seedbed for planting. Seeds were treated through cold stratification and/or acid scarification to promote germination in accordance with published recommendations (Schopmeyer 1974). Seeds were broadcast on entire study plots (i.e., there were no unplanted control plots). Eleven sites were planted with seeds of trees and shrubs (table 2), and 2 of the 13 sites were planted only with shrub seeds. After planting, sites were either disked, culti-packed, or rolled to incorporate seeds.

To assess seedling abundance, I used 2.52-m radius (20-m<sup>2</sup>) circular plots located systematically along parallel transects that spanned study sites. I assessed seedling abundance on 2 sites planted in 2000 during fall of 2002; all other sites were evaluated during fall, 2003.

### RESULTS

During 2000, seeds of 21 shrub species and 18 tree species were sown (table 1). Seeding rates varied slightly among study sites. High seeding rates were 870 to 1,250 g/ha for shrub seeds and 1,385 to 2,350 g/ha for tree seeds. Low seeding rates were 310 to 400 g/ha for shrub seeds and 418 to 890 g/ha for tree seeds. Cost of tree seed was \$14/ha at low density and \$65/ha at high density. Cost of shrub seed was \$25/ha at low density and \$43/ha at high density. During 2001, seeds of 25 shrub species and 14 tree species were sown (table 2). Seeding rates were 3,590 g/ha for shrub seeds and 3,120 g/ha for tree seeds.

On sites planted during 2000, I assessed seedling abundance on between 0.2 and 0.4 ha within sample plots. Mean stem density on direct seeded sites was 145.3 ± 47.1 stems/ha, but densities ranged from 45 to 258 stems/ha (fig. 1). However, seedling density on unplanted control areas ranged from 0 to 167 stems/ha. Thus, after adjusting for presumed natural invasion (i.e., density on control areas), net seedling densities ranged from 4 to 253 stems/ha (fig. 1). On sites planted during 2001, I assessed seedling abundance on between 0.1 and 0.2 ha within sample plots. Mean stem density on 2001 planted sites was 110.4 ± 66.3 stems/ha. Again, the range of observed densities was vast (0 to 888 stems/ha; fig. 2).

Only three direct-seeded species (*Cephalanthus occidentalis*, *Fraxinus* spp., and *Prunus* spp.) were detected at densities >10 stems/ha (table 3). Other species detected at densities of >2 stems/ha were *Celtis laevigata*, *Crataegus* spp., *Gleditsia*

**Table 2—Seeds of shrubs and trees direct seeded (broadcast) using a cyclone seeder on 13 bottomland restoration sites between 20 April and 3 May, 2001**

Species	Seeding rate		
	Seeds/g	g/ha	Seeds/ha
<i>Shrubs</i>			
<i>Callicarpa americana</i>	613	49	30,037
<i>Cercis canadensis</i>	58	10	580
<i>Cornus amomum</i>	20	182	3,640
<i>Cornus drummondii</i>	36	91	3,276
<i>Cornus florida</i>	9	91	819
<i>Crataegus crus-galli</i>	14	361	5,054
<i>Crataegus phaenopyrum</i>	87	46	4,002
<i>Crataegus viridis</i>	48	91	4,368
<i>Euonymus americanus</i>	47	15	705
<i>Ilex decidua</i>	79	273	21,567
<i>Ilex opaca</i>	97	55	5,335
<i>Morus rubra</i>	580	88	51,040
<i>Prunus americana</i>	2	271	434
<i>Prunus angustifolia</i>	3	266	798
<i>Prunus caroliniana</i>	1	451	338
<i>Prunus mexicana</i>	2	91	182
<i>Prunus serotina</i>	13	269	3,497
<i>Prunus virginiana</i>	12	183	2,196
<i>Rhus glabra</i>	128	112	14,336
<i>Rhus typhina</i>	111	46	5,106
<i>Sambucus canadensis</i>	567	23	13,041
<i>Sabal minor</i>	5	63	315
<i>Styrax americana</i>	9	12	108
<i>Viburnum dentatum</i>	55	269	14,795
<i>Viburnum prunifolium</i>	15	182	2,730
<i>Trees</i>			
<i>Acer negundo</i>	55	59	3,245
<i>Betula nigra</i>	550	52	28,600
<i>Catalpa bignonioides</i>	56	209	11,704
<i>Celtis laevigata</i>	15	59	885
<i>Diospyros virginiana</i>	2	658	1,119
<i>Fraxinus pennsylvanica</i>	47	227	10,669
<i>Gleditsia triacanthos</i>	4	229	916
<i>Nyssa biflora</i>	7	114	798
<i>Nyssa sylvatica</i>	11	113	1,243
<i>Platanus occidentalis</i>	380	100	38,000
<i>Quercus nigra</i>	1	681	749
<i>Quercus phellos</i>	1	460	575
<i>Robinia pseudoacacia</i>	47	112	5,264
<i>Sassafras albidum</i>	11	47	517
Total		6,710	292,583

*triacanthos* L., *Ilex decidua* Walt., *Morus rubra* L., *Robinia pseudoacacia* L., *Taxodium distichum* (L.) Rich., and *Ulmus* spp. (table 3). I detected seedlings of 8 additional species that had been direct seeded (table 3).

### DISCUSSION

Study sites seeded during 2000 had been disked the previous fall. Some crop residue remained in clumps, and these seedbeds did not provide ideal conditions for incorporation of broadcast seeds. Thus, soil-seed contact was highly variable

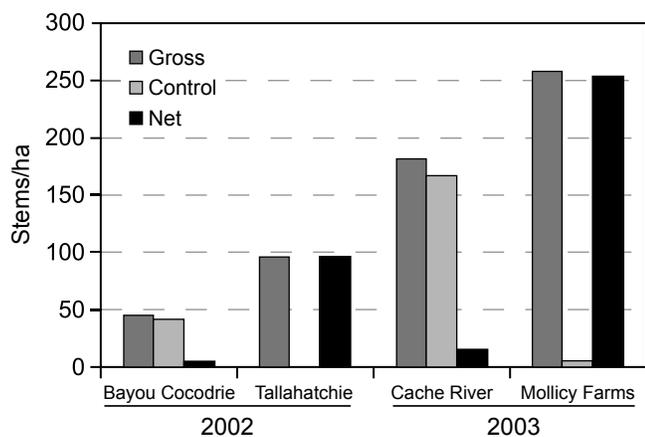


Figure 1—Stem density, during fall of 2002 or 2003, of shrubs and trees that were direct-seeded (broadcast) on four bottomland restoration sites during February, 2000, and their equivalent densities on unplanted control sites.

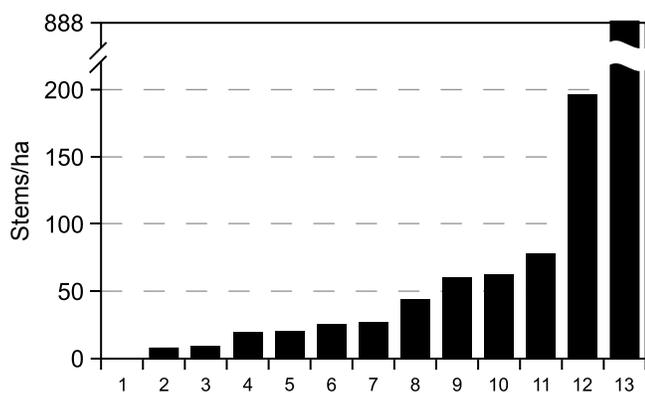


Figure 2—Stem density, during fall 2002, of shrubs and trees that were direct-seeded (broadcast) on 13 bottomland restoration sites during April or May, 2001.

within these sites and may have limited seed germination. Sparse establishment of seedlings contributed to my inability to determine any effect of mycorrhiza on seedling development.

Planting conditions at sites seeded during 2001 ranged from dry, sandy soils to wet, heavy-clay soils. Thus, not all species could be expected to perform similarly at all sites. Further, as no control sites were established during 2001 plantings, I could not account for confounding effects of natural invasion. Even so, most of these sites were >200 m from existing mature forest seed sources and likely had limited natural seeding. Notably, the site with highest stem density abutted mature forest.

Interestingly, of the sites planted in 2000, the two sites evaluated after three growing seasons had markedly higher stem densities than the two sites evaluated after two growing seasons (fig. 1). Lof and others (2004) found a similar increase in establishment percentages over a 4-year period for *Prunus avium* (L.) and *Crataegus monogyna* Jacq.

I recommend additional direct-seeding trials be undertaken using a limited number of species. Shrub species that appear to have promise for direct seeding on bottomland sites include:

**Table 3—Establishment rate of shrubs and trees that were direct seeded using a cyclone seeder on 17 bottomland restoration sites during spring 2000 and 2001**

Species	Stems/ha
<i>Shrubs</i>	
<i>Acer rubra</i>	0.3
<i>Amorpha fruticosa</i>	1.9
<i>Celtis laevigata</i>	7.6
<i>Cephalanthus occidentalis</i>	11.7
<i>Cornus</i> spp.	1.9
<i>Crataegus</i> spp.	3.2
<i>Diospyros virginiana</i>	1.6
<i>Fraxinus</i> spp.	47.6
<i>Gleditsia triacanthos</i>	4.1
<i>Ilex decidua</i>	5.4
<i>Liquidambar styraciflua</i>	0.9
<i>Morus rubra</i>	5.4
<i>Platanus occidentalis</i>	1.6
<i>Prunus</i> spp.	16.1
<i>Quercus</i> spp.	1.6
<i>Robinia pseudoacacia</i>	3.2
<i>Sabal minor</i>	0.3
<i>Taxodium distichum</i>	4.4
<i>Ulmus</i> spp.	3.5
Total	122.3

*Amorpha fruticosa*, *Cephalanthus occidentalis*, *Cornus* spp., *Crataegus* spp., *Ilex decidua*, *Morus rubra*, and *Prunus* spp. Tree species that should be further evaluated include: *Celtis laevigata*, *Diospyros virginiana*, *Fraxinus* spp., *Gleditsia triacanthos*, *Liquidambar styraciflua*, *Platanus occidentalis* L., *Robinia pseudoacacia*, *Taxodium distichum*, and *Ulmus* spp.

A few of these species (e.g., *Prunus* spp., *Diospyros* spp., *Gleditsia* spp., and *Robinia* spp.) have seeds that are large enough to be mixed with acorns when direct-seeding oaks using a modified soybean planter. I recommend a similar approach be undertaken with smaller-seeded species, wherein these seeds are planted using a modified “no-till” small grain seed drill.

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#### LITERATURE CITED

Allen, J.A. 1990. Establishment of bottomland oak plantations on the Yazoo National Wildlife Refuge Complex. *Southern Journal of Applied Forestry*. 14: 206-210.

- Allen, J.A.; McCoy, J.; Keeland, B.D. 1998. Natural establishment of woody species on abandoned agricultural fields in the lower Mississippi Valley: first- and second-year results. In: Waldrop, T.A., ed. Proceedings of the ninth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 263-268.
- Allen, J.A.; Keeland, B.D.; Stanturf, J.A. [and others]. 2001. A guide to bottomland hardwood restoration. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD/ITR-2000-0011. Gen. Tech. Rep. SRS-40. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 132 p.
- Burke, D.M.; Nol, E. 2000. Landscape and fragment size effects on reproductive success of forest-breeding birds in Ontario. *Ecological Applications*. 10: 1749-1761.
- Haynes, R.J. 2004. The development of bottomland forest restoration in the lower Mississippi Alluvial Valley. *Ecological Restoration*. 22: 170-182.
- Haynes, R.J.; Moore, L. 1988. Reestablishment of bottomland hardwoods within national wildlife refuges in the Southeast. In: Zelazny J.; Feierabend, J.S., eds. Proceedings of conference: increasing our wetland resources. Washington, DC; National Wildlife Federation: 95-103.
- Holt, C. 1998a. Direct seeding native trees and shrubs. Farmnote 34/98 Agriculture Western Australia, Narrogin. 9 p. <http://agspsrv38.agric.wa.gov.au/pls/portal30/docs/FOLDER/IKMP/LWE/VEGT/TREES/f03498.pdf> [Date accessed 10 Feb 2006].
- Holt, C. 1998b. Direct seeding of native plants for revegetation. Farmnote 40/98 Agriculture Western Australia, Narrogin. 10 p. <http://agspsrv38.agric.wa.gov.au/pls/portal30/docs/FOLDER/IKMP/LWE/VEGT/TREES/F04098.pdf> [Date accessed 10 Feb 2006].
- Kilgo, J.C.; Miller, K.V.; Smith, W.P. 1999. Effects of group selection timber harvest in bottomland hardwoods on fall migrant birds. *Journal of Field Ornithology*. 70: 404-413.
- Kimmons, J.H.; Lovell, G.R.; Everett, H.W. [and others]. 1980. Evaluation of woody plants for development of establishment procedures for direct woody seeding and/or vegetative reproduction. Tech. Rep. FHWA-MD-76-19A. Beltsville, MD: U.S. Department of Agriculture, Soil Conservation Service, National Plant Material Center. 26 p.
- King, S.L.; Keeland, B.D. 1999. A survey and evaluation of reforestation of the lower Mississippi River alluvial valley. *Restoration Ecology*. 7: 348-359.
- Lof, M.; Thomsen, A.; Madsen, P. 2004. Sowing and transplanting of broadleaves (*Fagus sylvatica* L., *Quercus robur* L., *Prunus avium* L. and *Crataegus monogyna* Jacq.) for afforestation of farmland. *Forest Ecology and Management*. 188: 113-123.
- Mancke, R.G.; Gavin, T.A. 2000. Breeding bird density in woodlots: Effects of depth and buildings at the edges. *Ecological Applications*. 10: 598-611.
- Nott, M.P. 2000. Identifying management actions on DOD installations to reverse declines in neotropical birds. Tech. Rep. of DOD legacy project no. 00103. The Institute for Bird Populations. <http://www.birdpop.org/DownloadDocuments/BigOaksNWR2002.pdf>. [Date accessed 10 Feb 2006]
- Robbins, C.S.; Dawson, D.K.; Dowell, B.A. 1989. Habitat area requirements of breeding birds of the middle Atlantic states. *Wildlife Monographs*. 103: 1-34.
- Schopmeyer, C.S., coord. 1974. Seeds of woody plants in the United States. Agric. Handb. 450. Washington, DC: U.S. Department of Agriculture, Forest Service. 883 p.
- Stanturf, J.A.; Gardiner, E.S.; Hamel, P.B. [and others]. 2000. Restoring bottomland hardwood ecosystems in the Lower Mississippi Alluvial Valley. *Journal of Forestry*. 98: 10-16.
- Stanturf, J.A.; Schoenholtz, S.H.; Schweitzer, C.J.; Shepard, J.P. 2001. Achieving restoration success: myths in bottomland hardwood forests. *Restoration Ecology*. 9: 189-200.
- Twedt, D.J. 2004. Stand development on reforested bottomlands in the Mississippi Alluvial Valley. *Plant Ecology*. 172: 251-263.
- Twedt, D.J.; Wilson, R.R. 2002. Development of oak plantations established for wildlife. *Forest Ecology and Management*. 162: 287-298.
- Twedt, D.J.; Best, C. 2004. Restoration of floodplain forests for the conservation of migratory landbirds. *Ecological Restoration*. 22: 194-203.
- Vega-Rivera, J.H.; McShea, W.J.; Rappole, J.H.; Haas, C.A. 1999. Postbreeding movements and habitat use of adult wood thrushes in northern Virginia. *Auk*. 116: 458-466.

# THE ROLE OF LARGE CONTAINER SEEDLINGS IN AFFORESTING OAKS IN BOTTOMLANDS

Daniel C. Dey, John M. Kabrick, Michael Gold<sup>1</sup>

**Abstract**—We planted large container (RPM®) and 1-0 bareroot seedlings of pin oak (*Quercus palustris* Muenchh.) and swamp white oak (*Q. bicolor* Willd.) in crop fields in the Missouri River floodplain. We also evaluated the benefits of soil mounding and a grass (*Agrostis gigantea* Roth) cover crop. RPM® oak seedlings had significantly greater survival and basal diameter increment after 3 years than bareroot seedlings. RPM® trees lost significantly more height during the first 3 years than bareroot seedlings due to rabbit herbivory, which was substantially greater in the natural vegetation than the redtop grass fields. Oak seedlings in redtop grass cover grew substantially more in diameter and height than oaks competing with natural vegetation. Soil mounding had no significant effect on oak survival or growth. Swamp white oak RPM® seedlings produced acorns annually the first 4 years. Planting large container seedlings in redtop grass improved early oak regeneration success and rapidly restored acorn production.

## INTRODUCTION

Public land managers and private land owners have a strong interest in regenerating native oak species (*Quercus* sp.) on what are largely agricultural floodplains. Bottomland oak species are highly valued for timber products and wildlife habitat. They are also of conservation concern because of the substantial decline in oaks from historic levels and the difficulty in regenerating them on highly productive floodplains.

The Great Flood of 1993 inundated floodplains throughout much of the summer ruining bottomland farms and causing extensive mortality of oaks in forests along the Missouri and Mississippi Rivers. Since 1993, many abandoned bottomland crop fields have naturally regenerated to forests dominated by pioneering species such as cottonwood (*Populus deltoides* Bartr. ex Marsh.), silver maple (*Acer saccharinum* L.), sycamore (*Platanus occidentalis* L.), and willow (*Salix nigra* Marsh.). These species are abundant in remnant floodplain forests, thus ensuring a local seed supply. They are prolific annual seed producers, and their seed are easily dispersed by wind and water. Seed germination is favored on mineral soils in open environments, typical of conditions following abandonment of bottomland crop fields. Their seedlings exhibit rapid juvenile growth, which makes them highly competitive on the productive bottomland soils.

Former small- to moderate-sized bottomland crop fields have developed into well-stocked sapling stands dominated by these pioneer species in the years since 1993. Cottonwood, willow, sycamore, silver maple, and other early successional tree species are native to bottomlands and are considered desirable reproduction. A widespread pattern in forest succession on former bottomland crop fields is the lack of oaks and other nut-producing trees. For example, Shear and others (1996) found a lack of hard mast species in 50-year-old forests that naturally regenerated on bottomland crop fields in southwestern Kentucky. Thus, artificial regeneration of oaks is needed to increase the likelihood that oaks are present in future forests.

Traditional methods of planting bareroot oak seedlings or direct seeding acorns in bottomlands have not always been successful. For example, in a survey of 4-year-old Wetland Reserve Program plantings in the Mississippi River floodplain, Schweitzer and Stanturf (1997) found that only 9 percent of the total reforested land in 13 Mississippi counties met the Natural Resources Conservation Service requirement for at least 125 hard mast stems per acre in 3-year-old stands.

Oak regeneration failures in bottomland crop fields are largely a result of the low competitiveness of small oak seedlings on sites that are capable of producing tremendous herbaceous biomass in one summer. Small oak seedlings also are less competitive than the pioneer tree species that invade abandoned crop fields. In addition, oak plantings are not often maintained by controlling competing vegetation, which makes successful oak regeneration less likely. Oak species are moderately tolerant to intolerant of shade and unable to persist in the heavy shade of competing vegetation.

Oak regeneration success can be improved, in part, by planting large seedlings, particularly those having well-developed root systems (Gardiner and others 2002, Johnson and others 2002, Kormanik and others 1998, Schultz and Thompson 1997, Stanturf and others 1998). Nursery managers can produce hardwood bareroot seedlings with large root systems that have five or more large lateral roots by undercutting the taproot, growing seedlings at lower seedbed densities, or by transplanting 1-0 seedlings for a second year. Air pruning the roots of seedlings grown in open-bottomed containers is another way to promote the growth of large lateral roots and dense fibrous root systems (Dey and others 2004).

In the Midwest, several private nurseries have begun commercial production of large (e.g., 3- to 5-gallon) container seedlings that are being used in the afforestation of bottomland crop fields on public and private lands. The Forrest Keeling Nursery of Elsberry, MO, has developed a nursery cultural technique, the Root Production Method (RPM®), to produce high-quality hardwood seedlings that have large basal diameter and height and a substantial fibrous root system (Dey

<sup>1</sup> Research Foresters, USDA Forest Service, North Central Research Station, Columbia, MO 65211; and Associate Director, University of Missouri, Center for Agroforestry, Columbia, MO 65211, respectively.

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and others 2004). For the past 5 years or so, these large container seedlings have been planted in various floodplain situations throughout the Midwest. In 1999, we began a study to evaluate the performance of these large container seedlings in the afforestation of bottomland crop fields. This paper presents early survival and growth performance of large container seedlings compared with that of 1-0 bareroot seedlings in regenerating pin oak and swamp white oak in bottomland crop fields along the lower Missouri River. We discuss the role of large container seedlings in regenerating oaks in floodplains.

## METHODS

Dey and others (2003) provided a detailed explanation of the experimental design and study establishment. In summary, a study was established to evaluate methods for regenerating pin oak and swamp white oak on former agricultural crop fields in the Missouri River floodplain in the fall of 1999. The study fields had been in crop production for years before this study. Soils at the study sites were mapped as Sarpy Fine Sand (mixed, mesic, Typic Udipsamments), Haynie Silt Loam (coarse-silty, mixed, superactive, calcareous, mesic Mollic Udifluvents), and Leta Silty Clay (clayey over loamy, smectitic, calcareous, mesic Aeric Fluvaquents). Two floodplain properties were used in this study, Smoky Waters and Plowboy Bend Conservation Areas, both managed by the Missouri Department of Conservation. The Smoky Waters site, which lies at the confluence of the Missouri and Osage Rivers, is not protected by levees and is subject to flooding. The site at Plowboy Bend, located along the Missouri River, is protected by a levee.

Both 1-0 bareroot and 3- and 5-gallon RPM® seedlings were planted to evaluate the effect of seedling size and nursery stock type on the survival and growth of pin oak and swamp white oak seedlings. Seedlings were planted in soil mounds created with a rice plow or in unmounded soil and with either a cover crop of redbud grass or with natural vegetation that normally colonizes abandoned bottomland crop fields.

Dey and others (2004) have described the RPM® cultural technique in some detail. Using oak as an example, the process generally involves (1) germinating seed on soil media in shallow, open-mesh, bottomless trays, (2) transplanting seedlings into 4-inch square bottomless band containers at the end of the first shoot flush, and (3) a final transplanting of seedlings into 3- or 5-gallon pots whether they are grown in the nursery for 1 or 2 years, respectively.

Initial total height and basal stem diameter 1 inch above the ground were measured on all seedlings after planting and again at the end of each growing season. Seedling survival was determined each year, and animal damage to seedlings was recorded. Animal damage consisted primarily of shoot clipping and girdling of main stems by eastern cottontail rabbits (*Sylvilagus floridanus* Allen) and white-tailed deer (*Odocoileus virginianus* Boddaert).

Analysis of variance (ANOVA) was used to determine significant ( $P < 0.05$ ) growth rate differences among species and stock type combinations between fields with and without redbud grass and between mounded and non-mounded planting units. In this ANOVA, site was a random effect and cover crop treatment, mounding treatment, and species and stock type combinations were fixed effects. The significance of

treatment effects on tree growth and survival was determined using their respective site interactions as error terms. For significant effects, orthogonal contrasts were used to compare mean differences. Logistic regression was used to develop models that predict survival based on seedling characteristics and management treatments.

## RESULTS AND DISCUSSION

### Comparison of Initial Planting Stock

Average basal diameters of 5-gallon RPM® seedlings were slightly larger than 3-gallon seedlings for both pin oak and swamp white oak, and diameters of both RPM® stock types were substantially larger than the bareroot seedlings (fig. 1). Pin oak and swamp white oak RPM® seedlings averaged 0.6 to 0.8 inches in basal diameter compared to 0.3 inches for bareroot seedlings. Similar trends were seen in average height of seedlings among the different stock types. Heights of RPM® seedlings averaged 4.9 feet or larger compared to bareroot seedlings, which averaged 2.3 feet or less. Pin oaks were generally slightly larger than swamp white oaks within a given stock type.

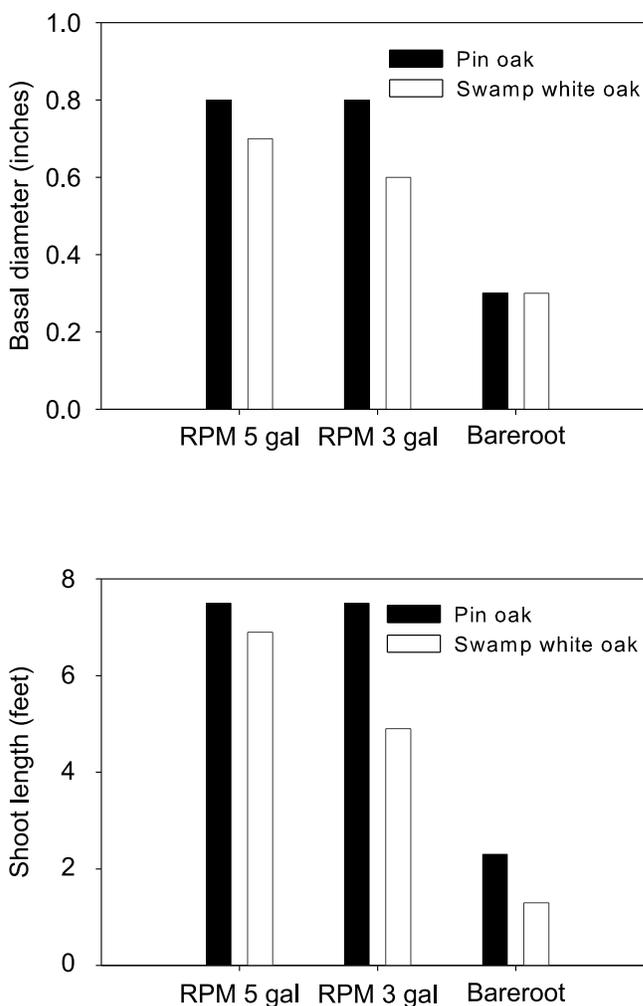


Figure 1—Average basal diameter (1-inch above the root collar) and shoot length of pin oak and swamp white oak RPM® and bareroot seedlings typical of those used in this study.

**Table 1—Root system differences between 1-0 bareroot (BR) and RPM® pin oak and swamp white oak seedlings planted in this study**

Stock type	Root volume	Root dry weight
	<i>cm<sup>3</sup> H<sub>2</sub>O</i>	<i>g</i>
Pin oak BR	26	17
Pin oak RPM® 3 gallon	236	117
Pin oak RPM® 5 gallon	223	118
Swamp white oak BR	33	20
Swamp white oak RPM® 3 gallon	141	64
Swamp white oak RPM® 5 gallon	252	138

The root systems of RPM® seedlings had substantially more volume and dry weight than bareroot seedlings, regardless of species (table 1). The root systems of 3- and 5-gallon pin oak RPM® seedlings were similar in volume and dry weight. For all RPM® seedlings, root volume and dry weight were greatest for 5-gallon swamp white oak RPM® seedlings and smallest for 3-gallon swamp white oak. However, the smallest RPM® root systems were substantially larger than those of bareroot seedlings.

The RPM® process builds a large root mass with numerous sizeable lateral roots concentrated just below the root collar in a short period of time (e.g., 210 days to produce a plantable 3-gallon pin oak seedling). Johnson and others (2002), Kormanik and others (1998), and Schultz and Thompson (1997) have emphasized that the key to successful oak regeneration, both natural and artificial, is the formation of a large root system. Any silvicultural systems or nursery practices that create favorable conditions for the growth of oak root systems enhance oak's competitiveness.

The perceived advantages of container grown RPM® seedlings include (1) rapid early growth that is driven by a large, intact root system, which minimizes transplant shock and facilitates early root growth in the establishment year; and (2) seedlings tall enough (e.g., ≥ 5 feet) to minimize deer herbivory on the terminal shoot and to improve chances that the live crown will remain above growing-season floods. Survival of seedlings is greatly enhanced if their live crowns avoid inundation during growing-season floods. Floods that cause defoliation of hardwood seedlings force trees to expend their remaining energy forming a second crown, which places them at a greater disadvantage with other competing vegetation on these highly productive sites.

### Natural Disturbances

**Rabbit herbivory**—Every winter after the first year, cottontail rabbits have girdled and shoot clipped oak seedlings and oak sprouts. The amount and severity of rabbit damage to planted oaks varied greatly between the cover crop treatments (i.e., redtop grass versus natural vegetation fields).

In the natural vegetation fields, the composition and structure of winter cover provided by forbs promoted higher rabbit densities (3 rabbits per acre) than in the redtop grass fields (1.0 rabbit per acre) (Dugger and others 2004). In the winter, the dead tops of forbs and clumps of Johnsongrass [*Sorghum*

*halepense* (L.) Pers.] remained somewhat erect, providing cover that was as high as 3 feet. However, redtop grass matted down to 0.6 feet and provided little hiding cover for rabbits from predators. Thus, rabbits were able to move freely across the natural vegetation fields causing damage to nearly all of the seedlings each winter. Rabbits clipped the shoots of all bareroot seedlings and severely girdled (more than half of the circumference of the stem) 90 percent or more of the RPM® seedlings in the natural vegetation fields by the end of the second winter. In comparison, damage to oak seedlings by rabbits was much less extensive and severe in the redtop grass fields. These differences in winter habitat between the cover crop treatments affected rabbit densities and movements, which in turn contributed to the significant differences in oak seedling survival, growth, and acorn production between the cover crop treatments.

**Flooding**—In 2 of the past 4 years (2001, 2002), the study site at Smoky Waters was flooded for up to 3 weeks in June. Duration of flooding was variable across the redtop grass and natural vegetation fields due to differences in elevation. Depth of flooding was also variable, with maximum depths reaching 4 to 5 feet, enough to completely inundate bareroot seedlings and oak sprout clumps formed by rabbit-girdled RPM® trees.

### Survival

Survival of oak RPM® seedlings remained high (> 94 percent) during the first 3 years (fig. 2), while survival of bareroot seedlings continued to decline for both swamp white oak and pin oak. There was no significant difference in survival between 3- and 5-gallon RPM® seedlings. After 3 years in the field, survival of swamp white oak bareroot seedlings was significantly higher ( $P < 0.01$ ) than pin oak bareroot seedlings. Swamp white oak bareroot survival averaged 76 percent, while survival for pin oak bareroot seedlings was 54 percent. There was no significant difference ( $P = 0.24$ ) between 3- and 5-gallon RPM® seedling survival, nor between swamp white oak and pin oak RPM® seedling survival ( $P = 0.87$ ). Soil mounding and cover crop treatments did not significantly affect oak seedling survival.

### Basal Diameter Growth

Basal diameter increment after 3 years was significantly greater ( $P < 0.01$ ) for RPM® seedlings than bareroot stock, regardless of species (fig. 2). There was no significant difference in basal diameter increment between 3- and 5-gallon RPM® seedlings. The average basal diameter of all RPM® oak seedlings increased 0.3 inches in the first 3 years, whereas bareroot seedlings increased only 0.1 inches. There was no significant difference ( $P = 0.34$ ) in basal diameter increment between the 3- and the 5-gallon RPM® seedlings. The basal diameter of pin oak 5-gallon RPM® seedlings increased the most during the first 3 years, averaging 0.4 inches of new growth. Basal diameter increment was least (0.03 inches in 3 years) for pin oak bareroot seedlings. The above analysis includes rabbit-damaged and undamaged trees. By removing the rabbit-damaged trees, average basal diameter increment was 0.6 inches for RPM® seedlings and 0.1 inches for bareroot trees.

Although soil mounds functioned as anticipated by improving drainage and aeration, they did not significantly affect diameter growth. Kabrick and others (2005) have reported more

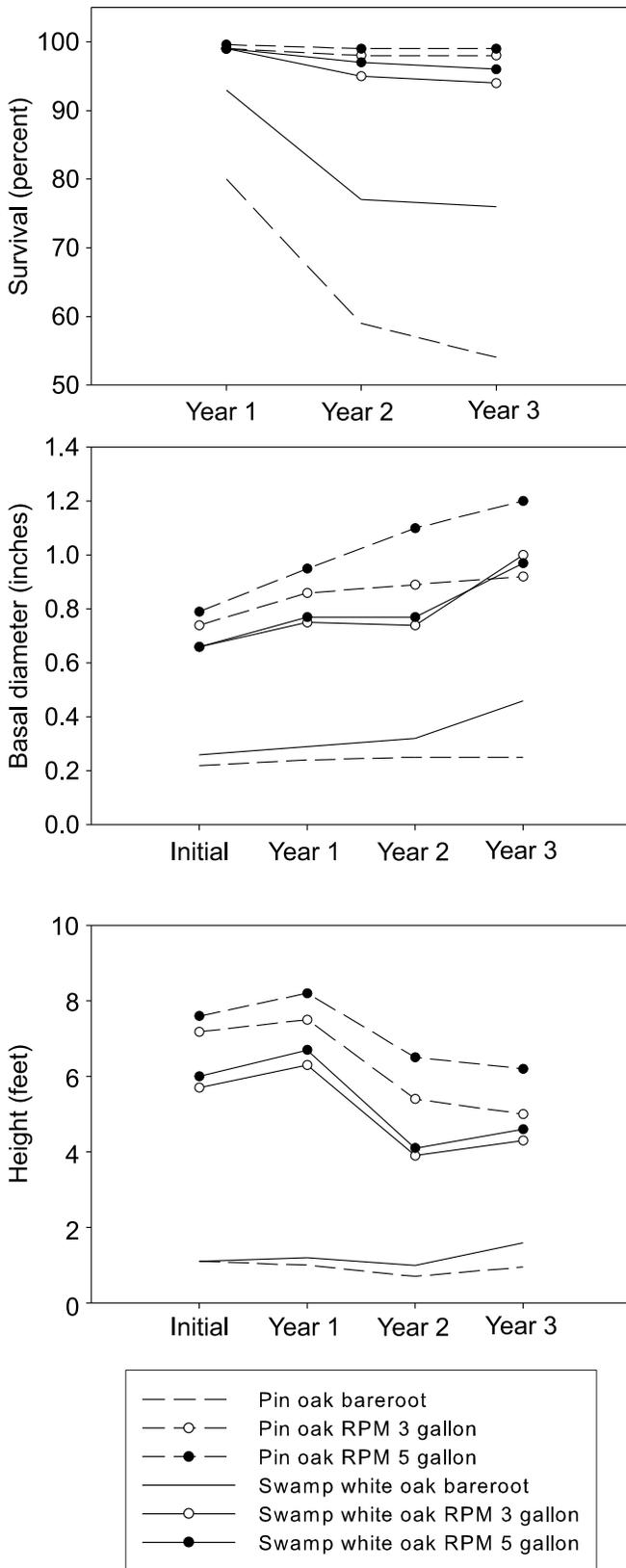


Figure 2—Survival, basal diameter and height of swamp white oak and pin oak RPM<sup>®</sup> and bareroot seedlings during the first 3 years in this study.

detailed effects of soil mounding on soil properties and oak regeneration based on the results from this study. Basal diameter increment of all trees combined was substantially larger in redtop grass fields (0.6 inches) than in natural vegetation fields (0.1 inches); however, no significant differences can as yet be reported ( $P = 0.08$ ). For undamaged trees, average basal diameter increment was 0.6 inches for RPM<sup>®</sup> seedlings in redtop grass fields and 0.2 inches in natural vegetation fields, while the basal diameter of bareroot seedlings increased by 0.1 inches in redtop grass but decreased by 0.1 inches in natural vegetation fields.

### Height Growth

Average height increment after 3 years was negative for most species and nursery stock types, because cottontail rabbits caused extensive damage by girdling the stems of RPM<sup>®</sup> seedlings or by clipping the shoots of bareroot seedlings at ground-level (fig. 2). Severely girdled or clipped trees that survived produced multiple-stemmed sprout clumps, but new shoot growth was insufficient to recover to original seedling heights, especially for RPM<sup>®</sup> seedlings.

Three-year height increment was significantly less ( $P < 0.01$ ) for RPM<sup>®</sup> than bareroot seedlings. There was no significant difference in height increment between 3- and 5-gallon RPM<sup>®</sup> seedlings. For bareroot seedlings that had been shoot-clipped by rabbits, annual sprout growth came close to, or slightly exceeded, the initial height, resulting in small negative or positive increments in height. In contrast, net height increment was much lower in initially tall RPM<sup>®</sup> trees, because rabbit girdling, which occurred in the lower 1.0 foot of the stem, caused shoot dieback to near ground-level. In addition, trees were often repeatedly damaged by rabbits each winter. Three-year height increment averaged -1.6 feet for the RPM<sup>®</sup> seedlings. Despite rabbit browsing, RPM<sup>®</sup> trees remained taller than bareroot seedlings 3 years after planting. Undamaged trees in the redtop grass fields had slightly positive average height growth (0.3 feet for bareroot and RPM<sup>®</sup> seedlings), but net growth was negative in natural vegetation fields, averaging -1.7 feet for RPM<sup>®</sup> and -0.4 feet for bareroot seedlings.

Height growth of undamaged RPM<sup>®</sup> seedlings may be low because these trees were planted on a 30 by 30 foot spacing; and widely spaced, open-grown trees often experience reductions in height growth, especially trees with weak epinastic control such as the oaks (Oliver and Larson 1996). Also, height growth of oak reproduction is slow at first, because seedlings characteristically allocate photosynthates to root growth often at the expense of shoot growth (Johnson and others 2002). Height growth of RPM<sup>®</sup> and bareroot seedlings may also be limited by low levels of foliar nitrogen, which averaged 2.05 percent at Smoky Waters and 1.71 percent at Plowboy Bend Conservation Areas (Kabrick and others 2005).

An analysis of all trees by cover crop treatment showed that 3-year height increment was significantly higher ( $P = 0.02$ ) for oak seedlings growing in the redtop grass fields than those trees competing with natural vegetation. There may be less light competition in the redtop grass fields during the growing season than in the natural vegetation fields. Redtop grass typically grows to a height of 1.5 to 2.0 feet, whereas herbaceous ground cover in the natural vegetation fields grew to over 6.6 feet in height, overtopping many of the oak seedlings.

Also, rabbit densities were less and fewer trees were damaged in the redtop grass than in the natural vegetation fields. There was no significant difference in height growth among trees on mounded and unmounded soils.

### Acorn Production

Swamp white oak RPM® seedlings that were 18 to 24 months old at time of planting produced acorns in each of the first 4 years following outplanting (table 2). Acorn production occurred in a small proportion (3.5 percent) of the 2,522 swamp white oak RPM® seedlings their first year in the field. Most of the production (60 percent) occurred in oaks from 5-gallon containers, but larger 3-gallon container RPM® trees also produced acorns. Individual trees were able to produce as many as 125 acorns. The probability of a RPM® swamp white oak seedling producing at least one sound acorn in the first year after planting was significantly related to initial basal diameter and height of the seedling (Grossman and others 2003).

The number of trees bearing acorns dropped in year 2 because rabbit herbivory and shoot dieback took RPM® trees in the natural vegetation fields out of production. Production in years 3 and 4 came almost exclusively from RPM® trees growing in the redtop grass fields. A single pin oak RPM® seedling produced acorns for the first time in the fourth year. Consistent, early production of acorns is surprising considering that open-grown oaks do not begin producing seed until they are 20 to 30 years old (Burns and Honkala 1990). In contrast, no bareroot oak seedlings have produced acorns after four growing seasons. Early fruiting and nut production in RPM® trees is a substantial benefit for wildlife, and it restores the ability for oaks to regenerate naturally on former bottomland crop fields where lack of local seed supply is a factor limiting oak regeneration.

### Role of Large Container Seedlings in Regenerating Hard Mast Species

In the afforestation of bottomland crop fields, managers need to consider the contributions that can be expected from natural regeneration and the need for artificial regeneration. In extremely large fields, artificial regeneration may be needed even for pioneering species such as cottonwood, silver maple, sycamore, and willow (Allen 1990, Twedt and Wilson 2002). Relying on natural regeneration in large fields may result in understocked stands, in part because of the difficulty in timing an appropriate seedbed and adequate competition control with seed dispersal to the site. In smaller fields, pioneering species often are able to regenerate to well-stocked stands

because establishment conditions are easier to control through site preparation and seed sources are often adjacent to the area. Regardless of field size, managers are almost always forced into artificially regenerating heavy nut species such as the oaks due to the lack of a natural seed source.

Planting bareroot seedlings and direct seeding are the most common methods for regenerating oaks in agricultural floodplains. Planting container seedlings is less common, especially trees grown in very large (3- to 5-gallon) containers. Of course, the initial cost of these seedlings is much higher than bareroot seedlings. For example, a 3-gallon container oak seedling may cost \$8.00 compared to \$0.50 to \$1.00 for a bareroot seedling. Our study is too young to consider an economic analysis, which should consider the cost of the entire regeneration prescription needed to produce a successful tree, one that is free-to-grow and that will be in a codominant or dominant position in the mature forest.

We have seen that large container seedlings have significantly higher survival and diameter growth than bareroot seedlings after 3 years. It is still too early in our study to determine if a planted oak is successful or not in the context of our definition of success but if trends continue, it will take fewer large container seedlings to get a successful tree than if bareroot seedlings are planted.

The manager's objectives must be considered before identifying artificial regeneration methods for restoring forests to agricultural floodplains. Public managers often want hard mast species as a component of a native bottomland forests. Thus, planting large container seedlings on a 60 by 60 foot spacing (12 trees per acre) may be an affordable way to increase the probability that hard mast species will be a component of the overstory and capable of producing good mast crops periodically. Interplanting with bareroot seedlings or direct seeding may be used to supplement hard mast regeneration and diversify the forest. Natural regeneration of pioneer species may fill in if an adequate seed source is available and site preparation is properly done.

In managing the greater floodplain property, which may be as large as 3,000 acres or more, it may be desirable to have hard mast production somewhere on the property but not necessarily on every acre. In this case, managers may choose to plant large container seedlings on tighter spacings, e.g., 30 by 30 feet (48 trees per acre) or 20 by 20 feet (109 trees per acre) and manage them more intensively on small parcels, e.g., 1 to 5 acres or so, located throughout the floodplain.

Commonly on abandoned bottomland crop fields, young (< 10 years), dense sapling stands of cottonwood, willow and sycamore have developed. In these stands, managers may consider planting large container oak seedlings in group openings. Openings can be created by combinations of mechanical and chemical treatments. Or, large container seedlings may be underplanted in thinned cottonwood sapling stands.

The early nut-producing capacity demonstrated by large container oak seedlings is of particular interest to owners of properties managed as waterfowl hunt clubs or public green-tree reservoirs. In many cases, acorn production on these properties is limited by the low abundance of oak trees, by the advanced age of oak trees that are declining in their acorn production capacity, or because many of the mature oak trees

**Table 2—Acorn production in swamp white oak RPM® seedlings during the first 4 years at Smoky Waters and Plowboy Bend Conservation Areas**

Year	No. nut-bearing trees	Average no. acorns per tree
1	86	4.3
2	29	5.2
3	70	6.3
4	152	12.5

were lost in a catastrophic flood such as the Great Flood of 1993. Although the initial cost of large container stock is relatively high compared to bareroot seedlings, acorn production is so desirable and such a part of waterfowl management that greentree reservoir managers and duck club owners are willing to pay for restoring acorn production.

There is no single silver bullet for regenerating oaks and other hardwood species in agricultural floodplains. More often managers are designing afforestation projects using a diversity of species and by combining natural regeneration with a variety of artificial regeneration techniques including direct seeding, planting bareroot and container seedlings, and using cuttings as a means of vegetatively reproducing a species. This integrated approach to regeneration is more likely to produce a diverse forest that is more resilient to flooding and other perturbations than are less-diverse monoculture forests and plantations.

Plant succession proceeds rapidly once bottomland crop fields are abandoned. Hence, there is a narrow window of opportunity for establishing trees in high enough stocking that they dominate the growing space before other competing vegetation establishes its dominance. Using natural and artificial regeneration in a planned manner improves the chances of obtaining well-stocked forests. Planting large container stock may be one way of ensuring that the forest has a component of oak.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Allen, J.A. 1990. Establishment of bottomland oak plantations on the Yazoo National Wildlife Refuge Complex. *Southern Journal of Applied Forestry*. 14: 206-210.
- Burns, R.M.; Honkala, B.H., eds. 1990. *Silvics of North America*, vol. 2. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service. 877 p.
- Dey, D.C.; Kabrick, J.M.; Gold, M.A. 2003. Tree establishment in floodplain agroforestry practices. In: Proceedings of the eighth North American agroforestry conference. [CD-ROM]. Corvallis, OR: Association for Temperate Agroforestry: 102-115.
- Dey, D.C.; Lovelace, W.; Kabrick, J.M.; Gold, M.A. 2004. Production and early field performance of RPM<sup>®</sup> seedlings in Missouri floodplains. In: Michler, C.H.; Pijut, P.M.; Van Sambeek, J.W. [and others], eds. Proceedings of the sixth walnut council research symposium. Gen. Tech. Rep. NC-243. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 59-65.
- Dugger, S.; Dey, D.C.; Millsbaugh, J.J. 2004. Vegetation cover effects mammal herbivory on planted oaks and success of reforestation Missouri River bottomland fields. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Dept of Agriculture, Forest Service, Southern Research Station: 3-6.
- Gardiner, E.S.; Russell, D.R.; Oliver, M.; Dorris, L.C., Jr. 2002. Bottomland hardwood afforestation: state of the art. In: Holland, M.M.; Warren, J.L.; Stanturf, J.A., eds. Proceedings of a conference on sustainability of wetlands and water resources. Gen. Tech. Rep. SRS-50. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 75-86.
- Grossman, B.C.; Gold, M.A.; Dey, D.C. 2003. Restoration of hardwood species for wildlife in Missouri using precocious flowering oak in the Missouri River floodplain, USA. *Agroforestry Systems*. 59: 3-10.
- Johnson, P.S.; Shifley, S.R.; Rogers, R. 2002. *The ecology and silviculture of oaks*. Wallingford, Oxon, UK: CABI Publishing CAB International. 503 p.
- Kabrick, J.M.; Dey, D.C.; Van Sambeek, J.W. [and others]. 2005. Soil properties and growth of swamp white oak and pin oak on bedded soils in the lower Missouri River floodplain. *Forest Ecology and Management*. 204: 315-327.
- Kormanik, P.P.; Sung, S.S.; Kass, D.J.; Schlarbaum, S. 1998. Effect of seedling size and first-order-lateral roots on early development of northern red oak on mesic sites. In: Waldrop, T.A., ed. Proceedings of the ninth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 247-252.
- Oliver, C.D.; Larson, B.C. 1996. *Forest stand dynamics*. New York, NY: John Wiley & Sons, Inc. 520 p.
- Schultz, R.C.; Thompson, J.R. 1997. Effect of density control and undercutting on root morphology of 1-0 bareroot hardwood seedlings: five-year field performance of root-graded stock in the central USA. *New Forests*. 13: 301-314.
- Schweitzer, C.J.; Stanturf, J.A. 1997. From okra to oak: reforestation of abandoned agricultural fields in the Lower Mississippi Alluvial Valley. In: Meyer, D.A., ed. Proceedings of the 25<sup>th</sup> annual hardwood symposium. Memphis, TN: National Hardwood Lumber Association: 131-138.
- Shear, T.H.; Lent, T.J.; Fraver, S. 1996. Comparison of restored and mature bottomland hardwood forests of southwestern Kentucky. *Restoration Ecology*. 4(2): 111-123.
- Stanturf, J.A.; Schweitzer, C.J.; Gardiner, E.S. 1998. Afforestation of marginal agricultural land in the Lower Mississippi River Alluvial Valley, U.S.A. *Silva Fennica*. 32(3): 281-287.
- Twedt, D.J.; Wilson, R.R. 2002. Supplemental planting of early successional tree species during bottomland hardwood afforestation. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 358-364.

# COMPARING NATURAL AND ARTIFICIAL METHODS FOR ESTABLISHING PIN OAK ADVANCE REPRODUCTION IN BOTTOMLAND FORESTS MANAGED AS GREENTREE RESERVOIRS

Nicholas Krekeler, John M. Kabrick, Daniel C. Dey, and Michael Wallendorf<sup>1</sup>

**Abstract**—In greentree reservoirs within the Mingo Basin in southeastern Missouri, we compared the survival and growth of underplanted pin oak (*Quercus palustris* Muenchh.) acorns, bareroot seedlings, and RPM<sup>®</sup> container seedlings in plots that were thinned with and without ground flora control. After one growing season, we found that RPM<sup>®</sup> container seedlings had the greatest survival (87 percent without ground flora control and 77 percent with) followed by bareroot seedlings (86 percent without ground flora control and 66 percent with). Survival of planted stock was similar to natural reproduction (85 percent in thinned-only plots, 60 percent where thinned with ground flora control and in untreated plots). Direct-seeded seedlings had the poorest survival (9 percent without ground flora control and 4 percent with). Diameter growth of planted stock was significantly less than that of direct-seeded or natural stock; height growth of bareroot stock was less than that of all others.

## INTRODUCTION

Oak regeneration has remained an important forest management issue for decades and has proven to be particularly problematic on mesic sites (Johnson and others 2002, Loftis and McGee 1993, Lorimer 1993). On mesic sites, adequate advance reproduction is critical for regenerating oaks (Johnson and others 2002, Lockhart and others 2000). However, oak advance reproduction generally does not accumulate readily in mesic sites (Hodges and Gardiner 1993, Johnson and others 2002), and oak seedlings are less competitive than mesophytic species following release by harvesting (Hodges and Gardiner 1993, Johnson and others 2002, Loftis 1983).

Regenerating oaks in hydric to wet-mesic bottomland hardwood forests presents many of the same challenges as on mesic upland sites (Clatterbuck and Meadows 1993, Janzen and Hodges 1987). Bottomlands commonly have a high capacity to supply both nutrients and water, which generally favors species having exploitive establishment strategies and rapid growth rates (Hicks 1998). Much like on mesic upland sites, oak advance reproduction is critical for regenerating bottomland stands (Clatterbuck and Meadows 1993) but often is inadequate in size and number largely because of competition by mesophytic species. Oak regeneration in bottomlands is further complicated by poorly drained soils and flooding, which favor species that are more tolerant of wet conditions than are most bottomland oaks.

The continued interest in regenerating bottomland oaks and the recognition of the importance of advance reproduction has led to many studies evaluating methods for establishing oak advance reproduction in bottomland forests (Gardiner and Hodges 1998; Janzen and Hodges 1985, 1987, Lockhart and others 2000). Most studies have focused on midstory and understory thinning with and without herbicides to control competition and to increase light levels reaching the forest floor in an effort to increase the density and size of advance reproduction (Janzen and Hodges 1985, 1987; Lockhart and others 2000). These studies have shown that increasing the sunlight reaching the forest floor increases the size and

density of natural oak advance reproduction (Janzen and Hodges 1985, 1987) as well as underplanted stock (Lockhart and others 2000) for many of the southern bottomland oaks.

Oak regeneration has remained an important problem in greentree reservoirs within the Mingo Basin in southeastern Missouri. Pin oak (*Quercus palustris* Muenchh.) is the most abundant overstory species in these forests and is valued for its mast production for waterfowl and other wildlife. However, efforts to regenerate pin oaks in the Mingo Basin have failed, largely because advance reproduction is absent or inadequate. It is unclear whether this inadequate advance reproduction has resulted from the lack of light reaching the forest floor, the fall and winter flooding associated with water management in greentree reservoirs, or a combination of both. During the past few years, greentree reservoir managers in Missouri have modified water management regimes to more closely resemble the natural hydrologic cycle and also have improved drainage in greentree reservoirs to keep them drier during the growing season. Studies are needed to determine how to modify the amount of sunlight reaching the forest floor to create or enhance pin oak advance reproduction in greentree reservoirs under the improved water management regimes. Moreover, unlike other commercially important bottomland oaks, relatively little is known about how to establish pin oak advance reproduction (Smith 1993).

Our objective was to compare natural and artificial methods for establishing advance reproduction of pin oak in greentree reservoirs in the Mingo Basin. We compared the survival and growth of natural pin oak reproduction in plots where the mid-story was thinned and the ground flora was or was not controlled, and in untreated (control) plots. We also compared the survival and growth of underplanted pin oak acorns, bare-root seedlings, and large container seedlings produced with the root production method (RPM<sup>®</sup>) (Dey and others 2004) in plots having these same thinning and ground flora treatments. Our goal was to determine if pin oak advance reproduction could be established within bottomland forests managed as greentree reservoirs.

<sup>1</sup> Graduate Research Assistant, University of Missouri, Forestry Department, 203 Natural Resources Building, Columbia, MO 65211; Research Foresters, USDA Forest Service, North Central Research Station, University of Missouri, 202 Natural Resources Building, Columbia, MO 65211; and Biometrician, Missouri Department of Conservation, Columbia, MO 65201, respectively.

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## METHODS

### Study Sites

This study was conducted within two greentree reservoir management pools, one in Mingo National Wildlife Refuge managed by the U.S. Fish and Wildlife Service and the other in Duck Creek Conservation Area managed by the Missouri Department of Conservation. Both study areas are located within the Mingo Basin in Stoddard County north of Puxico, MO. The Mingo Basin is the largest remaining tract of bottomland hardwood forest in the Upper Mississippi Alluvial Valley (Missouri Department of Conservation 1999).

The pools within these areas have been managed for waterfowl habitat and hunting for more than 50 years and are flooded nearly annually for short periods during the fall waterfowl migration and hunting season, approximately November and December. Before 1999, the pools were flooded to depths of 6 to 20 inches prior to the waterfowl hunting season and drained after the season ended. Since then, managers have varied the timing and duration of flooding to match the season's weather conditions by flooding some of the pools later for shorter durations during dry years and earlier and longer during wet years. The flood scheduling is varied by pool so that adjacent pools have slightly different regimes. This scheduling, on average, floods individual pools to shorter than average durations once every 3 years and longer than average durations once every 3 years (Missouri Department of Conservation 1999).

The two pools were selected so that we could evaluate methods for establishing advance reproduction in both healthy and declining stands. Pool eight (Mingo National Wildlife Refuge) was selected because the oaks appeared to be healthy, and there was very little observable crown dieback or mortality. Pool three (Duck Creek Conservation Area) was selected because the oaks exhibited moderate or advanced decline and had compromised mast production.

In these two pools, pin oak was the dominant species (54 percent of the basal area). Other important species included sweetgum (*Liquidambar styraciflua* L., 12 percent), overcup oak (*Q. lyrata* Walt., 10 percent), red maple (*Acer rubrum* L., 7 percent), American elm (*Ulmus americana* L., 6 percent), willow oak (*Q. phellos* L., 5 percent), green ash (*Fraxinus pennsylvanica* Marsh., 2 percent), persimmon (*Diospyros virginiana* L., 1 percent), and cherrybark oak (*Q. pagoda* Raf., 1 percent).

### Design

We used a randomized complete block design with a total of six blocks, each containing nine treatment units. During the summer of 2002 in each of the two management pools, we established 3 10-acre blocks containing 9 1.1-acre treatment units that were 220 by 220 feet wide. Blocks were positioned and configured so that they were internally homogeneous in stand conditions. In the center of each of the nine experimental units, we established a circular, 0.2-acre plot and recorded the species and diameter of all trees  $\geq 1.5$  inches d.b.h. Within 0.2-acre plots, trees  $< 1.5$  inch d.b.h. were inventoried in five 0.01-acre subplots.

### Treatments

In each of the experimental units within each block, we randomly assigned one of nine treatments (table 1). The nine treatments included thinning in combination with each of four

**Table 1—The nine treatment combinations compared in the study<sup>a</sup>**

Stock	Control	Midstory and understory thinning	
		With ground flora control	Without ground flora control
Natural	X	X	X
Direct seed		X	X
1-0 bareroot		X	X
RPM <sup>®</sup> container		X	X

<sup>a</sup> Midstory and understory thinning treatments were applied to all non-oaks as small as 0.5 inches d.b.h. Ground flora control was a foliar application of herbicide to all woody and herbaceous vegetation surrounding each tagged pin oak seedling. The control treatment was not thinned and only natural pin oak reproduction was monitored. Stock types (all pin oak) included natural seedlings  $\leq 1$ -year old, seedlings from direct-seeded acorns, 1-0 bareroot seedlings, and one-year-old RPM<sup>®</sup> container (3 gallon) seedlings.

stock types (natural, direct seed, bareroot, RPM<sup>®</sup> container) and two ground flora control treatments (herbicide versus none), and one control (not thinned). The thinning treatment was intended to increase the amount of photosynthetically active radiation (PAR) to the oak seedlings. The different artificial stock types represented those most commonly available to forest managers in the region to provide reasonable comparisons to the alternative of relying on natural reproduction. The ground flora control treatment was to remove competing vegetation including undesirable tree species and woody vines released by the thinning treatment.

The thinning treatment was conducted during February 2003, to remove all non-oaks in the midstory and understory as small as 0.5 inches d.b.h. This was done by spraying 0.03 ounces of Arsenal<sup>®</sup> AC solution (20 percent concentration) into hacks made in the tree bole with a hatchet having a 1.25-inch bit. We made a single hack (plus herbicide application) per 3 inches d.b.h. approximately 4.5 feet above the ground. Except for the control, the thinning treatment was applied across the entire 1.1-acre experimental unit. We revisited all treated trees after the first growing season and re-treated those that had not died.

In April 2003, we sowed pin oak acorns within 0.2-acre plots in all experimental units designated for direct seeding. Acorns were purchased from the Missouri State Nursery in Licking, MO. These had been collected during the preceding autumn and screened for soundness, stratified, and stored according to standard nursery practices. In each 0.2-acre plot, 40 acorns were planted by hand 3 inches deep approximately 15 feet apart in concentric circles around the plot center. All planting locations were marked with a numbered wire tag.

Also in April 2003, we planted 22 bareroot pin oaks and 22 RPM<sup>®</sup> pin oak container seedlings, each in their respective designated treatment units. These were planted approximately 20 feet apart in concentric circles around the plot center within each 0.2-acre plot and marked with a numbered metal tag. In treatment units designated for natural reproduction, we marked up to 22 natural pin oak seedlings with numbered tags within 0.2-acre plots. We selected only those individuals that appeared to be 1-year-old as evidenced by the presence of the acorn attached to the base of the stem. The initial basal diameter and height of all stock other than the direct-seeded acorns was recorded immediately after tagging.

In June 2003, the ground flora control was applied to those units designated for this treatment. For the ground flora control, we applied Garlon® 3A solution (6 ounces of chemical per gallon of water) with a Solo® backpack sprayer to the foliage of all herbaceous vegetation and non-oak woody vegetation within the 0.2-acre plot. Oak seedlings were shielded during the herbicide application to minimize their injury caused by drift.

### Measurements

In July, the canopy cover above each seedling was measured using a spherical crown densiometer. At this time, we re-measured the heights of all tagged seedlings. All plots were revisited again in late September so that first-year survival of tagged seedlings could be determined, and the basal diameter and height of each seedling could be re-measured.

Hydrology can influence seedling survival and growth, and because we could not be assured that hydrologic conditions would be uniform among treatment units within blocks, we monitored the soil water content. To do this, we buried Watermark sensors (Irrrometer Company, Inc., Riverside, CA) 4 inches below the soil surface in the center of each treatment unit. Meter readings were taken weekly during the first growing season from June 18 to September 17, 2003. We conducted a laboratory calibration study with soils from each block to determine the relationship between the meter reading and gravimetric water content. This calibration study allowed us to develop equations for converting meter readings made in the field to estimated gravimetric soil water content.

### Analysis

We used the general linear models procedure (SAS version 9.1) to evaluate the overall treatment effects ( $\alpha = 0.05$ ) on the basal diameter and height growth of each of the stock types. We included the gravimetric soil water content and percent canopy cover (averaged by plot) as covariates in this analysis. We also used orthogonal contrasts ( $\alpha = 0.05$ ) to compare growth of each of the artificial stock types to that of the natural stock.

### RESULTS

During the application of the midstory and understory thinning treatment, we treated 328 trees per acre (27 square feet per acre). Most of the treated trees were sweetgums, red maples, green ashes, and American elms, all of which were the most prevalent in midstories of these forests. This treatment effectively reduced the canopy cover from 91 to 83 percent (table 2). We found no canopy cover differences between declining (pool 3) and healthy (pool 8) plots.

In thinned plots without ground flora control, the first-year survival of the bareroot, RPM®, and natural stock exceeded 80 percent and was more than 20 percent greater than the survival of natural stock in non-thinned (control) plots (fig. 1). The survival of direct-seeded stock was less than 9 percent but largely because the acorns failed to germinate rather than because they died during the first growing season. We found that the ground flora control treatment decreased the survival of all stock by 5 to 20 percent.

The diameters and heights of the different stocks varied considerably from each other (fig. 2). When planted, the RPM® stock was about 3 feet tall and nearly 0.5 inches in basal diameter, about 30 percent larger than the bareroot stock and

**Table 2—Percent canopy cover thinned and unthinned (control) plots measured 6 months after treatment<sup>a</sup>**

Management pool	Canopy cover	
	Control	Thinned
	----- % -----	
Pool 3 (declining)	91	86
Pool 8 (healthy)	90	81
Overall	91	83

<sup>a</sup> Thinning treatment included deadening the mid-story and understory (approximately 328 stems per acre). Pool three (Duck Creek Conservation Area) was selected because the oaks exhibited moderate or advanced decline and had compromised mast production. Pool eight (Mingo National Wildlife Refuge) was selected because the oaks appeared to be healthy and there was very little observable crown dieback or mortality.

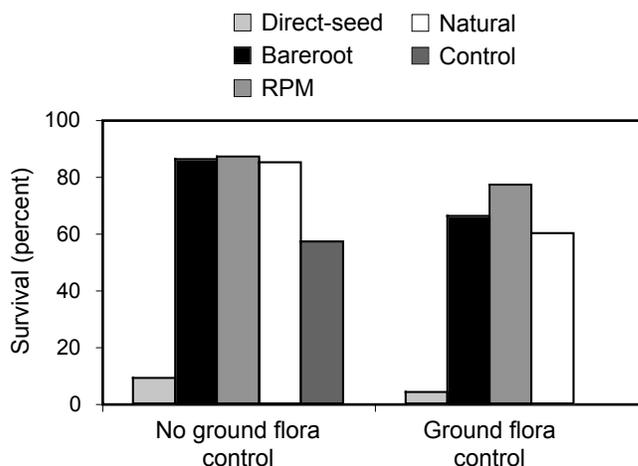


Figure 1—First-year pin oak seedling survival by treatment and the four stock types: natural seedlings, seedlings from direct-seeded acorns, bareroot seedlings, and RPM® container seedlings.

more than 5 times larger than the natural seedlings. Of greater interest to our study was the growth increment that occurred during the first growing season. The natural seedlings and direct-seeded stock had significantly greater ( $P < 0.01$ ) diameter growth than did the RPM® and bareroot stock. The bareroot stock produced significantly less ( $P < 0.01$ ) height growth than did the other stock types. We also found that controlling ground flora competition with Garlon® 3A did not significantly improve seedling diameter or height growth ( $P > 0.42$ ). Surprisingly, we also observed that the natural stock in the controls had positive diameter and height growth, comparable to natural stock in the thinned plots.

Neither canopy cover nor gravimetric soil water content were significant covariates in our analyses. This does not mean that these are not important determinants of seedling survival and growth. Rather, the lack of significance shows that we successfully designed the experiment so that it was not confounded by gross differences in canopy cover or gravimetric soil water content.

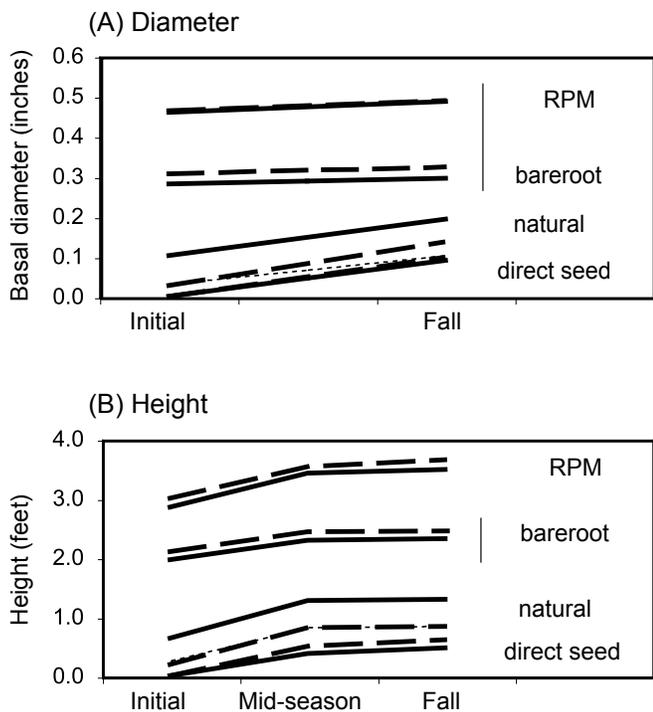


Figure 2—Diameter (A) and height (B) of pin oak seedlings measured during and after the first growing season for the four stock types: natural seedlings, seedlings from direct-seeded acorns, bareroot seedlings, and RPM® container seedlings. Dashed lines indicate data from plots where competing ground flora were controlled with a foliar application of Garlon® 3A; solid lines indicate data from plots where competing ground flora were not controlled. Vertical bars identify a growth increment that was significantly different ( $\alpha = 0.05$ ) from that of the natural stock.

## DISCUSSION

The thinning treatment reduced the stand density to similar levels reported by others who applied similar methods to bottomland forests in other regions. Janzen and Hodges (1985) reported that midstory and understory thinning removed about 25 square feet per acre in a bottomland forest located in north-central Mississippi. In our study, most of the stems that we treated (70 percent) were < 4 inches d.b.h. However, we cannot compare the number of stems that we treated to those of Janzen and Hodges (1985), because they only reported data for stems greater > 4 inches d.b.h.

Ultimately, the purpose of the midstory and understory thinning was to increase the PAR reaching the forest floor to benefit the oak seedlings while not releasing competing vegetation. Although we did not measure PAR in our study, we do note that Lockhart and others (2000) reported that midstory thinning in bottomland forests in north-central Mississippi increased PAR by > 4 to 10 times. Moreover, Gardiner and Hodges (1998) demonstrated that cherrybark oak seedlings had greater stem growth and produced more biomass under partial shade than under full sunlight. This was an important finding, because it demonstrated the benefits of partial sunlight to seedlings of species considered to be shade intolerant, as are many other bottomland oaks, including pin oak.

All stock grew well, and first-year growth was comparable to other bottomland oak seedlings in forests (Janzen and Hodges 1987, Lockhart and others 2000) or planted in former crop

fields (Kabrick and others 2005, Shaw and others 2003). Even the growth of the natural stock in the non-thinned (control) plots was not significantly less than in the thinned stands, although survival was considerably lower. It probably is too soon to know whether or not the midstory and understory thinning has benefited the seedlings. Most of the underplanting studies in bottomland forests suggest that it may take 3 to 5 years or more before large growth differences caused by midstory and understory thinning are observed (Janzen and Hodges 1987, Lockhart and others 2000).

We cannot explain why the direct-seeded acorns had such low germination rates, and undoubtedly many factors contributed to our poor success. The acorns that we sowed were provided by the Missouri state forest nursery and were collected and screened in the same manner as are all red oak group acorns routinely handled by this facility. We planted the acorns within 24 hours of receiving them from the nursery the following spring, so we assume that the acorns did not become too dry during our handling. However, most direct seeding is done during the fall and consequently, red oak group acorns are not routinely stored and stratified at the nursery for spring planting as were our acorns. We purposely seeded in the spring because we were concerned that acorns sowed in the fall would not only be subjected to extensive flooding but also to predation during waterfowl season. Despite our efforts to ensure higher germination and survival by seeding in the spring, we may have reduced our success by storing the seed. Although our germination rates do not represent the best that can be expected from direct seeding, they probably do represent what can happen following an operational spring seeding.

First-year control of ground flora competition with Garlon® 3A is probably unnecessary, because it decreased the survival and failed to increase the growth of the pin oak seedlings. Oaks, like many other woody species, are susceptible to Garlon® 3A. Despite our efforts to shield the oaks during the foliar application to surrounding competing vegetation, we apparently had sufficient drift or flashback to substantially reduce oak seedling survival. Moreover, the herbaceous and woody competition apparently was not sufficiently severe to reduce seedling growth. Similarly, Gardiner and Yeiser (1999) found that controlling Japanese honeysuckle (*Lonicera japonica* Thunb.) with herbicide in thinned bottomland stands did not increase the first-year survival or growth of underplanted cherrybark oak.

Future measurements include examining the net photosynthesis of the pin oak seedlings to determine if net photosynthetic production is positive under partial canopy cover created by the midstory and understory thinning. We will also continue to monitor seedling survival and growth for the next 3 to 5 years to determine the probability of producing advance pin oak reproduction of a specified caliper and height.

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## LITERATURE CITED

- Clatterbuck, W.K.; Meadows, J.S. 1993. Regenerating oaks in the bottomlands. In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: serious problems, practical solutions. Symposium proceedings. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 184-195.
- Dey, D.C.; Lovelace, W.; Kabrick, J.M.; Gold, M.A. 2004. Production and early field performance of RPM® seedlings in Missouri Floodplains. In: Michler, C.H.; Pijut, P.M.; Van Sambeek, J.W. [and others], eds. Black walnut in a new century. Proceedings of the sixth Walnut Council research symposium. Gen. Tech. Rep. NC-243. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 59-65.
- Gardiner, E.S.; Hodges, J.D. 1998. Growth and biomass distribution of cherrybark oak (*Quercus pagoda* Raf.) seedlings as influenced by light availability. *Forest Ecology and Management*. 108: 127-134.
- Gardiner, E.S.; Yeiser, J.L. 1999. Establishment and growth of cherrybark oak seedlings underplanted beneath a partial overstory in a minor bottom of southwestern Arkansas: first year results. In: Haywood, J.D., ed. Proceedings of the 10<sup>th</sup> biennial southern silviculture research conference. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 171-175.
- Hicks, R.R. 1998. Ecology and management of Central Hardwood forests. New York: John Wiley and Sons. 412 p.
- Hodges, J.D.; Gardiner, E.S. 1993. Ecology and physiology of oak regeneration. In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: serious problems, practical solutions. Symposium proceedings. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 54-65.
- Janzen, G.C.; Hodges, J.D. 1985. Influence of midstory and understory vegetation removal on the establishment and development of oak regeneration. In: Shoulders, E., ed. Proceedings of the third biennial southern silvicultural research conference. Gen. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 273-278.
- Janzen, G.C.; Hodges, J.D. 1987. Development of oak advanced regeneration as influenced by removal of midstory and understory vegetation. In: Phillips, D.R., comp. Proceedings of the fourth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 455-461.
- Johnson, P.S.; Shifley, S.R.; Rogers, R. 2002. The ecology and silviculture of oaks. Wallingford, Oxon, UK: CABI Publishing, CAB International. 503 p.
- Kabrick, J.M.; Dey, D.C.; Van Sambeek, J.W. [and others]. 2005. Soil properties and growth of swamp white oak and pin oak on bedded soils in the lower Missouri River Floodplain. *Forest Ecology and Management*. 204: 315-327.
- Lockhart, B.R.; Hodges, J.D.; Gardiner, E.S. 2000. Response of cherrybark oak reproduction to midstory removal and shoot clipping. *Southern Journal of Applied Forestry*. 42: 45-50.
- Loftis, D.L. 1983. Regenerating southern Appalachian mixed hardwoods with the shelterwood method. *Southern Journal of Applied Forestry*. 7: 212-217.
- Loftis, D.L.; McGee, C.E., eds. 1993. Oak regeneration: serious problems, practical recommendations. Symposium proceedings. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 319 p.
- Lorimer, C.G. 1993. Causes of the oak regeneration problem. In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: serious problems, practical solutions. Symposium proceedings. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 14-39.
- Missouri Department of Conservation. 1999. Duck Creek conservation area management plan. Internal publication. Jefferson City, MO: Missouri Department of Conservation. 29 p.
- Shaw, G.W.; Dey, D.C.; Kabrick, J.M. [and others]. 2003. Comparison of site preparation methods and stock types for artificial regeneration of oaks in bottomlands. In: Van Sambeek, J.W.; [and others], eds. Proceedings of the 13<sup>th</sup> Central Hardwood Forest Conference. Gen. Tech. Rep. NC-234. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 186-198.
- Smith, D.W. 1993. Oak regeneration: the scope of the problem. In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: serious problems, practical solutions. Symposium proceedings. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 40-53.

# CLONAL TESTS OF NEW COTTONWOOD SELECTIONS FROM THE SOUTHEAST

Jonathan Paul Jeffreys, Samuel B. Land, Jr., Emily B. Schultz, and Andrew J. Londo<sup>1</sup>

**Abstract**—One hundred “new” clones and 20 “check” clones were established with unrooted cuttings during March–April 2003 in a second-stage clonal trial in Missouri and Georgia. The new clones had been selected for 2-year superiority in *Melampsora* leaf rust resistance, height growth, and diameter growth during first-stage rooted cutting trials. All 120 clones were vegetatively multiplied in a cutting production nursery at Stoneville, MS, and cuttings from this nursery were used for the two second-stage trials. Results from second-year measurements of *Melampsora* leaf rust infection, height, and d.b.h. indicate that geographic patterns of genetic variation were apparent at both sites. Location effects were present for all traits except d.b.h. for the 120 clones tested, and additional gains from selection among clones within origins can be attained for these traits.

## INTRODUCTION

Eastern cottonwood (*Populus deltoides* Bartr. ex Marsh. var. *deltoides*) is the fastest growing native commercial forest species in North America (Cooper and van Haverbeke 1990). This rapid growth has led to the establishment of poplar plantations worldwide. Success of these plantations begins with the selection of the correct seed sources and/or clones. However decisions on which seed source or clone to use should not be made until thorough testing has been conducted (Zobel and Talbert 1984). Planting trees from the wrong seed source or clone can be financially costly and time-consuming due to delayed mortality or poor growth.

Genetic improvement of eastern cottonwood has been undertaken in several regions of the United States (Mohn 1973, Nelson and Tauer 1987, Wilcox and Farmer 1967, Ying and Bagley 1976). The U.S. Department of Energy has funded research on the development of high-yielding, short-rotation woody crops of *Populus* for energy and fiber production (Wright and Tuskan 1997). However, relatively few improved clones have been released for use in the Southeastern United States. The purpose of the present study is to select superior performing clones based on performance at a fiber-farm location in southeast Missouri and at a location in east Georgia.

## MATERIALS AND METHODS

Land and others (2001) divided the southeast region east of the Mississippi River into three subregions: Southeast Atlantic (SA), East Gulf (EG), and East Central (EC) (fig. 1). These were used in sampling the region's wild population of eastern cottonwood. Open-pollinated seeds were collected from mother trees in natural stands on various rivers within each subregion. The seeds were germinated and vegetatively multiplied as containerized rooted cuttings for four first-stage field trials (Warwell and others 1999). These field sites were located in Florida (30° 32.5' N, 84° 35' W), Alabama (32° 02' N, 88° 07' W), North Carolina (35° 58' N, 77° 09' W), and Missouri (32° 02' N, 89° 46' E). One hundred clones were selected for *Melampsora* leaf rust resistance and height and diameter growth based on second-year performance. An

additional 20 “check” clones from former trials of the USDA Forest Service and Oklahoma State University were chosen to include with these 100 “new” clones in second-stage field trials.

The 120 clones were vegetatively multiplied during 2002, in a cutting production nursery at Mississippi State University's (MSU) Delta Research and Extension Center in Stoneville, MS. On February 10 and 11, 2003, cuttings were collected from the 120 clones. These 12-inch unrooted hardwood cuttings were planted in second-stage clonal trials in Scott County, MO (MO), and Richmond County, GA (GA).

The MO location was planted on April 8, 2003, while the GA location was planted on March 12–13, 2003. The clones were planted in a randomized complete block design. Each location was divided into four replications and planted with two trees per clone per replication. Two cuttings of each clone were planted at each position to help insure survival. Border rows were planted at the same time around the studies at each location.

Measurements of *Melampsora* leaf rust infection were taken in both September (Y2rust1) and October (Y2rust2) of 2004. Severity of rust infection was scored according to the amount of urediospores (orange powder) visible on the leaf and the amount of leaf curl present. Scores ranged from 1 to 4, with 1 representing a clone with no visible infection and 4 representing a tree that was heavily infected and almost completely defoliated. Therefore clones with lower mean rust scores are preferred. Also, measurements were taken in October 2004 for height (Y2ht) and d.b.h. (Y2dbh). Clones that had not reached a height of 4.5 feet were assigned a d.b.h. of 0.1 inch. A performance level was calculated for each trait of each clone by subtracting the clone mean for the trait from the location mean of that trait and dividing by the standard deviation. Performance levels for d.b.h., height, and *Melampsora* leaf rust were combined to obtain the overall performance level for a clone. The overall clone performance levels were used to identify the best-performing clones for each location.

Analyses of variance for a random model were conducted for the randomized complete block design at each location. The

<sup>1</sup> Graduate Student and Professors, respectively, Mississippi State University, Department of Forestry, Mississippi State, MS 39762.

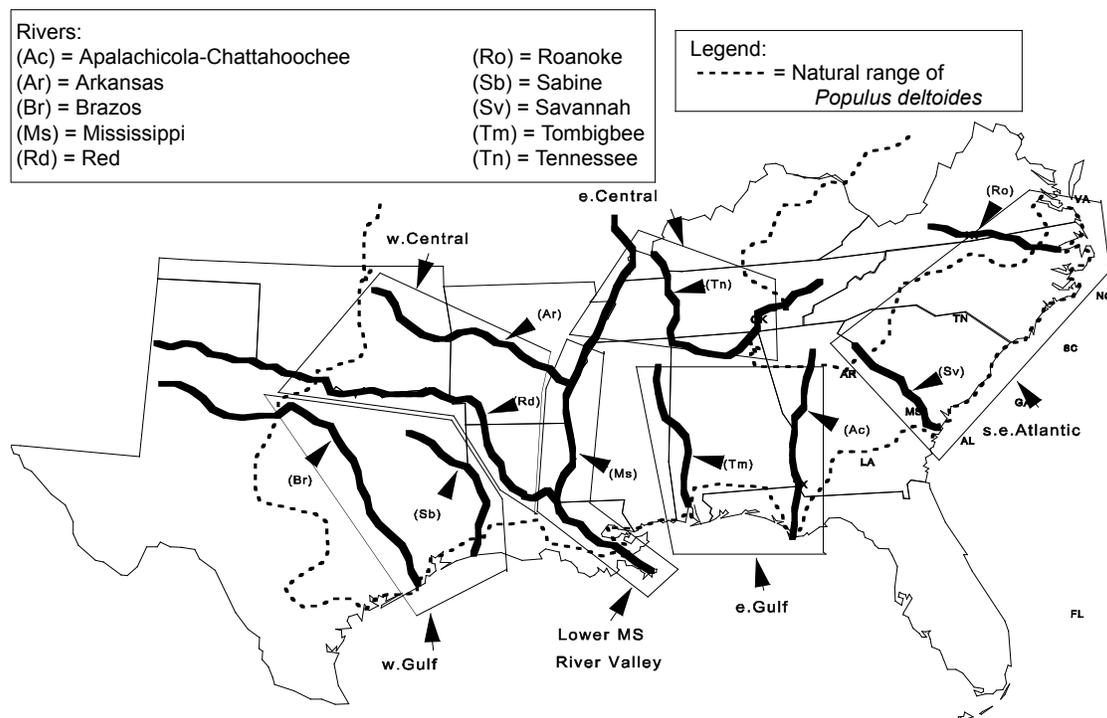


Figure 1—Map of subregions and some river systems from which open pollinated seed and cuttings were collected in 1995-1998. One-hundred “new” clones in this study came from the three eastern subregions: E. Gulf, E. Central, and S.E. Atlantic.

Tukey-Kramer test of ranked means was used to test differences among locations and among selection types (checks and new clones) for each trait.

## RESULTS AND DISCUSSION

### Location Effects

Locations differed significantly for all traits except d.b.h. in the analyses of variance, but even d.b.h. was significantly different if locations were considered fixed effects in the

Tukey-Kramer test (tables 1 and 2). Clones were taller, had slightly larger d.b.h., and had less leaf rust at the GA location. The larger amount of rust at the MO location could be due to adjacent cottonwood plantings that are present on the fiber farm. The MO location also had drip irrigation. This increase in moisture and humidity may provide a better environment for rust infection. A large incidence of *Melampsora* allows better detection of differences among clones in resistance, so the MO location was particularly helpful for this purpose.

Table 1—Analysis of variance<sup>a</sup> for test locations, replications within each location, clones, within clone groups, and locations by clone groups for *Melampsora* leaf rust infections, d.b.h. growth and height growth

Source of variation	DF	Measurement traits							
		Y2Rust1		Y2Rust2		Y2dbh		Y2Ht	
		MS	F-test <sup>b,c</sup>	MS	F-test <sup>b,c</sup>	MS	F-test <sup>b,c</sup>	MS	F-test <sup>b,c</sup>
Locations (L)	1	70.4	49.0**	106	31.9**	45.8	2.39 <sup>ns</sup>	8710	11.9*
Reps in locations	6	0.68	5.86**	2.17	13.8**	18.1	24.4**	718	91.1**
Clones	119	1.18	1.55*	2.34	1.99**	2.07	2.11**	47.3	4.09**
-new vs. check	1	3.42	29.7**	12.6	78.7**	0.09	0.12 <sup>ns</sup>	97.5	12.4**
-w/in new	99	1.03	9.00**	1.91	11.9**	1.98	2.68**	42.8	5.43**
-w/in checks	19	1.90	16.5**	4.07	25.4**	2.62	3.54**	68.2	8.64**
L x clones	119	0.76	6.61**	1.17	7.47**	0.98	1.32**	11.6	1.47**
-L x (new vs. checks)	1	7.45	64.8**	14.4	89.9**	1.35	1.82 <sup>ns</sup>	3.71	0.47 <sup>ns</sup>
-L x w/in new	99	0.67	5.80**	1.09	6.81**	1.08	1.46**	11.2	1.41**
-L x w/in checks	19	0.83	7.20**	0.85	5.31**	0.39	0.53 <sup>ns</sup>	14.3	1.81*
Error	1428	0.115		0.157		0.743		7.894	

<sup>a</sup> Model is completely random

<sup>b</sup> ns = non-significant at the 0.05 level

<sup>c</sup> \* = significant at the 0.05 level; \*\* = significant at the 0.01 level

**Table 2—Location means and results<sup>a</sup> of Tukey-Kramer test of ranked means for d.b.h. growth, height growth, September rust score, and October rust score for 100 “new” clones, 20 “check” clones, and location means for all 120 “new and check” clones combined**

Trait	Type of clones	Test location		Clone type over both locs.
		GA	MO	
D.b.h. (in.)	Checks	2.38b	1.92a	2.16S
	New	2.28b	1.99a	2.14S
	Loc. means	2.30B	1.98A	2.15
Height (ft.)	Checks	20.4e	15.9d	18.2U
	New	19.8e	15.1c	17.6T
	Loc. means	19.9D	15.3C	17.7
Rust (Sept.)	Checks	1.80f	2.51h	2.14W
	New	1.88f	2.23g	2.05V
	Loc. means	1.87E	2.28F	2.06
Rust (Oct.)	Checks	2.21i	3.12k	2.64Y
	New	2.23i	2.67j	2.44X
	Loc. means	2.23G	2.75H	2.47

<sup>a</sup> Means followed by the same letter and case for each trait are not significantly different (5% probability level)

### Checks vs. New Clones and Interactions with Locations

Selection types (checks vs. new clones) were not significantly different for d.b.h., but height was greater and rust infection was greater for the checks than new clones in the combined analyses over both locations (tables 1 and 2). Also, there were significant location-by-selection type interactions. The check clones had greater performance levels than the new select clones at the GA location, probably because of the greater d.b.h. and height growth by the checks (table 2). However, at the MO location, the new select clones had better performance levels than the check clones. This discrepancy was probably due to greater rust resistance by the new clones than the check clones at the MO location.

### Variation Among Check Clones

Significant variation existed within the check clones for all traits over both locations and for each individual location (table 1). The best five check clones for each location are listed in table 3 with the subregion, area (upland or bottom-

land), river, state of origin, and performance score. There were three check clones (ST111733, ST111234, and S7C8) that were represented in the top five checks at both locations. The top two “check” clones (ST111733 and S7C8) were the same rank at both locations. The geographic sources are different for these top “check” clones. ST111733 is from the Mississippi River in Mississippi, while S7C8 is from the Brazos River in the West Gulf subregion of Texas. The lack of change in rank indicates that clone-by-location effects may not be important for the best performers.

When the performance levels for the individual traits were compared, ST111733 performed better at the GA location due to high rust resistance and superior height growth. For the MO location, ST111733 was the top performer due to superior height growth, (which was higher than the height growth score for the GA location). However, performance of this clone for d.b.h. growth and rust resistance was only average. The second best performing “check” clone for each location was S7C8. This clone was second at the GA location

**Table 3—Performance levels and origins for the five best performing “check” clones at each location**

Location	Clone ID	Subr.	Area	River	State	Performance
GA	ST111733	LM	B	Mississippi	MS	4.1
	S7C8	WG	B	Brazos	TX	3.0
	ST111234	LM	B	Mississippi	MS	2.9
	ST904401	LM	B	Mississippi	MS	1.8
	ST111412	LM	B	Mississippi	MS	1.4
MO	ST111733	LM	B	Mississippi	MS	2.7
	S7C8	WG	B	Brazos	TX	2.4
	ST-148	LM	B	Mississippi	MS	2.2
	S7C1	WG	B	Brazos	TX	1.9
	ST111234	LM	B	Mississippi	MS	0.5

due to superior d.b.h. growth. Its height growth performance was somewhat above average, but it had only average rust resistance. For the MO location, S7C8 was second due to superior height growth, (which was better than the GA location) and average d.b.h. growth. S7C8 had a poor rust resistance score (0.02) at the MO location, but the height performance score is what pushed it ahead of the other “check” clones.

### Variation Among New Clones

Significant variation existed among the “new” 100 select clones for all traits in the combined analyses over locations (table 1). However, there were also significant locations-by-clones-within-new-selections interactions. The top 10 clones for each location are listed in table 4 along with the subregion, area, river, state of origin, and performance scores. There were 3 clones (MS072C-7, MS093-1, and MS094-1) that were in the top 10 at both sites. These three clones were from the Tombigbee River system in Alabama and the Apalachicola River in Florida, and they were all from bottomland areas.

The best 3 clones for the GA location were not in the top 10 clones at the MO location, and vice versa. This indicates that some clones show greater genetic x environment interaction than others. This also indicates that the interaction between locations and new clones may be more important than that for checks.

The best “new” clone for the GA location was MS093-6, which is from a bottomland area in the Tombigbee River system in Alabama (East Gulf subregion). This clone was superior because of a high d.b.h. growth performance level. None of the remaining clones in the top 10 at this location were within 1.5 standard deviations of MS093-6’s d.b.h.

performance level. The 3 clones that were in the top 10 at both locations were ranked differently at each location. At the GA location, MS094-1 was ranked highest of the three. This ranking was due to the clone’s rust resistance. MS093-1 was second of the three due to slightly above average scores for all three traits. MS072C-7 was third at this location due to slightly above average rust resistance and d.b.h. growth. However, this clone had a below-average performance level for height growth.

The best “new” clone for the MO location was MS095A-6, which is from a bottomland area in the Escambia River system in Florida (East Gulf subregion). This clone’s superiority was due to a high height growth performance level, high rust resistance, and a better than average d.b.h. growth performance. MS093-1 was the top performer of the 3 clones that were in the top 10 at both locations. This was due to good height growth and slightly above average d.b.h. growth and rust resistance. MS072C-7 came in second of the three due to a high rust score and average d.b.h. and height growth. MS094-1, which was the best of the three at the GA location, was the worst of the three at the MO location. However, at this location, it still had good rust resistance and height growth, but the d.b.h. growth performance score was below average.

With the exception of one unknown clone, the best clones for the MO location consisted of trees from the Tombigbee River in southwest Alabama and the Escambia and Apalachicola River systems in northwest Florida. The Tombigbee River system in both Alabama and Mississippi was also the primary source for the GA location’s best clones. For the 2 locations combined, >50 percent of the top performing clones came from the Tombigbee River system.

**Table 4—Performance levels and origins for the 10 best performing “new” clones at each location**

Location	Clone ID	Subr.	Area	River	State	Performance
GA	MS093-6	EG	B	Tombigbee	AL	3.2
	MS096-2	EG	B	Tombigbee	MS	2.6
	MS086-6	EG	U	Chattahoochee	AL	2.4
	MS094-1	EG	B	Tombigbee	AL	2.3
	MS093-1	EG	B	Tombigbee	AL	2.1
	MS154A-1	SA	U	Saluda	SC	2.0
	MS118-4	EG	U	Tombigbee	AL	2.0
	MS130B-1	SA	B	Pee Dee	SC	1.2
	MS118-3	EG	U	Tombigbee	AL	1.2
	MS072C-7	EG	B	Apalachicola	FL	1.1
MO	MS095A-6	EG	B	Escambia	FL	4.0
	MS094-4	EG	B	Tombigbee	AL	3.1
	MS105-5	EG	B	Tombigbee	AL	2.5
	MS119-1	EG	U	Tombigbee	AL	2.3
	MS092-5	EG	B	Tombigbee	AL	2.2
	MS093-1	EG	B	Tombigbee	AL	2.2
	MS006-4			Unknown		2.2
	MS072C-7	EG	B	Apalachicola	FL	2.0
	MS094-1	EG	B	Tombigbee	AL	2.0
	MS093-5	EG	B	Tombigbee	AL	1.9

## Comparison of Best Clones from Checks and New Clones Combined

The best performing check clone (ST111733) for the GA location performed better than the top performing “new” clone (MS093-6) for that location. However, S7C8 did not perform better than the best “new” clone. The 2 superior check clones did, however, perform better than the 3 new clones that occurred in the top 10 at both locations. The two best “new” clones (MS095A-6 and MS094-4) at the MO location performed better than the best two check clones. However, the top 2 check clones performed better than the 3 new clones that occurred in the top 10 at both locations.

The 5 clones of choice for the entire southeast would be the 3 new clones that occurred in the top 10 at both locations and the 2 best check clones. The 3 “new” clones, while not the best at each location, have shown the ability to perform better across the southeast than 90 percent of the 100 select clones. The clones of choice for the MO location, and other locations similar to that location, would be the two top check clones along with the top three “new” clones (MS095A-6, MS094-4, and MS105-5) at that location. The clones of choice for the GA location, and locations similar to it, would be the top two check clones that occurred at both locations, the third best performing check clone (ST111234) at GA, and the top two “new” clones (MS093-6 and MS096-2) at that location.

## SUMMARY AND CONCLUSIONS

There were significant differences between the GA and MO locations for all traits except d.b.h., when locations were considered random. Clones were taller, had slightly larger d.b.h.s, and had less rust infection at the GA location. Mean performance of “check” clones was better than mean performance of “new” clones at the GA location, while the “new” clones had better performance levels than the “checks” at the MO location. There were three “check” clones that were in the top five “checks” at the two locations. However, relative contributions of rust resistance, d.b.h., and height to the high overall performance level of these three check clones differed at the two locations. There were three “new” clones that performed well at both locations. These were in the top 10 new clones at each location, but they were not among the top 3 ranking new clones at either location. The top 3 “new” clones in rank for the GA location were not in the top 10 “new” clones at the MO location, and likewise the top 3 “new” clones at the MO location were not in the top 10 “new” clones at the GA location. The clones of choice for the GA location

are the three “check” clones (ST111733, ST111234, and S7C8) and the top two “new” clones (MS093-6 and MS096-2). The ideal clones for the MO location would be the top two “check” clones (ST111733 and S7C8) and the top three “new” clones (MS095A-6, MS094-4, and MS105-5). All of these new-clone selections come from the Tombigbee, Escambia, and Apalachicola Rivers in south Alabama and northwest Florida.

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## LITERATURE CITED

- Cooper, D.T.; van Haverbeke, D. 1990. *Populus deltoides* Bartr. ex Marsh Eastern Cottonwood. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America, volume 2. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 530-543.
- Land, S.B., Jr.; Stine, M.; Ma, X. [and others]. 2001. A tree improvement program for eastern cottonwood in the Southeastern United States. Proceedings of the 26<sup>th</sup> biennial southern forest tree improvement conference. Athens, GA: The University of Georgia: 84-93.
- Mohn, C.A. 1973. Practical breeding of cottonwood in the northcentral region. In: Joint Proceedings of the 10<sup>th</sup> Lake States forest tree improvement conference and the 7<sup>th</sup> Central States forest tree improvement conference. Gen. Tech. Rep. NC-3. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 35-39.
- Nelson, C.D.; Tauer, C.G. 1987. Genetic variation in juvenile characters of *Populus deltoides* Bartr. from the southern great plains. *Silvae Genetica*. 36(5-6): 216-221.
- Warwell, M.V.; Alker, G.R.; Rockwood, D.L [and others]. 1999. Culture and genetic influences on greenwood cutting propagation of a new collection of eastern cottonwood in the South. In: Proceedings of the 25<sup>th</sup> biennial southern forest tree improvement conference. New Orleans, LA: Louisiana State University: 174-176.
- Wilcox, J.R.; Farmer, R.E., Jr. 1967. Variation and inheritance of juvenile characters of eastern cottonwood. *Silvae Genetica*. 16: 162-165.
- Wright, L.L.; Tuskan, G.A. 1997. Strategy, results and directions for woody crop research funded by the US Department of Energy. In: Proceedings of the 1997 pulping conference. Atlanta, GA: TAPPI Press: 791-799.
- Ying, C.C.; Bagley, W.T. 1976. Genetic variation of eastern cottonwood in an eastern Nebraska provenance study. *Silvae Genetica*. 25: 67-73.
- Zobel, B.J.; Talbert, J.T. 1984. The importance of source of seed in tree improvement programs. In: Applied forest tree improvement. New York: John Wiley and Sons, Inc.: 76-116.

# SURVIVAL, GROWTH, AND ACORNET PRODUCTION OF ARTIFICIALLY REGENERATED NORTHERN RED OAK ON TWO HIGH-QUALITY MESIC SITES AT YEAR SEVEN

Paul P. Kormanik, Shi-Jean Susana Sung, Taryn L. Kormanik, Stanley J. Zarnoch, Catharine D. Cook, Tom Tibbs, and Scott E. Schlarbaum<sup>1</sup>

**ABSTRACT**—Open-pollinated, half-sib northern red oak (*Quercus rubra* L.) 1-0 seedlings were grown under an improved nursery protocol. Minimum seedling grading standards for this test were six first-order lateral roots, 8-cm root-collar diameter, and 0.7-m height. At the Brasstown site on a salvage clearcut in North Georgia, we spot-applied glyphosate herbicide annually for 6 years to prevent the seedlings from being overtopped. At the Wayah shelterwood site (30 trees/ha) in western North Carolina, we restricted herbicide applications and used brush saws to clear around each planted seedling after the fourth and the sixth growing seasons. The northern red oak trees on the Brasstown site performed significantly better for all parameters. At Brasstown site, trees from eight of the nine families produced an acornet crop at year seven. We observed no acornets or acorns at the Wayah site. We attributed differences in response between the two primarily to inadequate control of rapidly growing competing vegetation on the Wayah site.

## INTRODUCTION

Northern red oak [*Quercus rubra* L. (NRO)] has a broad geographic distribution, but no single regeneration mechanism can explain its presence in current stands. However, NRO is rapidly declining in numbers and importance on high-quality mesic sites throughout its range. Many researchers feel NRO may become threatened or endangered on these sites without new regeneration techniques (Kellison 1993).

Human activity or biological catastrophes such as the chestnut blight fungus, *Cryphonectria parasitica* (Murr.) Barr., that killed American chestnut [*Castanea detata* (Marsh.) Borkh.], started many NRO-dominated stands. Past land use, harvesting practices, and fires have enabled NRO to occupy a broad geographic and physiographic range (Abrams and Norwacki 1992). However, as NRO on high-quality mesic sites were harvested or disturbed, they did not establish new stands.

A shelterwood method for regenerating NRO on low-quality sites (site index<sub>50</sub> ≤ 21 m) reliably produced new stands of both stump sprouts and individuals of seedling origin (Sander 1972). The method consists of thinning the mature stands to specific densities and then allowing NRO seedlings to regenerate under the canopies. When seedlings reach the desired densities and sizes, the overstory canopy is removed. This method popularized the term “advanced oak regeneration” and specified the minimum stem standards for oak management in the eastern and central United States.

Sander’s (1972) system proved effective on low-quality sites where faster-growing competitors to NRO were absent or at minimal levels. However, the necessary advanced NRO regeneration might take 10 to 20 years. To shorten this cycle, Johnson (1993) tried artificial regeneration on low-quality

upland sites and on high-quality mesic sites. Severe competition from faster growing, more shade-tolerant species (Barton and Gleeson 1996, Crunkilton and others 1992) and the absence of quality NRO planting stock, however, made artificial regeneration impractical. Others modified Sander’s prescription to use it on high-quality mesic sites. Their results showed that shade-tolerant species as well as yellow poplar (*Liriodendron tulipifera* L.) responded well to these shelterwood modifications, but NRO did not (Loftis 1983).

In the mid-1980s, we initiated an effort to develop a nursery protocol to produce the proper-sized, high-quality 1-0 hardwood planting stock that would be comparable to size requirements described for advanced oak regeneration by Sander (1972). Many researchers and forest managers had essentially discounted the usefulness of 1-0 oak planting stock. Even now many still recommend 2 or even 3 years in the nursery to achieve proper-sized seedlings (Hill 1986, Zaczek and others 1997). Our nursery protocol for growing 1-0 oak seedling also evaluated seedlings for beneficial root and stem characteristics (Kormanik 1986; Kormanik and others 1994, 1995). Given new technology and the continued critical need for oak regeneration on high-quality mesic sites, evaluation of oak seedling field performance is crucial.

In this study we observed survival, growth, and early acornet production potential of artificially regenerated NRO on two high-index sites. We employed a specific nursery protocol to produce large, high-quality 1-0 NRO stock and compared half-sib family effects on these parameters of NRO seedlings grown on either clearcut or shelterwood sites.

<sup>1</sup> Principal Silviculturist and Research Plant Physiologist, respectively, Institute of Tree Root Biology, USDA Forest Service, Southern Research Station, Athens, GA; Graduate student, School of Forest Resources, University of Georgia, Athens, GA; Research Mathematical Statistician, USDA Forest Service, Southern Research Station, Asheville, NC; Biological Science Technician, Institute of Tree Root Biology, USDA Forest Service, Southern Research Station, Athens, GA; retiree, Genetics Resource Management, USDA Forest Service, Southern Region, Atlanta, GA; and Professor, Department of Forestry, Wildlife and Fisheries, University of Tennessee, Knoxville, TN.

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## MATERIALS AND METHODS

### Nursery Practices

Open-pollinated half-sib acorns were collected during the fall of 1993 from individual NRO mother trees at the Watauga Seed Orchard in eastern Tennessee. The acorns were collected daily from shade cloth placed beneath the trees' crown area and were immediately placed in water-filled buckets. Floating acorns were discarded. Acorns that sank were presumed to be sound and were used in this study. Acorns were stored at 4 to 6 °C for approximately 40 to 55 days until sowing at the Georgia Forestry Commission's Flint River Nursery near Montezuma, GA.

Acorns were sown during early December 1993 in seedling beds at a density of 54 to 57/m<sup>2</sup>. The acorns from specific mother tree seed lots were sown continually within a bed with a 2-m void left between seed lots. Approximately 3-cm depth of well-decomposed sawdust was then applied to the surface of all beds. The nursery fertilization schedule reported by Kormanik and others (1994) was used in all nursery beds throughout the growing season. Prior to sowing, the extractable soil nutrient concentrations were determined and adjusted to maintain calcium at 500, potassium at 130, phosphorus at 100, magnesium at 75, copper at 0.3 to 3, zinc at 3 to 8, and boron at 0.4 to 1.2 ppm. A total of 1,322 kg/ha of NH<sub>4</sub>NO<sub>3</sub> was applied to the developing seedlings incrementally through the growing season. Initial increments were gradually increased as the seedlings developed. The first two applications equaled 17 kg nitrogen (N)/ha; the third was 56 kg N/ha. The next six applications were 168 kg N/ha, and the final two were 112 kg N/ha. These N applications began in mid-May and continued at 10- to 14-day intervals until mid-September. Irrigation was provided through the growing season when rainfall was < 2.5 cm per week. After October 15, irrigation continued at a reduced rate until leaf abscission layers developed in early December.

The seedling taproots were undercut at approximately 30-cm depth prior to lifting in February 1995. The lifted seedlings were then graded, and their first-order lateral roots trimmed to 15 cm. The minimum acceptable seedling morphological grading standards for this study were six first-order lateral roots, 8-mm root-collar diameter (rcd), and 0.7-m height (hgt) for all progeny groups. The seedlings were packaged and kept at 4 to 6 °C until outplanting.

### Site Conditions, Outplanting, and Silvicultural Management Practices

Both planting sites had comparable site quality. The site indices<sub>50</sub> ranged between 28 and 32 m for yellow poplar, which was the original dominant species in both stands. The Wayah site had approximately 30 co-dominant yellow poplar trees/ha left in the shelterwood created during spring and summer of 1993. All understory stems were cut, and the logging debris was moved to the perimeter of the planting site. The soil at Wayah is a Trimont fine loam (mixed, active Humic Hapludult) with a northeast aspect, an elevation between approximately 885 to 900 m, and a slope of 25 to 35 percent.

The Brasstown site on the Brasstown Ranger District in north Georgia was about 100 km southwest of the Wayah site and was clearcut in late summer 1993 in a salvage operation, after a severe wind incident 2 years earlier. Slash and other

logging debris were moved to the perimeter of the planting. The soil at Brasstown is a Tusquitee fine loam (mesic typic Dystrudept); the site has a northeast aspect, an elevation of approximately 830 to 850 m, and a slope of 15 to 25 percent.

The study design consisted of separate randomized block experiments with 10 replications at each of the 2 sites. In February 1995, in each replication at both sites, progeny from nine NRO families were planted at 3.1 by 3.1 m in five tree plots. In addition, each site had a unique set of 16 NRO families. Because these additional families were not common to both sites, they were not used in the statistical analysis. However, they did provide supplemental information for data interpretation.

Seedling hgt and rcd at lifting (year zero) were recorded. The Brasstown site was measured after year one and then annually from year four through year seven for hgt and diameter at breast height (d.b.h.). The Wayah site was measured annually from year two through year five and at year seven for the same parameters. In addition, a surrogate for total stem relative volume (vol) was defined as the product of d.b.h.<sup>2</sup> and hgt and was also analyzed. Since no reliable volume equations were available for NRO saplings at these sites, the surrogate allowed us to compare the relative productivity. We evaluated all trees at both locations for acorn presence in year seven and acorn production in year eight.

Originally, glyphosate herbicide was to be applied on both sites at recommended rates, beginning with stump treatment prior to planting, to control sprouting and other competing vegetation (Loftis 1978). Thus, the only silvicultural difference between the two sites would have been yellow poplar as shelterwood on the Wayah site. However, herbicide application was delayed until in year two (1996) at Brasstown, and no herbicide was ever used at Wayah. In year two, glyphosate was used to control stump sprouts and to reduce competition from innumerable newly established yellow poplar seedlings at Brasstown. These new seedlings were spot treated with glyphosate during year three (1997). From years four to seven, spot application of glyphosate was primarily used to control grapevine (*Vitis* spp.), which invaded along the perimeter of the planting. Annual weeds such as asters and ragweed (*Ambrosia* spp.) on either site were not controlled.

On the Wayah site, where herbicide use was not permitted, stump sprouts prior to planting were removed by chain saw or brush saw. However, these stumps resprouted, along with new yellow poplar seedlings, blackberry (*Rubus* spp.), and grapevine that apparently responded well to the openings created during the first 3 years. All such competing vegetation was removed around each tree with hand tools and brush saws following the fourth growing season. This release treatment was again applied after year six to control the rapidly growing competition.

### STATISTICAL ANALYSIS

Separate randomized block experiments were established at each site to determine the family effect (a fixed factor) on survival and growth. The Brasstown site had 10 replications, but the Wayah site had only 9 replications, because 1 incomplete replication was deleted from subsequent analyses. Variables for analysis were survival, hgt, rcd, d.b.h., and vol on a plot mean basis. During the course of the study, we interpreted

any stump sprouts from previously recorded dead trees as dead in any subsequent year's analyses.

Analysis of variance was performed with PROC GLM (SAS Institute 1989) to detect family differences. For simplicity, Tukey's mean separation tests are presented only for year seven. Initially, hgt, diameter, and vol were analyzed for individual trees with a generalized linear model to reflect the unbalanced statistical design at the subsampling level. Least square means were computed, and F-tests were performed by synthesizing the appropriate denominator mean squares by using the RANDOM statement with the TEST option in SAS. Despite the unbalanced statistical design, these results were virtually identical to those based on the plot means. In addition, since survival was defined as the proportion of surviving trees per plot, it had to be analyzed on a plot basis. Thus, for consistency and simplicity, the analysis of variance based on plot means was used in the study.

To formulate a comparison between the two sites (fixed effect) and thus increase the scope of inference for the family effects, a combined analysis over sites was performed by using the nine common families at each site in a randomized block design. The site-family interaction was tested, and, when non-significant, the main effects of site and family were analyzed for the same variables as those in the separate analyses. Analysis of variance procedures tested the site effect with the block (site) mean square, while the family and site-family interaction was tested with the residual mean square (McIntosh 1983).

Growth models were developed to predict hgt, d.b.h., and vol as a function of years. The nonlinear exponential model was fitted on an individual tree basis for the nine families. PROC NLIN (SAS Institute 1989) was used to obtain the parameter estimates and the mean square error.

## RESULTS

No statistical significance was found for survival between the nine families on either the Brasstown or Wayah sites (table 1). Year seven survival ranged from 56 to 86 percent at Brasstown and from 60 to 87 percent at Wayah (data not shown). In the combined analysis of survival, the effects of site, family, and the site-family interaction were not significant. Survival at year seven was 76 percent for Brasstown compared to 72 percent for Wayah (table 2). Vole (*Cricetidae* spp.) predation was a major mortality factor on both sites for 2 years after outplanting.

Seedling hgt, rcd, and vol had significant family differences at both sites at the initial outplanting (year zero). This result reflects the varying genetic growth potentials in the nursery for the nine different families (table 1). Based on randomization of seedlings at study installation, there should be no difference between sites in the growth parameters at year zero. As expected, the mean values for seedling hgt and vol were not different between two sites (table 1). The mean values for hgt and vol were 91 cm and 99 cm<sup>3</sup> for Brasstown and 89 cm and 105 cm<sup>3</sup> for Wayah. Although seedlings at Brasstown had smaller rcd than those at Wayah, 10.1 mm vs. 10.5 mm, respectively, the difference is not of much biological significance.

At the Brasstown site, the family effect became nonsignificant at 5 and 7 years for hgt (table 1). However, d.b.h. and, consequently, vol showed significant family effects. The Wayah site maintained significant family effects for hgt and d.b.h. for years

five and seven. The combined analysis revealed no significant interactions for site-family for any of the variables (table 1).

Growth analyses revealed similar results at years five and seven (table 1) and thus, for simplicity, table 2 presents only mean comparisons for year seven. Over both sites, family means ranged from 2.92 m to 3.71 m for hgt, 20.8 to 30.9 mm for d.b.h., and 2,072 to 5,789 cm<sup>3</sup> for vol. Despite highly significant family *p*-values, Tukey's test revealed very few differences among the family means in all growth parameters in the combined analysis (table 2). Based on vol, families 482, 479, and 473 were significantly larger than family 448. Although not statistically significant, family 442 had the largest mean hgt and d.b.h. of all families. Family 442, however, did not have larger mean vol than family 448. This result may have been due to a different hgt-d.b.h. relationship for this family. For example, a tall tree may have a relatively smaller d.b.h., while a small tree may have a relatively larger d.b.h. Since vol was calculated for individual trees, the discrepancy reflected by family mean of vol for family 442 was not alarming.

At year seven, Brasstown's growth parameters were larger than Wayah's, with hgt 27 percent larger, d.b.h. 62 percent larger, and vol, 179 percent larger (table 2). Thus, although survival was similar on both sites, stand productivity was markedly superior on the Brasstown site. The nonlinear exponential growth models for hgt, d.b.h., and vol derived from nine family means on each site appear in figure 1. The growth parameter estimates in the exponent of models were greater at the Brasstown site.

We first observed acornets on trees of the Brasstown site at year seven and mature acorns in the fall of year eight. Eight of the nine families at Brasstown had at least one tree that produced acornets (table 2). A total of 5.3 percent of trees in all nine families produced acornets at Brasstown. Only family 438 did not show any precocious acornet production in year seven (table 2). Of the 16 supplemental families at Brasstown, 8 had at least 1 tree producing acornets. A total of 3.9 percent of all the 16 families produced acornets. We observed no acornets on any trees at the Wayah site through year seven.

## DISCUSSION

The same nursery protocol employed in this study has consistently produced large, quality NRO seedlings from well over 100 open-pollinated NRO families (Kormanik and others 1994, 1995, 1998, 1999). These seedlings meet or exceed size standards associated with desirable NRO advanced regeneration (Loftis 1983, Sander 1972). Seedlings meeting our grading criteria, i.e., six first-order lateral roots, 8-mm rcd, and 0.7-m hgt, can survive and develop well after outplanting in various locations in Georgia, North Carolina, South Carolina, and Tennessee (Kormanik and others 1998, P. Kormanik unpublished data). Our results disagreed with previous reports that 1-0 NRO seedlings are unsuitable for artificial regeneration (Dey and Buchanan 1995, Zaczek and others 1997). These studies employed different cultural practices and grading criteria than ours. Varying seedbed density, fertility, and irrigation regimes can alter the absolute value of any size-based seedling grading criteria. However, the grading of seedlings by first-order lateral root numbers remains consistent, because it is a highly heritable trait within a population (Kormanik 1986; Kormanik and others 1998, 1999). As the first-order lateral root count drops below the mean value for a

**Table 1—Results (*p*-values) from the analysis of variance for nine families of nursery grown northern red oak 1-0 seedlings outplanted in February 1995**

Variable	Source	Year 0	Year 5	Year 7
<b>Brasstown</b>				
Survival	Family	—	0.065	0.122
Arcsine $\sqrt{\text{Survival}}$	Family	—	0.084	0.177
Height	Family	0.000	0.208	0.128
Diameter <sup>a</sup>	Family	0.000	0.047	0.036
Volume	Family	0.000	0.027	0.020
<b>Wayah</b>				
Survival	Family	—	0.716	0.688
Arcsine $\sqrt{\text{Survival}}$	Family	—	0.482	0.455
Height	Family	0.000	0.005	0.005
Diameter	Family	0.000	0.002	0.005
Volume	Family	0.000	0.056	0.056
<b>Brasstown and Wayah Combined</b>				
Survival	Site	—	0.490	0.415
	Family	—	0.373	0.524
	S*F	—	0.249	0.240
Arcsine $\sqrt{\text{Survival}}$	Site	—	0.409	0.363
	Family	—	0.278	0.441
	S*F	—	0.193	0.192
Height	Site	0.164	0.027	0.000
	Family	0.000	0.001	0.002
	S*F	0.071	0.238	0.080
Diameter	Site	0.010	0.001	0.000
	Family	0.000	0.000	0.001
	S*F	0.697	0.479	0.216
Volume	Site	0.083	0.001	0.001
	Family	0.000	0.002	0.003
	S*F	0.295	0.551	0.276

— = not applicable.

<sup>a</sup> Diameter was root collar at year 0 and breast height at years 5 and 7.

given half-sib family, seedling sizes are smaller, and their survival and growth in field plantings are significantly reduced (Kormanik and others 1998, 1999).

Survival of transplanted NRO was similar on Brasstown and Wayah sites through year seven (tables 1, 2). Most of the mortality occurred within the first 2 years of outplanting due to vole damage. However, despite vole damage, the use of large, high-quality 1-0 planting stock may account for > 70 percent seedling survival on both sites. Comparing actual survival among families is of minimum value, because survival may represent rather random results of vole feeding rather than the inherent competitive ability of specific families.

Throughout its range, NRO has the reputation of being difficult to regenerate on high-quality mesic sites. However, most regeneration procedures do not adequately consider the biological requirements of NRO. On high-quality mesic sites, NRO cannot thrive in understory shade. On shelterwood regeneration sites, poor root system development under shade conditions makes this species a questionable choice (Barton and

Gleeson 1996, Kormanik and others 1998, Sung and others 1998). Our study shows that early performance of individual NRO seedlings on high-quality mesic sites depends upon the level of maintenance imposed upon the site (table 2, fig. 1). Seedlings at Brasstown had 179 percent greater vol than those at Wayah. Residual shelterwood trees at the Wayah site were not the primary factor affecting NRO growth. Although both sites sustained vole damage during the first 2 years, by year three at Wayah, grasses, brambles, and stump sprouts overtopped seedlings, adversely affecting their growth. At the end of the fourth growing season at the Wayah site, mechanical release temporarily reduced competition; however, with no subsequent vegetation control, severe overtopping again occurred by year six.

Seedlings at the Brasstown site, on the other hand, experienced no overtopping. In many NRO field trials we have observed, although top growth during the first 3 years after outplanting may be limited, root development is rapid. If overtopping occurs during this early period, it is highly unlikely that a competitive root system will develop, and the seedlings

**Table 2—Least square means for site and family effects at year 7 for nine families of nursery grown northern red oak 1-0 seedlings outplanted in February 1995**

Site <sup>a</sup>	Survival %	Height <i>m</i>	D.b.h. <i>mm</i>	Volume <i>cm</i> <sup>3</sup>	Acornets <sup>b</sup>
Brasstown	76 a	3.80a	33.3a	5936a	18
Wayah	72 a	3.00b	20.5b	2128b	0
Family <sup>a</sup>					
435	73 a	2.92b	21.1bc	2964ab	1
438	76 a	3.55ab	27.2abc	3812ab	0
439	79 a	3.26ab	26.6abc	3493ab	1
442	84 a	3.71a	30.9a	4840ab	1
443	74 a	3.67a	28.2abc	3749ab	2
448	72 a	3.01ab	20.8c	2072b	1
473	65 a	3.59ab	30.9a	5254a	5
479	72 a	3.58ab	29.9ab	5407a	5
482	73 a	3.54ab	29.8ab	5789a	2
Site (extra families) <sup>c</sup>					
Brasstown	76	3.49	30.2	4901	24
Wayah	66	2.77	17.7	1620	0

<sup>a</sup> Means within a column followed by the same letter are not significantly different at the 0.05 level based on Tukey's studentized range test.

<sup>b</sup> Number of trees with acornets.

<sup>c</sup> Simple means for 16 additional families at the Brasstown and 16 additional at the Wayah sites.

will not become part of the main canopy (Sung and others 1998). Growth at the Brasstown site was rapid, and some crowns began to touch in year five. By year seven, many more individual crowns of adjacent trees were beginning to touch. No branch touching was observed among the oaks at the Wayah site through year seven. Although not statistically analyzed, the supplemental 16 families also exhibited the trend of better growth at the Brasstown site when compared with the other 16 families planted at the Wayah site at year seven (table 2).

### Acorn Production

Oak species, particularly NRO, show considerable variability as to when they initiate acorn production. In a German forest environment, acorn initiation can begin by age 40 (Büsgen and Münch 1929), but more recent research in the United States reports acorn production within 25 to 50 years (Sander 1990). In our study, only the most competitive seedlings were outplanted. Given a favorable growing environment, we assumed that some trees would be genetically capable of early mast production by age 10 to 15. While we observed no acorn development at the Wayah site, at least one tree in 18 of 25 families at Brasstown had produced acornets in year seven (table 2). Even though only a few individuals developed acornets, such early production is unusual in a stand without irrigation or fertilizer application. In year eight, we planned to place nets under the crowns of all trees that had maturing acorns. In September 2002, we completed the necessary clearing beneath the trees and initiated weekly observations of acorn drop. Approximately 2 weeks later, before acorn drop began and netting was in place, squirrels (*Sciuridae* spp.) migrated from adjacent areas and harvested the entire maturing crop. While we do not know the exact number of

maturing acorns, the crop varied from few (about 20 to 30 acorns) to heavy (100 to 200 acorns) on individual trees.

Zimmermann and Brown (1971) suggested that tree age may not be the critical factor governing flower production. They speculated that optimal nutrition and increased vigor may be sufficient to switch on the flowering genes at an early age in individual trees. Similarly, Cecich (1993) concluded that while acorn production is highly heritable, maintaining a vigorous crown is critical to enhance this trait. Sugars may play dual roles as an energy source and a signal for flowering (Bernier and others 1993 and references cited therein). Roldan and others (1999) showed that supplying sucrose exogenously to the aerial parts of dark-grown *Arabidopsis thaliana* plants induced flowering. In our study, early mast production occurred only at the Brasstown site where vegetation competition was controlled and the crowns were essentially free from competition. This result supports the concept that adequate sunlight is important to early acorn production, because energy-intensive flower initiation requires high sugar levels from enhanced photosynthesis (Cecich 1993, Kramer and Kozlowski 1960). In other field studies in Northern Carolina, South Carolina, and Georgia, using the same nursery protocol and silvicultural management practices as on the Brasstown site, we have observed acorn production as early as age 5 in NRO, cherrybark oak (*Q. pagoda* Raf.), and white oak (*Q. alba* L.).

### CONCLUSIONS

This study clearly established that large plantable 1-0 seedlings can enhance artificially regenerating NRO on high-quality mesic sites where its existence is precarious. However, competing vegetation must be controlled adequately to realize growth of approximately 3.5 to 4.0 m at year seven and early

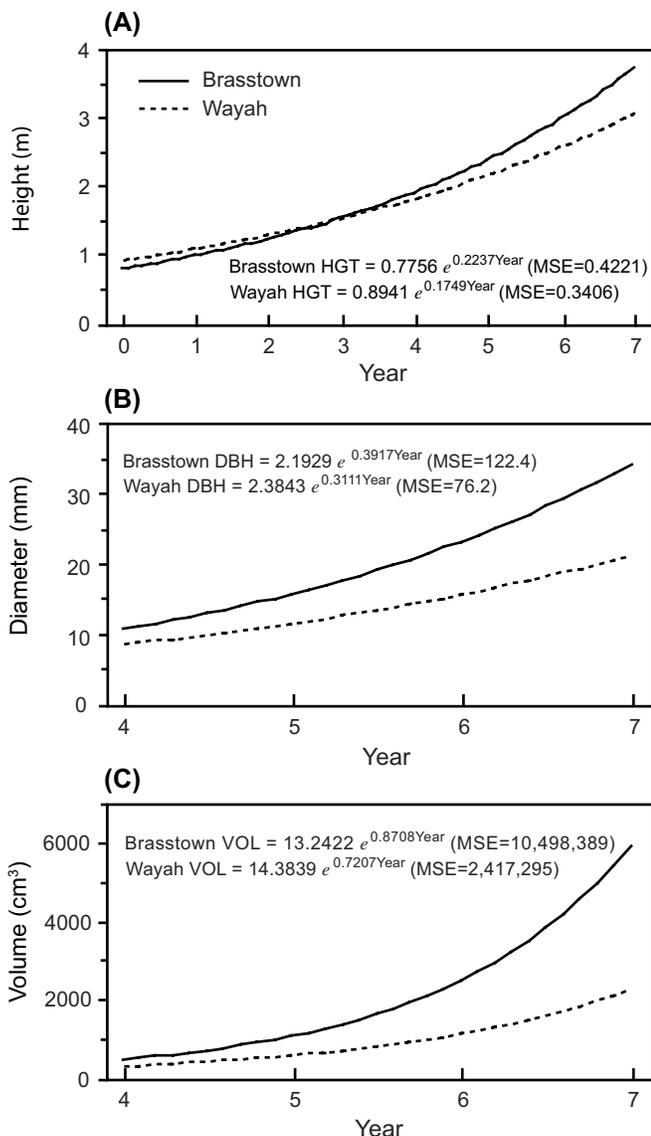


Figure 1—Growth relationships for (A) height, (B) diameter at breast height, and (C) volume for young northern red oak stands established in February 1995 on the Brasstown and Wayah sites.

acorn production. At the Brasstown planting site, artificial regeneration of high-quality NRO produced mast to satisfy both wildlife and regeneration. Judicial use of herbicides and cultural measures, such as fertilization and insect control, helped establish small oak stands and enhanced early acorn production.

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## LITERATURE CITED

Abrams, M.D.; Norwacki, G.J. 1992. Historical variation in fire, oak recruitment, and post-logging accelerated succession in central Pennsylvania. *Bulletin of the Torrey Botanical Club*. 119: 19-28.

Barton, A.M.; Gleason, S.K. 1996. Ecophysiology of seedlings of oaks and red maple across a topographic gradient in eastern Kentucky. *Forest Science*. 42: 335-342.

Bernier, G.; Havelange, A.; Houssa, C. [and others]. 1993. Physiological signals that induce flowering. *Plant Cell*. 5: 1147-1155.

Büsgen, M.; Münch, E. 1929. The structure and life of forest trees. Thompson, T., translator. New York: John Wiley. 436 p.

Cecich, R.A. 1993. Flowering and oak regeneration. In Loftis, D.L.; McGee, C.E., eds. Symposium proceedings. Oak regeneration: serious problems, practical recommendations. Gen Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 79-95.

Crunkilton, D.D.; Pallardy, S.G.; Garrett, H.E. 1992. Water relations and gas exchange of northern red oak seedlings planted in a central Missouri clearcut and shelterwood. *Forest Ecology and Management*. 53: 117-129.

Dey, D.; Buchanan, M. 1995. Red oak (*Quercus rubra* L.) acorn collection, nursery culture and direct seedling: a literature review. Forest Research Information Paper 122. Sault Ste. Marie, Ontario: Ontario Forest Research Institute. 46 p.

Hill, J.A. 1986. Survival of Pennsylvania state nursery seedlings, 1971-1981. In: Proceedings of the Northeast area nurserymen's conference. State College, PA: [Publisher unknown]: 1-4.

Johnson, P.S. 1993. Sources of oak reproduction. In: Loftis, D.L.; McGee, C.E., eds. Symposium proceedings. Oak regeneration: serious problems, practical recommendations. Gen Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 112-131.

Kellison, R.C. 1993. Oak regeneration - where do we go from here? In: Loftis, D.L.; McGee, C.E., eds. Symposium proceedings. Oak regeneration: serious problems, practical recommendations. Gen Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 308-315.

Kormanik, P.P. 1986. Lateral root morphology as an expression of sweetgum seedling quality. *Forest Science*. 32: 595-604.

Kormanik, P.P.; Sung, S.S.; Kass, D.J. [and others]. 1998. Effect of seedling size and first-order lateral roots on early development of northern red oak on mesic sites. In: Waldrop, T.A., ed. Proceedings of the ninth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 247-252.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. 1994. Toward a single nursery protocol for oak seedlings. In: Proceedings of the 22<sup>nd</sup> southern forest tree improvement conference. Atlanta, GA: Southern Forest Tree Improvement Center Publication 44: 89-98.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. [and others]. 1995. Oak regeneration: why big is better. In: Landis, T.D.; Cregg, B., tech. coords. National proceedings of the forest and conservation nursery associations. Gen. Tech. Rep. PNW-GTR-365. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Pacific Northwest Station: 117-123.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. [and others]. 1999. Heritability of first-order lateral root number in *Quercus*: implication for artificial regeneration of stands. In: Stokes, A., ed. Supporting roots of trees and woody plants: form, function and physiology. Amsterdam, The Netherlands: Kluwer Academic Publishers. *Developments in Plant and Soil Sciences*. 87: 171-178.

Kramer, P.J.; Kozlowski, T.T. 1960. Physiology of trees. New York: McGraw-Hill. 642 p.

Loftis, D.L. 1978. Preharvest herbicide control of undesirable vegetation in southern Appalachian hardwoods. *Southern Journal of Applied Forestry*. 2: 51-54.

Loftis, D.L. 1983. Regenerating southern Appalachian mixed hardwood stands with the shelterwood method. *Southern Journal of Applied Forestry*. 7: 212-217.

McIntosh, M.S. 1983. Analysis of combined experiments. *Agronomy Journal*. 75: 153-155.

Roldan, M.; Gomez-Mena, C.; Ruiz-Garcia, L. [and others]. 1999. Sucrose availability on the aerial part of the plant promotes morphogenesis and flowering of *Arabidopsis* in the dark. *Plant Journal*. 20: 581-590.

- Sander, I.L. 1972. Size of oak advance reproduction: key to growth following harvest cutting. Res. Pap. NC-79. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 6 p.
- Sander, I.L. 1990. *Quercus rubra* northern red oak. In: Silvics of North America. 2: Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 727-733.
- SAS Institute. 1989. SAS/STAT user's guide. Version 6. 4<sup>th</sup> ed., Vol. 2. Cary, NC: SAS Institute. 846 p.
- Sung, S.S.; Kormanik, P.P.; Zarnoch, S.J. 1998. Photosynthesis and biomass allocation in oak seedlings grown under shade. In: Waldrop, T.A., ed. Proceedings of the ninth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 227-233.
- Zaczek, J.J.; Steiner, K.C.; Bowersox, T.W. 1997. Northern red oak planting stock: 6-year results. *New Forests*. 13: 177-191.
- Zimmermann, M.H.; Brown, C.L. 1971. *Trees: structure and function*. New York: Springer-Verlag. 336 p.

# EFFECT OF ACORN MOISTURE CONTENT AT SOWING ON GERMINATION AND SEEDLING GROWTH OF WHITE OAK AND NORTHERN RED OAK

Shi-Jean Susana Sung, Paul P. Kormanik, Catharine D. Cook,  
Stanley J. Zarnoch, and Taryn L. Kormanik<sup>1</sup>

**Abstract**—White oak (*Quercus alba* L.) and northern red oak (*Q. rubra* L.) acorns were collected locally or from seed orchards in October 2002. Mean acorn moisture content (MC) was 48 percent for white oak and 39 percent for northern red oak. These acorns were air dried to different MCs before being sown into nursery beds in early December 2002. Acorn MC at sowing had a great impact on germination percentage, especially for white oak. White oak acorns with 48, 40, 30, and 20 percent MC had 70, 53, 12, and 3 percent germination, respectively. Northern red oak acorns with 39, 35, 25, and 15 percent MC had 84, 80, 68, and 46 percent germination, respectively. However, acorn MC at sowing did not affect first-year seedling growth or grading for either species. In November 2003, another study of white oak acorn MC was implemented. Germination was 90, 57, and 22 percent for acorns with 49, 33, and 25 percent MC, respectively. In this experiment, as in the first one, acorn MC at sowing did not affect growth of white oak seedlings.

## INTRODUCTION

There are six major steps in the process of artificial oak regeneration on high-quality mesic sites: acorn collection and handling, nursery protocol, seedling grading, site preparation, seedling outplanting, and stand maintenance. The success of each step is critical to the success of the next step, and early production of acorns by planted stands is essential to complete the cycle. Kormanik and others (1998, 2000, 2004) have demonstrated successful establishment of white oak (*Quercus alba* L.) and northern red oak (*Q. rubra* L.) stands using graded, high-quality 1-0 seedling stocks on high-quality mesic sites in Georgia and North Carolina. They also reported that vegetation control on these sites is essential for the continued growth of oak plantings. Northern red oak trees in this type of extensive management have produced acorns in < 8 years after outplanting (Kormanik and others 2004). Characteristically, this species is reported to start acorn bearing at age 40 to 50 years (Sander 1990).

Using an improved nursery protocol, Kormanik and others (1994) were able to consistently grow and grade seedlings to a minimum standard of 70 cm in height, 8 mm in root-collar diameter (RCD), and five first-order lateral roots (FOLRs) for many red oak species. However, growth of white oak seedlings with this specific nursery protocol has not been consistent among progeny from different mother trees. White oak acorn germination can be sporadic for progeny of some mother trees and > 80 percent for others (Kormanik and others 1997; Sung and others 2002, 2004). Negative effects of desiccation on acorn germination have been reported in various oak species, especially species in the white oak group (Connor and Sowa 2003, Farmer 1975, Finch-Savage and others 1996, Gosling 1989, Schroeder and Walker 1987). In almost all of these studies, however, the acorns were germinated in containers and under a controlled environment; thus, subsequent seedling growth was not followed. Here we tested the hypoth-

eses that acorn MC at sowing is critical for germination and for subsequent seedling growth under field conditions for both white oak and northern red oak.

## MATERIALS AND METHODS

### Experiment 1

Open-pollinated white oak acorns were collected from seven mother trees in Athens, GA, and from three mother trees at the Georgia Forestry Commission's Arrowhead Seed Orchard (Milledgeville, GA) in October 2002. Open-pollinated northern red oak acorns were collected from eight mother trees in Athens, GA, and from two mother trees at the Georgia Forestry Commission's Flint River Nursery Seed Orchard (Montezuma, GA) in October, 2002. Immediately after collection, acorns were floated for 10 minutes. Only those that sank and did not have any holes, cracks, or discolored cap scars were used in the study. All acorns were stored in plastic bags at 4 °C until air-drying treatments were imposed in mid-November 2002.

Before the air-drying treatments were applied, 50 acorns from each family were randomly sampled and analyzed for the day zero MC (based on percent fresh weight). Acorns of each family of each species were randomly separated into four treatment groups. Fresh weight of each treatment group was recorded. Acorns in the air drying treatment groups were placed in glass trays on a lab bench. Room temperature was approximately 21 °C. Subgroups of five acorns each were marked and their fresh weight recorded on day zero. On various days throughout the air-drying process, these subgroups of acorns were removed for the determination of actual residual MC. The estimated residual MC on day X (MC<sub>x</sub>) for each treatment group was calculated as:

$$MC_x (\%) = [(FW_x - DW_0) / FW_x] * 100\%$$

<sup>1</sup> Research Plant Physiologist, USDA Forest Service, Southern Research Station, Pineville, LA 71360; Principal Silviculturist and Biological Technician, respectively, USDA Forest Service, Southern Research Station, Athens, GA 30602; Research Mathematical Statistician, USDA Forest Service, Southern Research Station, Asheville, NC 28802; and Graduate Student, School of Forest Resources, University of Georgia, Athens, GA 30602.

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where FW<sub>x</sub> is acorn fresh weight on day X and DW<sub>0</sub> is acorn dry weight on day zero.

White oak acorns were air dried to 40 (40MC), 30 (30MC), or 20 percent MC (20MC). Acorns that were not air dried served as the control (C) and were stored at 4 °C throughout the drying treatment. Northern red oak acorns were dried to 35 (35MC), 25 (25MC), or 15 percent MC (15MC), or were not dried (C). When a group of acorns reached targeted MC, this group of acorns was stored at 4 °C until sowing. The stored acorns did not lose more MC during this short period of storage. A radicle protruded from about 40 percent of acorns in some white oak families during drying treatment or in storage at 4 °C. No radicle protrusion was observed with the northern red oak acorns.

Acorns were sown at the Whitehall Experimental Nursery (Athens, GA) in early December 2002. There were six replications for each species. In each replication, 10 families were randomly planted with 4 treatments randomly assigned within each family. There were 13 acorns per treatment per family per replication. Seedlings were grown according to the oak nursery protocol developed by Kormanik and others (1994). Germination was assessed in mid-April 2003. In January 2004, all seedlings were lifted and growth parameters recorded. The growth parameters assessed included seedling height (HT), RCD, number of FOLRs, lateral root fibrosity, and taproot forking. Only roots that originated from the taproot, had diameter > 1 mm, and had sturdy structure were counted as FOLRs. An arbitrary ranking system was used for lateral root fibrosity: 0 for absence of fine (< 1 mm in diameter) lateral roots on taproots; 1 for few fine lateral roots on taproots; 2 for intermediate number of fine lateral roots on taproots; and 3 for many fine lateral roots on taproots. Taproot forking was recorded as yes or no.

### Experiment 2

Open-pollinated white oak acorns were collected from five mother trees in Athens, GA, and from three mother trees at the Arrowhead Seed Orchard (near Cockran, GA) in October 2003. Acorns from four of these trees were also collected for use in experiment 1. Only sunk and sound acorns (without any hole, crack, or discolored cap scar) were used in this experiment. Air-drying treatments were imposed on these acorns much as in experiment 1. In addition to the C treatment, acorns were air dried to 33 (33MC) and 25 percent MC (25MC). Two days before sowing, half of the acorns from each of the 33MC, 25MC, and C groups were soaked in water for 2 days and designated as 33S, 25S, and CS, respectively. Fewer than 2 percent of acorns in experiment 2 had radicle protrusion at sowing. Acorns were sown in late November 2003. There were four replications for each species. In each replication, eight families were planted randomly, and six treatments, namely C, CS, 33MC, 33S, 25MC, and 25S, were randomly assigned within each family. There were 13 acorns per treatment per family per replication. Seedlings were grown using the same protocol as in experiment 1. Germination was recorded in mid-April 2004. In late December 2004, all seedlings were lifted and growth parameters recorded.

### Statistical Analysis

Both experiments were analyzed as split-plot designs with replication by means of blocks in the nursery beds. The whole-plot factor was family, which was assigned at random

within each block. Experiment 1 had six blocks, and experiment 2 had four blocks. The subplot factor was acorn MC, which was assigned at random within each whole plot. Each subplot had 13 acorns that were assessed for germination and subsequently for HT, RCD, and FOLR number. Percent germination was computed as the percentage of the 13 acorns originally sown. The seedlings per subplot were considered subsamples. Nongermination of some acorns or early seedling mortality resulted in unequal numbers, and this was taken into account in the analysis. In addition, measures of lateral root fibrosity and taproot forking were recorded for white oak in both experiments. The analysis for family, MC, and the family\*MC interaction was performed, least square means were computed, and Tukey-Kramer pairwise comparisons were obtained. PROC MIXED (SAS Institute 2004) was used for all analyses at the 0.05 significance level. Because some observations were missing, least squares means were nonestimable for various families, and not all 10 families were used in the analysis. Most analyses for northern red oak in experiment 1 were for eight families. Most analyses for white oak in experiment 1 were for five families, and most analyses for white oak in experiment 2 were for seven families. The exception was the analysis of percent germination, where all families were used.

## RESULTS AND DISCUSSION

### Experiment 1

Figure 1 shows some typical patterns in acorn MC change during air-drying treatment for white oak acorns (fig. 1A) and northern red oak acorns (fig. 1B). Mean acorn MC at day zero was 48 percent for white oak and 39 percent northern red oak. Between 3 and 5 percent of MC was lost during the first day of air drying. Throughout the air-drying period, estimated acorn MC was within 3 percent of actual MC obtained from subgroups of acorns for each species. Mean numbers of days required to dry white oak acorns to 40, 30, and 20 percent MC were 1.9, 4.3, and 7.0 days, respectively. Mean numbers of days required to dry northern red oak acorns to 35, 25, and 15 percent MC were 1.5, 4.7, and 9.3 days, respectively. The drying rates reported here probably represent the maximum MC loss rate for fallen acorns in field. This rate of MC loss is slower if the fallen acorns are covered by fallen leaves or if it rains often in late fall or winter. Nevertheless, the quickness of acorn MC loss warrants frequent and timely acorn collection for artificial regeneration purposes.

There were significant treatment differences in germination percentage for white oak acorns (table 1). Both the 30MC and 20MC treatments proved detrimental to white oak acorns. Connor and Sowa (2003) reported a sharp decrease, from 90 percent to 10 percent, in germination of white oak acorns when their MC dropped below 30 percent. After just a short period of drying (< 2 days), germination of the 40MC acorns was 17 percent lower than that of the C acorns (table 1). Finch-Savage and others (1996) and Gosling (1989) reported that MC levels < 40 percent were associated with desiccation damage in *Q. robur* acorns. Özbingöl and O'Reilly (2005) reported that drying soaked *Q. robur* acorns from an MC of 46 percent to 37 percent decreased germination from 68 to 8 percent after 2 months of freezing storage. Although the current study did not test the effects of cold storage of acorns, sowing acorns in early December and scoring germination in April would make this study comparable to the study design

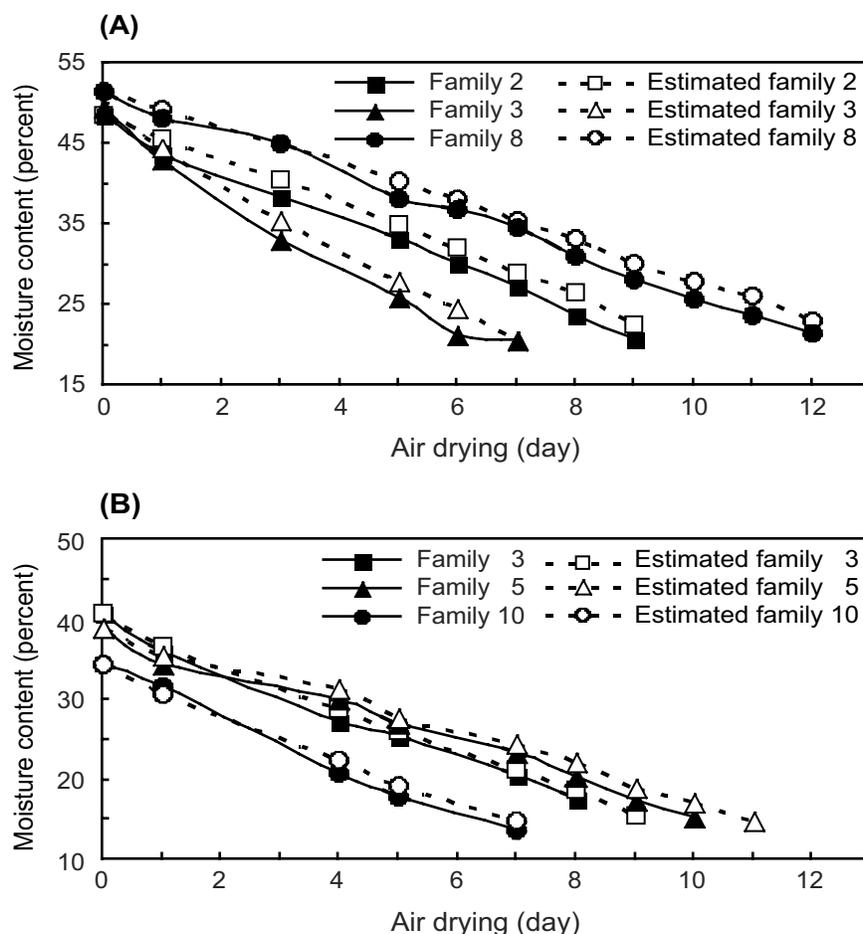


Figure 1—Acorn moisture content (MC) changes during air drying of acorns. Solid symbols represent actual MC, and open symbols represent estimated MC. (A) White oak acorns from families 2, 3, and 8, dried to about 20 percent MC. (B) Northern red oak acorns from families 3, 5, and 10, dried to about 15 percent MC.

**Table 1—Effects of white oak acorn moisture content at sowing on germination and first-year seedling growth in 2003**

Treatment	Germ <sup>a</sup>	HT <sup>b</sup>	RCD	FOLR	Lateral root fibrosity ranking <sup>c</sup>	Seedlings with forked taproot
Percent MC	%	cm	mm	no.		percent
C (48MC)	70d	39a	8.2a	3.3a	0.80a	10a
40MC	53c	40a	8.3a	3.3a	0.72a	28b
30MC	12b	41a	8.3a	2.8a	0.72a	14a
20MC <sup>d</sup>	3a	— <sup>d</sup>	— <sup>d</sup>	— <sup>d</sup>	— <sup>d</sup>	— <sup>d</sup>

Germ = germination; HT = height; RCD = root-collar diameter; FOLR = first-order lateral roots; MC = moisture content.

Means in a column followed by the same letter are not significantly different at the 0.05 level.

<sup>a</sup> All 10 families were included in the statistical analysis.

<sup>b</sup> Five families that had seedlings in every treatment were included in the statistical analysis for all growth parameters.

<sup>c</sup> Ranking of lateral root fibrosity was: 0 = absence of fine (<0.5 mm in diameter) lateral roots on taproots; 1 = few fine lateral roots on taproots; 2 = intermediate number of fine lateral roots on taproots; and 3 = many fine lateral roots on taproots.

<sup>d</sup> Because the germination percentage for this treatment was very low, no values of growth parameters are presented.

of Özbingöl and O'Reilly (2005). Here we showed the sensitivity of white oak germination to acorn MC at sowing.

Germination percentages also differed significantly from family to family for white oak acorns (data not shown). No significant treatment\*family interaction was observed, however. Generally, acorns collected at the Arrowhead Seed Orchard had much higher germination in all treatments than acorns collected from the field. In the C treatment, five families had > 80 percent germination, and three of these families were from the seed orchard. The other five families had germination ranging from 47 to 62 percent. In the C group, families that had the lowest (47 percent) and highest (89 percent) germination had, respectively, 50.7 and 49.4 percent acorn MC. The family that had the lowest MC (44.9 percent) had 81 percent germination. It is possible that besides MC, other factors, which are not readily apparent in this study, may contribute to low germination in some white oak families.

Because the germination percentage was extremely low for the 20MC treatment, differences in growth parameters were analyzed for the other three treatments (table 1). No treatment differences were observed for growth parameters such as HT, RCD, number of FOLR, or lateral root fibrosity. The percentage of seedlings with a forked taproot was higher for the 40MC treatment than for the C or 30MC treatments. Although this experiment was not designed to test the effect of taproot forking on subsequent survival and growth of transplanted seedlings, seedlings with forked taproots are usually harder to plant.

Table 2 shows the percentage of white oak seedlings in each treatment group that satisfied a set of seedling grading standards based on those developed by Kormanik and others (1994, 1997) but with some modifications. A shorter standard for HT (45 cm vs. 70 cm) was used here. Seedlings that met minimum HT and RCD standards and had > 0 lateral root fibrosity were considered meeting the grading standards even if they had fewer than five FOLR. Treatment effects did not

change the percentage of seedlings meeting grading criteria (table 2), nor did they affect growth parameter means. Fewer than 30 percent of seedlings in any of the treatment groups met the grading standards. The percentage of seedlings that met the standards was lower for seedlings having a forked taproot than for those that did not have a forked taproot.

As with white oak MC, northern red oak acorn MC at sowing affected germination but not subsequent seedling growth (table 3). However, northern red oak acorns were less sensitive to drying than were white oak acorns. Germination percentages for the C and 35MC treatments did not differ. And, acorns with MC as low as 15 percent still had 46 percent germination (table 3). Although family affected germination percentages significantly, no correlation was found between day zero MC (which ranged from 34.4 to 42.9 percent) and germination percentage (which ranged from 71 to 97 percent) of the C group acorns.

Less than 0.5 percent of northern red oak seedlings had forked taproots in any treatment group (data not shown). Between 37 and 45 percent of northern red oak seedlings in each treatment met the grading standards (data not shown). Treatment means for northern red oak seedlings that met the standards were 89 to 99 cm for HT, 12.2 to 12.6 mm for RCD, and 9.3 to 9.6 for FOLR number. Treatment means for seedlings that did not meet the standards were 44 to 47 cm for HT, 7.8 to 8.4 mm for RCD, and 1.7 to 2.8 for FOLR number.

## Experiment 2

In experiment 1, a high percentage of white oak acorns in some families started radicle protrusion during air-drying treatment or in cold storage. Therefore, experiment 2 was implemented within 2 weeks of acorn collection so that the effect of radicle damage would not be confounded with the effects of acorn MC on germination and growth. As in experiment 1, drying treatment in experiment 2 decreased germination but not subsequent seedling growth. Furthermore, soaking the 25MC acorns only increased their germination

**Table 2—Effects of white oak acorn moisture content at sowing on first-year (2003) seedling grading results**

Treatment	Meet grading standard <sup>a</sup>	Seedlings	HT	RCD	FOLR	Lateral root fibrosity ranking <sup>b</sup>	Seedlings with forked taproot
<i>Percent MC</i>		<i>%</i>	<i>cm</i>	<i>mm</i>	<i>no.</i>		<i>percent</i>
C (48MC)	Yes	23	65	11.0	7.9	1.24	17
	No	77	28	7.2	1.5	0.52	31
40MC	Yes	28	71	11.1	8.3	1.31	26
	No	72	28	7.3	1.1	0.47	40
30MC	Yes	23	74	11.6	9.8	0.91	4
	No	76	26	6.9	1.2	0.45	25
20MC	Yes	20	69	12.0	12.5	1.25	0
	No	80	26	6.8	2.3	0.69	13

HT = height; RCD = root-collar diameter; FOLR = first-order lateral roots; MC = moisture content.

<sup>a</sup> All 10 families were included in grading. Grading standards were 45 cm HT, 8 mm RCD, and 5 FOLR or presence of fibrous roots.

<sup>b</sup> Ranking of lateral root fibrosity was: 0 = absence of fine (<0.5 mm in diameter) lateral roots on taproots; 1 = few fine lateral roots on taproots; 2 = intermediate number of fine lateral roots on taproots; and 3 = many fine lateral roots on taproots.

**Table 3—Effect of northern red oak acorn moisture content at sowing on germination and first-year seedling growth in 2003**

Treatment	Germ <sup>a</sup>	HT <sup>b</sup>	RCD	FOLR
% MC	%	cm	mm	no.
C (39MC)	84c	68a	10.0a	5.7a
35MC	80c	67a	10.0a	5.4a
25MC	68b	66a	9.8a	5.3a
15MC	46a	66a	9.9a	5.2a

Germ = germination; HT = height; RCD = root-collar diameter; FOLR = first-order lateral roots; MC = moisture content.

Means in a column followed by the same letter are not significantly different at the 0.05 level.

<sup>a</sup> All 10 families were included in the statistical analysis.

<sup>b</sup> Eight families that had seedlings in every treatment were included in the statistical analysis for all growth parameters.

percentage to half that of the C acorns, although their MC was increased to a level similar to that of the C acorns (table 4). Even the 33S acorns did not have germination percentage as high as that of the C or CS acorns. Since the MC of these soaked acorns almost reached the MC of the C acorns, some irreversible damage must have occurred in some 25S and 33S acorns and rendered them not viable.

For treatments C, CS, 33MC, 33S, 25MC, and 25S, the percentages of white oak seedlings that met the grading standards were 20, 19, 19, 21, 12, and 16, respectively. Mean treatment growth parameters in experiment 2 (data not shown) were similar to those of white oak seedlings in experiment 1.

The cause of taproot forking observed with white oak seedlings in this study is not known. Table 5 presents the results of

our efforts to identify any correlation between taproot forking and seedling growth. To avoid the confounding effect of the air-drying treatment, only the control groups in experiments 1 and 2 were analyzed. Also, all 10 families in experiment 1 and all 8 families in experiment 2 were included. Growth means for seedlings with forked taproots did not differ meaningfully from those for seedlings without forked taproots in either experiment. The percentage of white oak seedlings with forked taproots was higher in experiment 1, in which many acorns had radicle protrusion before sowing, than in experiment 2 (table 5). Furthermore, only 6 percent of seedlings with forked taproots met the grading standards in both experiments, whereas about 20 percent of seedlings with nonforked taproots met the grading standards. Barden and Bowersox (1991) showed that cutting off 50 percent of each protruding radicle before sowing increased northern red oak first-year seedling growth but not the first-year growth after transplanting. They did not report any taproot forking in their study. A more detailed study is needed of the effects of various kinds of damage to the protruding radicle before sowing on white oak germination and subsequent seedling growth, including taproot forking.

## CONCLUSIONS

Germination of white oak acorns was very sensitive to acorn MC at sowing. Air drying of white oak acorns to 30 percent or lower MC resulted in < 25 percent germination. Soaking of the air-dried acorns helped increase germination to some extent. Air drying of northern red oak acorns to 15 percent MC decreased germination to about half that of the control acorns. First-year seedling growth in the nursery was not affected by acorn MC at sowing for either oak species. To achieve successful artificial oak regeneration, the first step is to collect acorns before they start to dry in the field. Soaking should help germination if the acorns have not lost too much moisture.

**Table 4—Effects of white oak acorn moisture content (MC) at sowing on germination and first-year seedling growth in 2004. Acorns were air dried to the target MC and half of them were then soaked for 48 hours before sowing**

Treatment	MC at sowing	Germ <sup>a</sup>	HT <sup>b</sup>	RCD	FOLR	Lateral root fibrosity ranking <sup>c</sup>	Seedling with forked taproot
	--- percent ---		cm	mm	no.		percent
C	49	90e	34a	7.5a	3.6a	0.45a	12a
C+soak	49	88e	34a	7.5a	3.9a	0.42a	14a
33MC	33	57c	34a	7.7a	4.4a	0.43a	19a
33MC+soak	48	73d	33a	7.7a	3.9a	0.48a	19a
25MC	25	22a	31a	7.0a	3.2a	0.30a	12a
25MC+soak	46	42b	32a	7.5a	3.6a	0.53a	14a

MC = moisture content; Germ = germination; HT = height; RCD = root-collar diameter; FOLR = first-order lateral roots.

Means in a column followed by the same letter are not significantly different at the 0.05 level.

<sup>a</sup> All eight families were included in the statistical analysis.

<sup>b</sup> Seven families that had seedlings in every treatment were included in the statistical analysis for all growth parameters.

<sup>c</sup> Ranking of lateral root fibrosity was: 0 = absence of fine (<0.5 mm in diameter) lateral roots on taproots; 1 = few fine lateral roots on taproots; 2 = intermediate number of fine lateral roots on taproots; and 3 = many fine lateral roots on taproots.

**Table 5—Comparisons of white oak seedling growth of the controls in experiments I and II. Many acorns in experiment 1 had radicle protrusion at sowing and very few had radicle protrusion in experiment 2**

Item	Experiment 1 <sup>a</sup>		Experiment 2 <sup>b</sup>	
	Forked	Nonforked	Forked	Nonforked
Seedlings (%)	28	72	13	87
HT (cm)	32	39	30	34
RCD (mm)	7.9	8.2	7.2	7.6
FOLR (no.)	1.4	3.5	2.5	3.7
Lateral root fibrosity <sup>c</sup>	0.79	0.65	0.52	0.43
Meeting grading standard (%) <sup>d</sup>	6	21	6	19

HT = height; RCD = root-collar diameter; FOLR = first-order lateral roots.

<sup>a</sup> All 10 families were included.

<sup>b</sup> All eight families were included.

<sup>c</sup> Ranking of lateral root fibrosity was: 0 = absence of fine (<0.5 mm in diameter) lateral roots on taproots; 1 = few fine lateral roots on taproots; 2 = intermediate number of fine lateral roots on taproots; and 3 = many fine lateral roots on taproots.

<sup>d</sup> Grading standards were 45 cm HT, 8 mm RCD, and 5 FOLR or presence of fibrous roots.

## LITERATURE CITED

- Barden, C.J.; Bowersox, T.W. 1991. Effects of radicle clipping on subsequent growth of red oak seedlings in high and low moisture environments. In: Coleman, S.S.; Neary D.G., eds. Proceedings of the sixth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 131-137.
- Connor, K.F.; Sowa, S. 2003. Effects of desiccation on the physiology and biochemistry of *Quercus alba* acorns. *Tree Physiology*. 23: 1147-1152.
- Farmer, F.T., Jr. 1975. Long term storage of northern red and scarlet oak seed. *The Plant Propagator*. 21: 11-14.
- Finch-Savage, W.E.; Blake, P.S.; Clay, H.A. 1996. Desiccation stress in recalcitrant *Quercus robur* L. seeds results in lipid peroxidation and increased synthesis of jasmonates and abscisic acids. *Journal of Experimental Botany*. 47: 661-667.
- Gosling, P.G. 1989. The effect of drying *Quercus robur* acorns to different moisture contents, followed by storage, either with or without imbibition. *Forestry*. 62: 41-50.
- Kormanik, P.P.; Sung, S.S.; Kass, D.J. [and others]. 1998. Effect of seedling size and first-order lateral roots on early development of northern red oak on mesic sites. In: Waldrop, T.A., ed. Proceedings of the ninth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 247-252.
- Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. 1994. Toward a single nursery protocol for oak seedlings. In: Proceedings of the 22<sup>nd</sup> southern forest tree improvement conference. Publication No. 44. [Place of publication unknown]: Southern Forest Tree Improvement Center: 114-123.
- Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. [and others]. 1997. Heritability of first-order lateral roots in five *Quercus*: effect on 1-0 seedling quality evaluation. In: Steiner, K.C., ed. Diversity and adaptation in oak species. Proceedings of the second meeting of IUFRO working party 2.08.05, Genetics of *Quercus*. University Park, PA: Pennsylvania State University: 194-200.
- Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. [and others]. 2000. Heritability of first-order lateral root number in *Quercus*: implication for artificial regeneration of stands. In: Stokes, A., ed. Supporting roots of trees and woody plants: form, function and physiology. The Netherlands: Kluwer Academic Publishers. *Developments in Plant and Soil Sciences*. 87: 171-178.
- Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. [and others]. 2004. Northern red oak from acorns to acorns in 8 years or less. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 555-558.
- Özbingöl, N.; O'Reilly, C. 2005. Increasing acorn moisture content followed by freezing-storage enhances germination in pedunculate oak. *Forestry*. 78: 73-81
- Sander, I.L. 1990. Northern red oak (*Quercus rubra* L.). In: Burns, R.M.; Honkala, B.H., tech. coords. *Silvics of North America: 2. Hardwoods*. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 727-733.
- SAS Institute. 2004. SAS/STAT user's guide. Version 9.1. Cary, NC: SAS Institute. 5121 p.
- Schroeder, W.R.; Walker, D.S. 1987. Effects of moisture content and storage temperatures on germination of *Quercus macrocarpa* acorns. *Journal of Environmental Horticulture*. 5: 22-24.
- Sung, S.S.; Kormanik, P.P.; Zarnoch, S.J. 2002. Growth and development of first-year nursery-grown white oak seedlings of individual mother trees. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 346-351.
- Sung, S.S.; Kormanik, P.P.; Zarnoch, S.J. 2004. Flush development dynamics in first-year nursery-grown seedlings of eight oak species. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 542-546.

# STOCKTYPE AND HARVEST GAP SIZE INFLUENCE NORTHERN RED OAK REGENERATION SUCCESS

Douglass F. Jacobs, Ron A. Rathfon, Anthony S. Davis, and Don E. Carlson<sup>1</sup>

**Abstract**—Four different northern red oak (*Quercus rubra* L.) stocktypes (standard- or low-nursery-density bareroot seedlings and 11.4 or 18.9 L container seedlings) were outplanted into large-, medium-, and small-harvested gap openings (0.400, 0.024, and 0.100 ha, respectively) and closed-canopy control plots in southern Indiana. Two-year survival, height, and diameter were each lower in small gaps and control plots, but there were no differences between medium and large openings. Container seedlings had reduced survival compared to bareroot stock, which was attributed to root damage incurred during overwintering. Diameter growth of container seedlings was greater than that of bareroot stock, though height growth did not differ. Both initial and final height and diameter were greater for container than bareroot stock. Container stock in the two larger gap-opening treatments established a dominant, free-to-grow status. These results illustrate the potential suitability of certain gap opening sizes and stocktypes to promote oak regeneration after harvesting.

## INTRODUCTION

Northern red oak (*Quercus rubra* L.) is an important forest tree species of the Central Hardwood Forest Region, providing valuable timber, wildlife habitat, and recreation resources. Oak species have been present in this region for over 7,000 years (Davis 1981) and have dominated these forests through pre-settlement time (Dyer 2001). Trends toward reductions in both disturbance intensity and fire return intervals over the past approximately 100 years have shifted the proportion of small- to mid-size growing stock toward more shade-tolerant species (Abrams 1992), which will likely decrease the proportion of oak in future mature stands. Thus, ensuring adequate oak regeneration is a major concern of forest managers in this region.

Even-aged regeneration is the accepted system for successfully regenerating oak (Roach and Gingrich 1968, Sander and Graney 1992). Following a harvest disturbance, natural regeneration of oak may be successful if adequate oak advance regeneration or stump sprouting potential is present on the site and sufficient basal area is removed during harvest (Sander and Graney 1992).

In the Central Hardwood Region, disturbance areas are relatively small since much of the harvesting involves single-tree selection. Additionally, forest land is often divided into small ownership parcels, further limiting the area to which disturbance may be applied. In Indiana, for example, approximately 150,000 non-industrial private forest landowners own 85 percent of the 1.8 million ha of forests (Tormoehlen and others 2000). Many landowners are reluctant to clearcut and may favor creating small circular group openings to provide adequate light to regenerate oak. Though the recommended diameter of these openings is 1 to 2 times the height of the surrounding dominant trees (Sander and Graney 1992), relatively few studies have examined response of planted seedlings to an array of gap opening sizes.

Most hardwood tree plantings in Indiana involve afforestation plantings of bareroot seedlings (Jacobs 2003, Jacobs and others 2004). These plantings have had variable success,

with mean survival during the first 5 years estimated at 65 percent and < 50 percent of seedlings considered free-to-grow by age 5 (Jacobs and others 2004). Inconsistent plantation establishment success of oaks has often been associated with competing vegetation, damage from animal browse, and poor seedling quality (Jacobs and others 2004, Johnson and others 2002).

Artificial oak regeneration may be improved by using large, vigorous, bareroot seedlings (Jacobs and others in press, Johnson and others 2002, Schultz and Thompson 1997). Additionally, advances in nursery production techniques for forest tree seedlings have resulted in the availability of new stocktypes that may further improve oak regeneration success. For instance, use of container seedlings reduced water stress of planted northern red oak seedlings on a mine reclamation site (Davis and Jacobs 2004). Dey and others (2004) found that use of large (i.e., 11 to 19 L) container stock may enhance early plantation development of oaks on floodplain sites. The potential for large container stock to improve oak regeneration success in harvested gap openings has not been thoroughly examined. Thus, our objectives were to (1) examine potential for large container stock to enhance northern red oak establishment success in harvested gap openings compared to traditional bareroot stock and (2) determine the effect of gap opening size on seedling establishment success.

## MATERIALS AND METHODS

### Study Site

The study was conducted at the Southern Indiana Purdue Agricultural Center near Dubois, IN. Four different forest stands with relatively uniform site conditions within a stand (i.e., slope, aspect, dominant tree species, pre-harvest basal area, etc.) were identified. Aspect differed among the stands, ranging from north, east, south, or southwest. The pre-harvest stands contained a substantial proportion of both red and white oak.

Circular gap opening treatments were randomly allocated within each stand; treatments consisted of a large (0.400 ha),

<sup>1</sup> Assistant Professor, Extension Forester, Graduate Research Assistant, and Forester, respectively, Purdue University, Department of Forestry and Natural Resources, West Lafayette, IN 47907.

medium (0.100 ha), or small (0.024 ha) opening and a 0.100-ha control (no harvest). Harvest gap-diameters were 73.2, 36.6, 18.3, and 0 m, respectively. Since heights of adjacent dominant trees were in the range of 25 to 35 m, the medium- and large-gap openings represented the approximate recommended range of 1 to 2 times the height of the surrounding dominant trees (Sander and Graney 1992). Harvesting was conducted during the winter of 2002-2003. Trees were harvested using chain saws; merchantable logs were cut to length and skidded from the site by tractor. All stems < 5 cm d.b.h. were cut and stumps treated with herbicide.

### Plant Material and Study Establishment

Northern red oak seedlings were planted into the site in spring 2002. Stocktypes consisted of low (LD) and high (HD) nursery-bed-density bareroot seedlings, or small (SC) and large container (LC) seedlings. Bareroot seedlings were obtained from the Indiana Department of Natural Resources Vallonia Nursery near Vallonia, IN. Seedlings were grown during 2001 using standard nursery practices (Jacobs 2003) at either the operational nursery-bed spacing of 75 seedlings m<sup>-2</sup> (HD) or at a density of 21 seedlings m<sup>-2</sup> (LD), which was achieved by thinning during early spring. Seedlings were lifted in fall, 2001, and cold stored (2 °C) prior to transport to the planting site. Container stock consisted of 11.4 (SC) or 18.9 L (LC) seedlings that were operationally grown during 2000-2001 at the Woody Warehouse near Lizton, IN. Seedlings were initially grown in 650 cm<sup>3</sup> pots and transplanted into larger pots for the second year of growth. Container seedlings were transported to the field site in late 2001 and overwintered outside in the growing pots.

All seedlings were planted in spring, 2001, using shovels. Due to the uneven size of the gap openings, the number of planted seedlings varied within an opening. Additionally, to ensure that adequate numbers of seedlings were available for the study, planting density varied by opening treatment ranging from 7.6 × 6.7 m for the large opening, 4.6 × 4.6 m for the medium opening and control, and 3.6 × 3.6 m for the small opening. This resulted in a total number of 60, 40, 40, or 20 seedlings planted for the large, medium, control, and small openings, respectively. An equal number of seedlings were planted per stocktype treatment within a particular gap opening size. Immediately following plantings, seedlings were measured for height and root-collar diameter (RCD). Following the first two growing seasons, seedlings were assessed for survival and re-measured for height and RCD.

### Experimental Design and Data Analysis

The study was established as a randomized complete block design with factorial treatment structure (4 gap openings × 4 stocktypes). Each of the four forest stands comprised a replication. A sampling unit consisted of each individual seedling, and the experimental unit for data analysis was the mean response value for a treatment within a replicate. Data were analyzed using Analysis of Variance (ANOVA). When significant ( $P < 0.05$ ) treatment differences were detected in the ANOVA, Tukey's highly significant differences test was used to separate treatment means at  $\alpha = 0.05$ .

## RESULTS AND DISCUSSION

### Harvest Gap Openings

First- and second-year seedling survival differed significantly among gap size openings (table 1). Seedlings planted into large and medium openings had second-year survival of 68 to 78 percent, while survival in the small opening was 50 percent and that in the control was only 23 percent (fig. 1). Gap openings similarly affected total height and RCD, as well as RCD growth (table 1). No significant differences were detected between the large and medium openings, but seedlings in the small opening had significantly lower total height and RCD compared to the large and medium openings (fig. 2). Seedlings in the non-harvested control plot had the lowest mean total height and RCD (fig. 2). These results help confirm the contention of Sander and Graney (1992) that gap diameters should be at least 1 to 2 times the height of adjacent dominant trees. Smaller gaps create a large ratio of perimeter to opening area (Johnson and others 2002), thereby limiting the amount of light that seedlings receive. A threshold level exists beyond which growth is affected; this level was reached in our study in the 0.100-ha openings.

### Stocktypes

Stocktype affected survival during both growing seasons (table 1), with container seedlings having significantly lower survival than bareroot stock during each growing season (fig. 1). Bareroot stock had 68 to 70 percent survival after the second growing season, compared to a range of 44 to 52 percent mean survival for container stock (fig. 1). Although LC had greater survival than SC during the first growing season (64 versus 48 percent), differences were non-significant after the second growing season (fig. 1).

We attributed the reduced survival of container stock primarily to differences in overwintering procedures. While bareroot stock was stored in a controlled cooler environment throughout winter, container seedlings were subjected to winter freeze-thaw events during outdoor storage adjacent to the site. Roots are more sensitive than shoots to cold temperatures, and at time of planting we noticed substantial root damage to some container seedlings. This likely contributed to the reduced survival of container stock. Furthermore, a significant gap opening × stocktype interaction effect was detected for survival (table 1). This was a reflection of

**Table 1—Analysis of variance results for effects of gap opening and stocktype treatments on survival, shoot height, and root-collar diameter (RCD) response variables**

Response variable	Gap size	Stocktype	Gap size X stocktype
	----- P-value -----		
Survival – year 1	< 0.0001	< 0.0001	0.0002
Survival – year 2	< 0.0001	< 0.0001	0.0038
Height - initial	0.1387	< 0.0001	0.4267
Height – growth	0.4837	0.2128	0.1353
Height – final	< 0.0001	< 0.0001	0.1039
RCD - initial	0.7449	< 0.0001	0.0523
RCD – growth	< 0.0001	< 0.0001	0.7524
RCD – final	< 0.0001	< 0.0001	0.6740

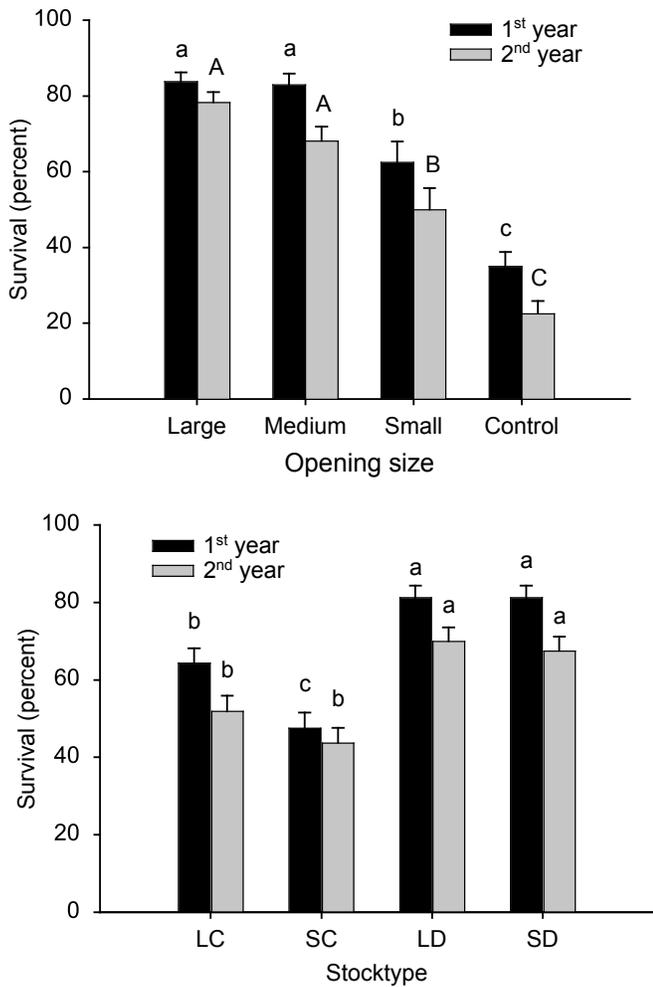


Figure 1—First- and second-year northern oak seedling survival as affected by gap size (top) and stocktype (bottom). Gap treatments consisted of large (0.400 ha), medium (0.100 ha), or small (0.024 ha) openings and a control (no opening). Stocktype treatments included 18.9- or 11.4-L container stock (LC and SC, respectively) or low- or high-density bareroot stock (LD and HD, respectively). For either gap size or container treatments, treatments with similar letter groupings within a sampling year were not statistically different at  $\alpha = 0.05$ .

increased mortality for container versus bareroot seedlings planted into non-harvested control plots. The larger container seedlings (fig. 3) likely had greater respiratory demand compared to bareroot stock, and low light levels within the control plots probably did not allow for adequate photosynthetic assimilation to meet basic physiological maintenance requirements. This effect further contributed toward the decreased mean survival of container seedlings when averaged across all gap openings.

Stocktypes varied in initial height and RCD (table 1), with container stock being significantly larger for both traits compared to bareroot stock. Initial mean height and RCD for container stock ranged from 165 to 169 cm and 1.4 to 1.6 cm, respectively, compared to 52 to 53 cm and 0.6 to 0.7 cm, respectively, for bareroot stock. Dey and others (2004) reported similar discrepancies in initial size of large container versus bareroot stock of pin oak (*Quercus palustris* Muenchh.) and swamp white oak (*Quercus bicolor* Willd.). Height growth

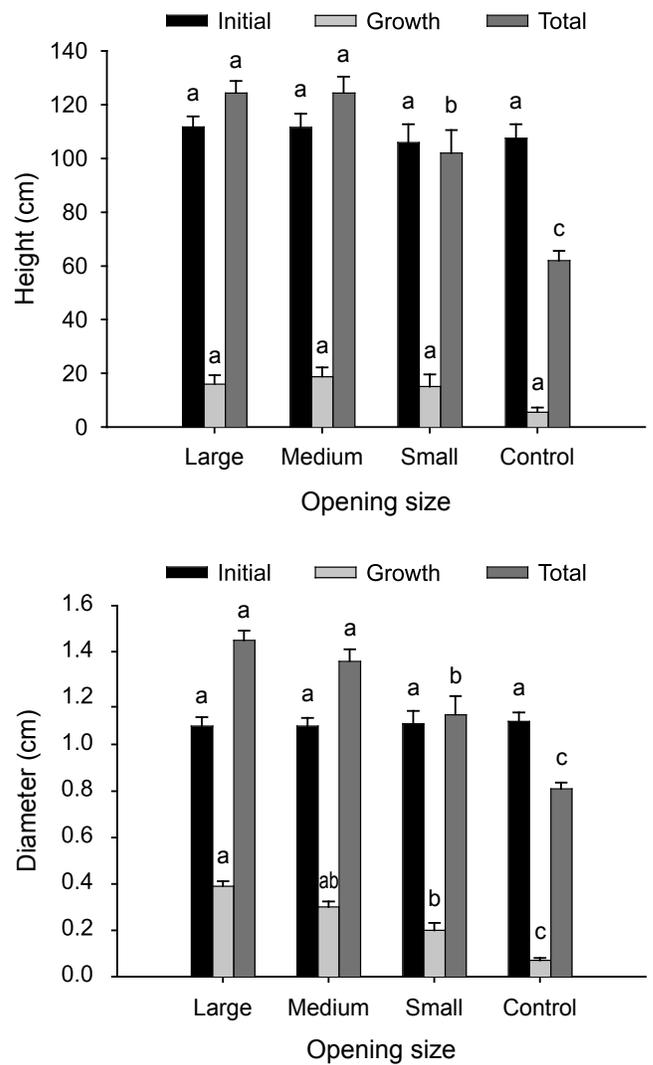


Figure 2—Initial, 2-year growth and total height (top), and root-collar diameter (bottom) as affected by gap size. Gap treatments consisted of large (0.400 ha), medium (0.100 ha), or small (0.024 ha) openings and a control (no opening). For either initial, 2-year growth, or total response, treatments with similar letter groupings within a sampling year were not statistically different at  $\alpha = 0.05$ .

during the two growing seasons was not affected by stocktype, though container seedlings had significantly greater RCD growth than bareroot seedlings (table 1, fig. 3). Oak seedlings tend to allocate significant resources toward root versus shoot growth during establishment (Johnson and others 2002), which serves as an adaptive mechanism to help resist drought. Since seedling root proliferation is well correlated with RCD (Jacobs and Seifert 2004), container seedlings were able to establish larger root systems for resource acquisition, which should continue to facilitate growth over time.

### Management Implications

Ensuring adequate oak regeneration following harvest is an important objective for many landowners. On some sites, reliance on natural regeneration is not likely to facilitate maintenance of a large oak component in the ensuing stand. Artificial regeneration may offer a means to help enhance oak regeneration on these sites.

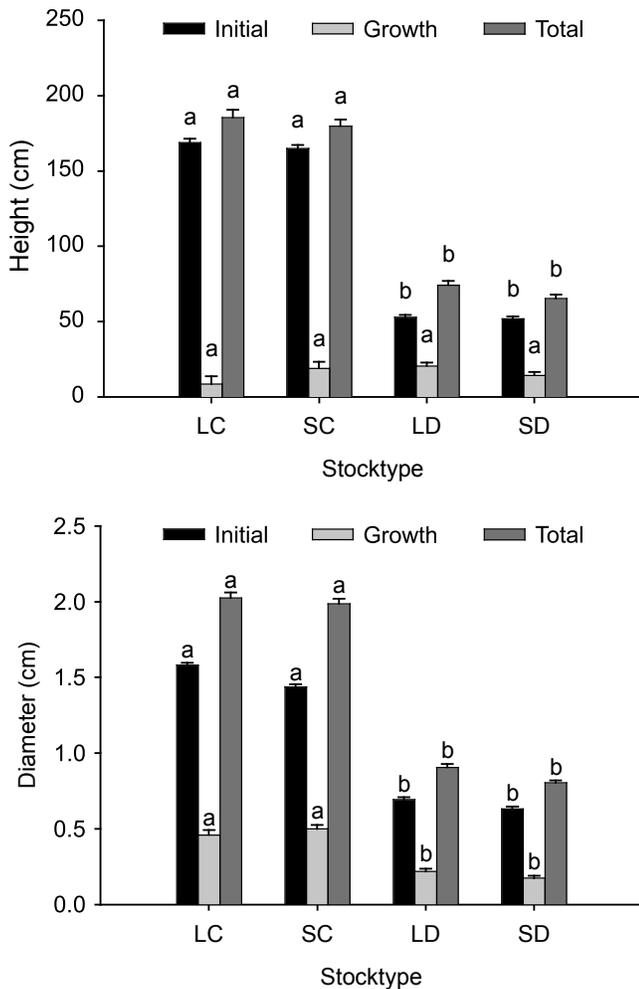


Figure 3—Initial, 2-year growth and total height (top), and root-collar diameter (bottom) as affected by stocktype. Stocktype treatments included 18.9- or 11.4-L container stock (LC and SC, respectively) or low- or high-density bareroot stock (LD and HD, respectively). For either initial, 2-year growth, or total response, treatments with similar letter groupings within a sampling year were not statistically different at  $\alpha = 0.05$ .

A clear advantage of using large container stock is that the planted seedlings are in a free-to-grow state (i.e., above levels of deer browse and competing vegetation) at time of planting. For instance, initial mean height for container stock in this study was > 165 cm. An obvious disadvantage is the higher seedling cost and increased transport and labor requirements to plant this large stock. Greater costs may restrict use of large container stock to specific sites where natural oak regeneration is unlikely to be successful or to small-scale reforestation projects for which landowners are willing to pay a premium to ensure maintenance of oak in the succeeding stand. When using container stock, it is critical to ensure that seedlings are overwintered properly to alleviate potential for damage as documented in this study. Since large container seedlings require substantial cooler space for winter storage, they are often operationally stored outside in a horizontal position with insulating cover.

Our data also suggests that there is little variation in northern red oak seedling establishment success within a gap opening range of 0.100 to 0.400 ha. As the forest canopy continues to

converge over time in these gaps, we expect that these results may change. Additionally, we observed prolific yellow poplar (*Liriodendron tulipifera* L.) regeneration in the larger gap openings. Long-term evaluation of this site will be useful to determine if established oak seedlings are able to maintain dominance within the stand.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Abrams, M.D. 1992. Fire and the development of oak forests. *Bioscience*. 42: 346-353.
- Davis, M.B. 1981. Quaternary history and the stability of forest communities. In: West, D.C.; Shugart, H.H.; Botkin, D.B., eds. *Forest succession: concepts and applications*. New York: Springer-Verlag: 132-153.
- Davis, A.S.; Jacobs, D.F. 2004. First-year survival of northern red oak seedlings planted on former surface coal mines in Indiana. In: Barnhisel, R.L., ed. *Proceedings of a joint conference of American Society of Mining and Reclamation 21<sup>st</sup> annual national conference and 25<sup>th</sup> West Virginia surface mine drainage task force symposium*. Lexington, KY: American Society of Mining and Reclamation: 480-502.
- Dey, D.; Lovelace, W.; Kabirck, J.M.; Gold, M.A. 2004. Production and early field performance of RPM<sup>®</sup> seedlings in Missouri floodplains. In Michler, C.H.; Pijut, P.M.; Van Sambeek, J. [and others], eds. *Proceedings of the sixth black walnut symposium*. Gen. Tech. Rep. NC-243. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 59-65.
- Dyer, J.M. 2001. Using witness trees to assess forest change in southeastern Ohio. *Canadian Journal of Forest Research*. 31: 1708-1718.
- Jacobs, D.F. 2003. Nursery production of hardwood seedlings. FNR-212. West Lafayette, IN: Purdue University Cooperative Extension Service. 8 p.
- Jacobs, D.F.; Ross-Davis, A.; Davis, A.S. 2004. Establishment success of conservation tree plantations in relation to silvicultural practices in Indiana, USA. *New Forests*. 28: 23-36.
- Jacobs, D.F.; Seifert, J.R. 2004. Re-evaluating the significance of the first-order lateral root grading criterion for hardwood seedlings. In: Yaussy, D.; Hix, D.M.; Goebel, P.C.; Long, R.P., eds. *Proceedings of the fourteenth central hardwood forest conference*. Gen. Tech. Rep. NE-316. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 382-388.
- Jacobs, D.F.; Salifu, K.F.; Seifert, J.R. [In press]. Relative contribution of initial root and shoot morphology in predicting field performance of hardwood seedlings. *New Forests*.
- Johnson, P.S.; Shifley, S.R.; Rogers, R. 2002. *The ecology and silviculture of oaks*. New York, NY: CABI Publishing. 503 p.
- Roach, B.A.; Gingrich, S.F. 1968. Even-aged silviculture for upland central hardwoods. *Agric. Handb.* 355. Washington, DC: U.S. Department of Agriculture, Forest Service. 39 p.
- Sander, I.L.; Graney, D.L. 1992. Regenerating oaks in the central states. In: Loftis, D.L.; McGee, C.E., eds. *Oak regeneration: serious problems practical recommendations*. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Experiment Station: 174-183.
- Schultz, R.C.; Thompson, J.R. 1997. Effect of density control and undercutting on root morphology of 1+ 0 bareroot hardwood seedlings: five-year field performance of root-graded stock in central USA. *New Forests*. 13: 297-310.
- Tormoehlen, B.; Gallion, J.; Schmidt, T.L. 2000. *Forests of Indiana: a 1998 overview*. Tech. Publ. NA-03-00. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. 17 p.

# HOW DOES PROLONGED EXPOSURE TO NATURAL CONDITIONS AFFECT ACORN MOISTURE AND VIABILITY?

Kristina Connor, Jillian Donahoo, and Gretchen Schafer<sup>1</sup>

**Abstract**—After placing acorns on a lab bench to dry, we saw changes in moisture content, germination, and seed biochemistry in as few as 3 days. As drying progressed, we found that irrevocable damage to membrane lipids and protein secondary structure occurred in just 5 days. However, we did not know if these experiments mimic what happens to acorns in the field. We cleared an area beneath two open-grown white oak (*Quercus alba* L.) trees and collected acorns after they were shed. Acorns found each morning under the trees were marked with spots of paint, different colors for each day. Five hundred acorns were marked each day, and the remaining acorns were raked from the site. The experiment continued until acorns shed from the trees dropped below 500. We found that, unlike the laboratory experiment, acorn germination showed no distinct pattern of decreasing viability. Additionally, moisture content of the acorns from both trees remained relatively high, never dropping below 35 percent. The high moisture content was no doubt in some part due to the 8 days of precipitation that occurred during each tree's collection period. We also confirmed that insect damage was more prevalent on acorns first shed from the trees.

## INTRODUCTION

Desiccation-resistant seeds can be dried without damage to a moisture content (MC) of  $\leq 12$  percent and stored for long periods of time, while the viability of recalcitrant, or desiccation-sensitive, seeds is affected by moisture loss and/or cold temperatures (Roberts 1973). This susceptibility to drying makes any period of storage for some temperate recalcitrant seeds very short, while others, such as water oak (*Quercus nigra* L.), can survive for 3 years under proper storage conditions (Connor and Bonner 1999). Hypotheses to explain the physiological basis of recalcitrance include (1) changes in membrane and storage lipids (Flood and Sinclair 1981, Pierce and Abdel Samad 1980); (2) physical disruption of seed membranes (Seewaldt and others 1981, Simon 1974); (3) changes in seed proteins and carbohydrates (Bochicchio and others 1997, Finch-Savage and others 1994, Golovina and others 1997, Greggains and others 2000); (4) changes in the water properties of desiccating seeds (Farrant and others 1985, 1988); and (5) aberrant metabolic processes during hydrated storage and as water is lost (Pammenter and others 1994).

In earlier laboratory experiments on temperate recalcitrant seeds (Connor and Sowa 2003, 2004; Sowa and Connor 2003), we found that marked changes in seed biochemistry can occur in just 3 days, and irrevocable damage to membrane lipids and protein secondary structure can occur in just 5 days. In these laboratory experiments, acorns were spread on lab benches and left to dry at room temperature and ambient relative humidity. Moisture was completely excluded until acorns were rehydrated prior to germination testing. While these experiments have provided much information on biochemical changes that occur during desiccation, we do not know if they reflect what happens to acorns in the field. The objectives of this experiment were to determine what changes in MC and germination occurred in acorns left exposed to natural conditions. We also evaluated the percentage of collected acorns that had insect damage.

## MATERIALS AND METHODS

Acorn collections began when the daily number of acorns shed reached at least 500 under each of the two open-grown white oak (*Q. alba* L.) study trees near Starkville, MS. The collected acorns were marked with Uni-Paint® PX-21 Opaque oil-base paint-marking pens (Mitsubishi Pencil Company), a different color or color combination for each day. Remaining acorns were raked aside so that only freshly shed acorns were collected each day. Marked acorns were transported to an area with few predators and placed under the canopy of a (non-oak) tree. The experiment on each tree ended when acorn fall dropped below 500 acorns per day. On the last day of collection (October 26, 2004, for tree one and October 31, 2004, for tree two), all marked acorns were brought to the lab. The following experiments were performed on each day's collection of acorns:

1. Germination tests: White oak acorns were soaked overnight in tap water prior to viability testing. The end of the acorn with the cup scar was cut off and discarded. The acorns were then placed cut-side-down on moist Kimpac® under a diurnal cycle of 20 °C for 16 hours in the dark and 30 °C for 8 hours with light. Germination was tallied weekly for up to 4 weeks on 6 replications of 50 acorns from each day's collection. The number of acorns that germinated while acorns were still in the field was also recorded.
2. Moisture content: Whole acorns chopped into pieces were used to determine MC. Samples were oven dried at 103 °C for  $17 \pm 1$  hours (Bonner 1981, International Seed Testing Association 1993). Measurements were made on five replications of three acorns each.
3. Damage: Bug damage was recorded for each acorn cut open and used in the above two measurements and for all other acorns collected. Damage was recorded as either present or absent.
4. Weather information: Minimum and maximum temperatures, relative humidity, and rainfall data were obtained from the Mississippi State University weather site.

<sup>1</sup> Project Leader, USDA Forest Service, Southern Research Station, Auburn, AL 36842; and Technicians, USDA Forest Service, Southern Research Station, Mississippi State, MS 39762, respectively.

## RESULTS AND DISCUSSION

### Acorn Germination and MC: Laboratory Experiments

White oak acorns, among the most recalcitrant of the Fagaceae, are high in carbohydrates and, when freshly collected, have a higher MC than acorns that have a high lipid content such as water oak (*Q. nigra* L.) or cherrybark oak (*Q. pagoda* Raf.) (Connor and Sowa 2004, Connor and others 1996). In laboratory experiments, where moisture was excluded, viability dropped below 50 percent when MC reached 27 percent (fig. 1). This happened, on average, in just 5 to 6 days. Additionally, biochemical and physiological changes were observed in as few as 3 to 5 days in these artificially dried acorns (Connor 2004, Connor and Sowa 2003, Sowa and Connor 2003).

### Acorn Field Experiments

**Acorn shed**—The two trees used in this experiment were large, open-grown trees no more than 100 m apart. Both had a bumper crop of acorns. The experiment spanned 21 days and began when acorn drop reached 500 acorns per day. The experiment on tree 1 ran from October 12 through October 26; the experiment on tree 2 ran from October 19 through November 1.

**Germination and MC**—Unlike in the laboratory experiments, germination tests on acorns left in the field gave variable results and no distinct pattern of decreasing viability (fig. 2). Additionally, MC of the acorns from both trees remained relatively high, never dropping below 37 percent on tree 1 and 35 percent on tree 2 (fig. 3). This is well above the MC obtained in laboratory drying experiments and, for the most part, the higher percent germination results reflect this. In the laboratory experiments, germination did not drop below 50 percent until moisture fell to 27 percent. The results from the field experiment are no doubt attributable to the moderating effects of the rainfall that occurred throughout the experiment. Although three times as much rainfall occurred over the collection period for tree 1 (October 12 through October 26, 2004) than for tree 2 (October 19 through October 31, 2004) (figs. 4 and 5), MC remained high in acorns from both trees. This was not surprising, because during the collection period

some precipitation occurred on 8 days at both trees, and although relative humidity did drop as low as 34 percent during the day, the maximum daily relative humidity never fell below 90 percent (fig. 6).

We believe that the random declines in acorn viability we observed are more a reflection of problems in the germination cabinets we used than of physiological changes. The number of acorns we tested filled every tray in the four germination cabinets. This restricted light penetration to some areas of the trays. Also, moisture accumulated on trays, resulting in mold growth. We think germination would have been uniformly high if moisture-wicking problems were controlled and mold growth reduced.

**Insect Damage**—Although the two trees were within 100 m of one another, insect damage on tree 1 was significantly higher than on tree 2 (fig. 7). On average, 66 percent of the

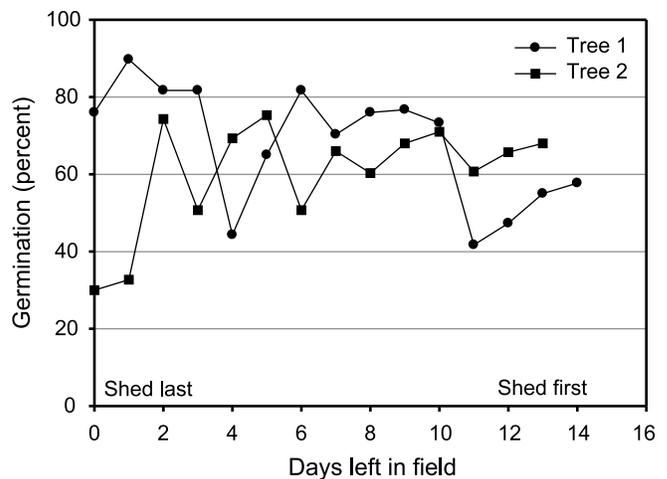


Figure 2—Germination of acorns from field experiment trees 1 and 2. Data points to the left of the graph represent acorns that remained on the ground the least amount of time (shed last) before being brought into the laboratory for analyses.

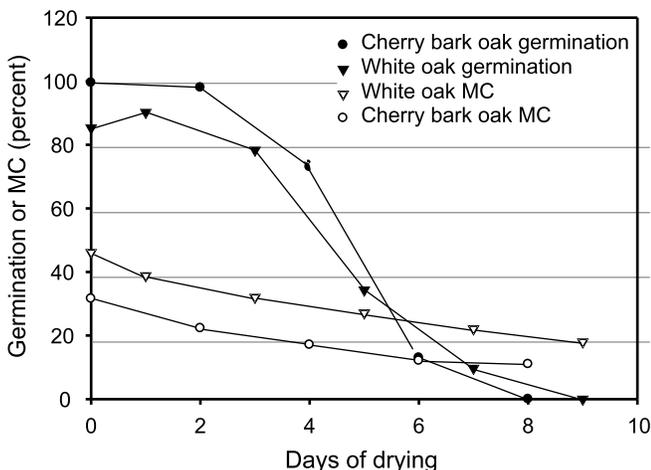


Figure 1—Germination and moisture content (MC) of white oak and cherrybark oak acorns desiccated in the laboratory over 8 to 10 days. From Connor and Sowa (2004).

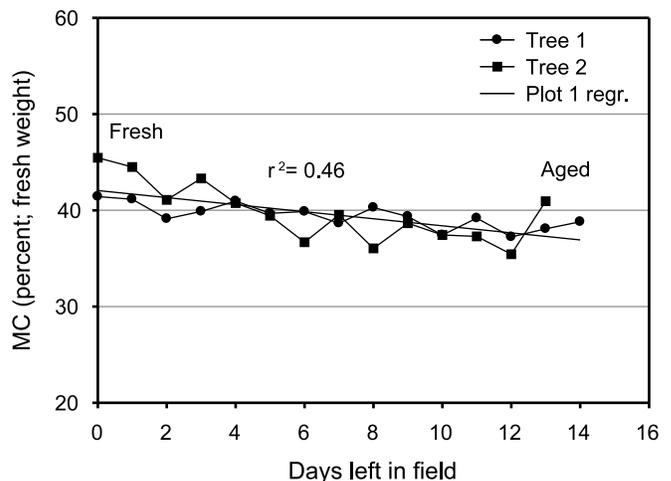


Figure 3—Moisture content (MC) (fresh-weight basis) of acorns collected from trees 1 and 2. Data points to the left of the graph represent acorns that remained on the ground the least amount of time (shed last) before being brought into the laboratory for analyses.

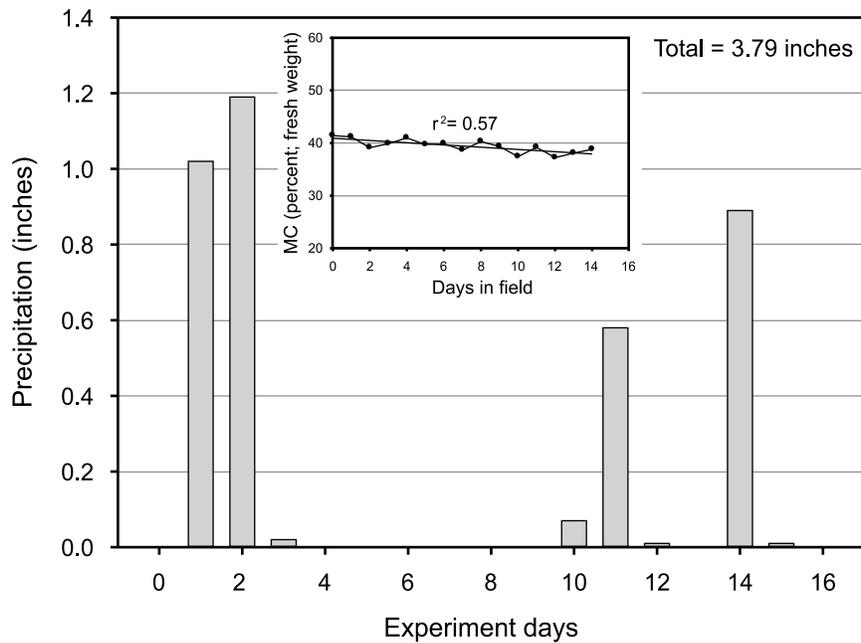


Figure 4—Precipitation during the acorn collection period for tree 1. MC = moisture content.

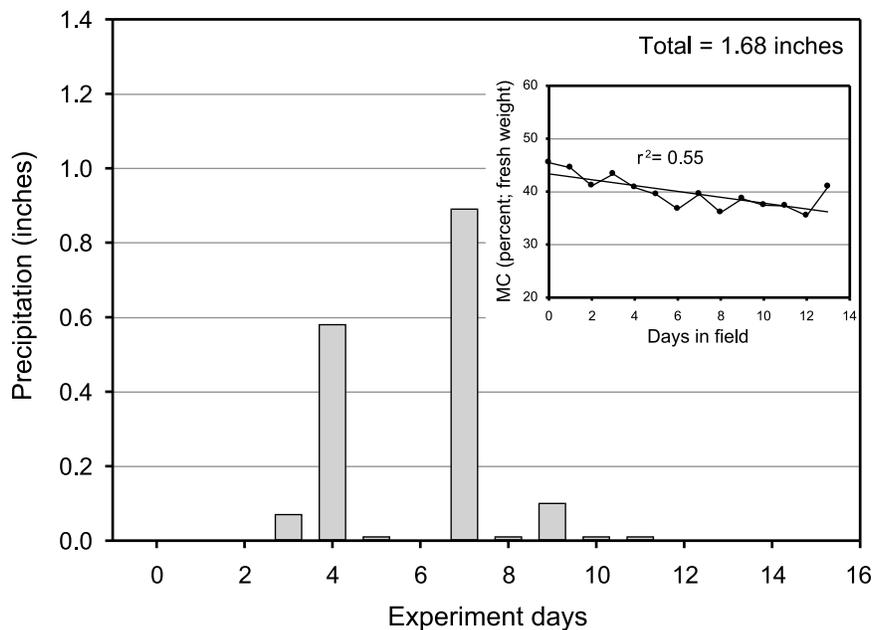


Figure 5—Precipitation during the acorn collection period for tree 2. MC = moisture content.

acorns collected from tree 1 in the first 4 days of the experiment were damaged, and this percentage did not drop below 40 percent for the duration of the experiment. Damage was much lower on tree 2, averaging 19 percent over the first 4 days. Damage on this tree also peaked early in the experiment, supporting the claim that damaged acorns are the first to fall. Because we did not begin collecting acorns until 500 per day were available, damage may very well have been even higher in the early drop.

## SUMMARY

We observed some interesting differences between the two *Q. alba* trees used in this experiment. Acorn shed began a full week earlier on tree 1 than on tree 2, despite the fact that they were < 100 m apart and exposed to the same meteorological conditions. This must signify significant morphological differences between the two trees in flowering times and acorn development. The high incidence of insect damage on tree 1 compared to tree 2 was surprising—again because of their proximity, but also because we have often collected acorns from tree 1 for experiments in good acorn production years and have never noted such a high percentage of damage.

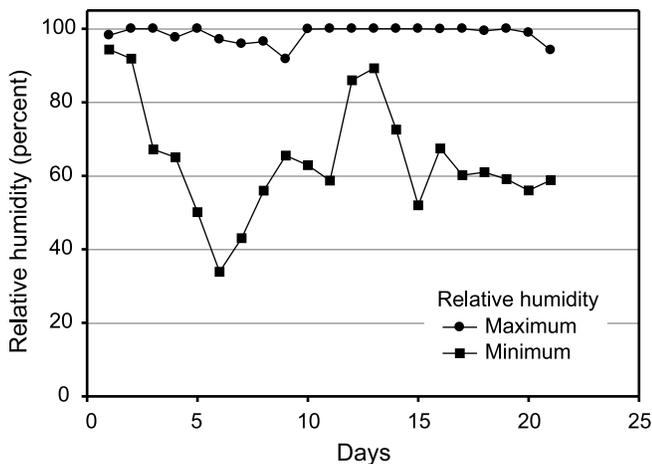


Figure 6—Maximum and minimum relative humidity data for the acorn field experiment.

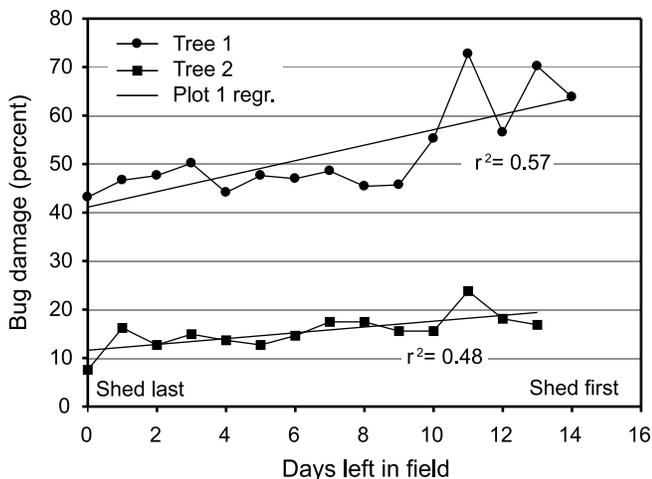


Figure 7—Percent of insect-damaged acorns collected from trees 1 and 2. Data points to the left of the graph represent acorns that remained on the ground the least amount of time (shed last) before being brought into the laboratory for analyses.

Moisture content remained fairly high in acorns from both trees, primarily, we believe, due to the amount of rainfall occurring during the experiment. These rainfall events also occurred over the entire collection period, thus keeping the ground moist and relative humidity high.

We believe that the high acorn germination in this experiment reflects the mild temperatures and significant rainfall that occurred during acorn drop, and also that care should be taken to make frequent collections during years when high temperature and low rainfall occur during acorn drop. While the results from this experiment have provided some interesting information, such tests obviously should be repeated before drawing any definite conclusions.

#### ACKNOWLEDGMENT

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#### LITERATURE CITED

- Bochicchio, A.; Vernieri, P.; Puliga, S. [and others]. 1997. 2. Desiccation tolerance in immature embryos of maize: sucrose, raffinose, and the ABA-sucrose relation. In: Ellis, R.H.; Black, M.; Murdoch, A.J.; Hong, T.D., eds. Basic and applied aspects of seed biology. Proceedings of the fifth international workshop on seeds; Reading, 1995. London: Kluwer Academic Publishers: 13-22.
- Bonner, F.T. 1981. Measurement and management of tree seed moisture. Res. Pap. S0-177. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Experiment Station. 11 p.
- Connor, K.F. 2004. An update on oak seed quality research: hardwood recalcitrant seeds. In: National proceedings of the forestry and conservation nursery associations 2003. RMRS-P-33. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 111-116.
- Connor, K.F.; Bonner, F.T. 1999. Effects of temperature and moisture content on the storability of hardwood seeds. In: Haywood, J.D., ed. Proceedings of the 10th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 123-126.
- Connor, K.F.; Bonner, F.T.; Vozzo, J.A. 1996. Effects of desiccation on temperate recalcitrant seeds: differential scanning calorimetry, gas chromatography, electron microscopy, and moisture studies on *Quercus nigra* and *Quercus alba*. Canadian Journal of Forest Research. 26: 1813-1821.
- Connor, K.F.; Sowa, S. 2003. Effects of desiccation on the physiology and biochemistry of *Quercus alba* acorns. Tree Physiology. 23: 1147-1152.
- Connor, K.F.; Sowa, S. 2004. The physiology and biochemistry of desiccating white oak and cherrybark oak acorns. In: Connor, K.F., ed. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 473-477.
- Farrant, J.M.; Berjak, P.; Pammenter, N.W. 1985. The effect of drying rate on viability retention of recalcitrant propagules of *Avicennia marina*. South African Journal of Botany. 51: 432-438.
- Farrant, J.M.; Pammenter, N.W.; Berjak, P. 1988. Recalcitrance – a current assessment. Seed Science and Technology. 16: 155-166.
- Finch-Savage, W.E.; Pramanik, S.K.; Bewley, J.D. 1994. The expression of dehydrin proteins in desiccation-sensitive (recalcitrant) seeds of temperate trees. Planta. 193: 478-485.
- Flood, R.G.; Sinclair, A. 1981. Fatty acid analysis of aged permeable and impermeable seeds of *Trifolium subterraneum* (subterranean clover). Seed Science and Technology. 9: 475-477.
- Greggains, V.; Finch-Savage, W.E.; Quick, W.P.; Atherton, N.M. 2000. Putative desiccation tolerance mechanisms in orthodox and recalcitrant seeds of the genus *Acer*. Seed Science Research. 10: 317-327.
- Golovina, E.A.; Wolkers, W.F.; Hoekstra, F.A. 1997. Behavior of membranes and proteins during natural seed aging. In: Ellis, R.H.; Black, M.; Murdoch, A.J.; Hong, T.D., eds. Basic and applied aspects of seed biology. Dordrecht: Kluwer Academic Publishers: 787-796.
- International Seed Testing Association. 1993. International rules for seed testing. Seed Science and Technology. 21 [supplement, rules]. 258 p.
- Pammenter, N.W.; Berjak, P.; Ross, G.; Smith, M.T. 1994. Why do hydrated, recalcitrant seeds die? Seed Science Research. 4: 187-191.
- Pierce, R.S.; Abdel Samad, M. 1980. Changes in fatty acid content of polar lipids during ageing of peanut (*Arachis hypogea* L.). Journal of Experimental Botany. 41: 1549-1557.
- Roberts, E.H. 1973. Predicting the storage life of seeds. Seed Science and Technology. 1: 499-514.
- Seewaldt, V.; Priestly, D.A.; Leopold, A.C. [and others]. 1981. Membrane organization of soybean seeds during hydration. Planta. 152: 19-23.
- Simon, E.W. 1974. Phospholipids and plant membrane permeability. New Phytologist. 73: 377-420.
- Sowa, S.; Connor, K.F. 2003. Recalcitrant behavior of cherrybark oak seed: an FT-IR study of desiccation sensitivity in *Quercus pagoda* Raf. acorns. Seed Technology. 25(2): 110-123.

# IMPACT OF DEFOLIATION ON HEIGHT AND DIAMETER OF A FIRST YEAR RISING COTTONWOOD PLANTATION

T. Keith Beatty, W. Doug Stone, and T. Evan Nebeker<sup>1</sup>

## Poster Summary

In 2003, an 8-year study was initiated to determine the impact of herbivores on three selected eastern cottonwood clones. The plantation, managed by MeadWestvaco, is located just north of Hayti, Pemiscot County, MO. Each clone was planted in 100 (10 x 10) tree plots. There was a total of 8 blocks, each of which contained all 3 clones (300 trees). Four of the eight blocks were not protected from defoliation (untreated) and the remaining four (treated) were treated with an insecticide to control the cottonwood leaf beetle (CLB) (*Chrysomela scripta* F.) and other incidental herbivores. The 8-year objective is to determine the overall losses and/or gains associated with controlling or not controlling defoliation caused primarily by the CLB.

Monthly height, ground-line diameter (gld), and degree of defoliation were recorded and statistically analyzed. Degree of defoliation (damage rating) utilized the Leaf Plastochron Index (LPI) 1 to 8 leaves to assess the severity of defoliation (Fang and Hart 2000, Larson and Isebrands 1971). A damage rating of 0 indicated no feeding on LPI 1 to 8 leaves whereas a damage rating of 4 indicated heavy feeding with > 50 percent of LPI 1 to 8 missing plus the main leader and terminal bud are severely damaged or destroyed.

The treated blocks received an insecticide treatment as needed throughout the growing season. Insecticide treatments reduced CLB feeding and held the damage rating below 1.0 throughout the growing season. Untreated blocks had damage ratings between 3.5 and 4.0 for September and October, 2003. Results clearly demonstrated that insecticide treatments can reduce CLB feeding and early volume loss. Significant differences in gld and height among treated and untreated blocks were observed during the first year. The greatest increase in both gld and height occurred in the treated blocks. In the untreated blocks, CLB caused significant growth reduction. Average volume loss across the stand was 72 percent. This was

similar to an earlier study by Coyle and others (2002) in that the above-ground volume was reduced by as much as 73 percent. Results from the first and second year of this study are reported in Nebeker and others (2006).

As cottonwoods continue to gain popularity, the need will arise for the control of pests that affect them. With CLB being a significant herbivore in this plantation culture, it is important that this pest be controlled to reduce growth loss and stress reduction.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Coyle, D.R.; McMillin, J.D.; Hall, R.B.; Hart, E.R. 2002. Cottonwood leaf beetle (Coleoptera: Chrysomelidae) defoliation impact on *Populus* growth and above-ground volume in a short-rotation woody crop. *Agricultural and Forest Entomology*. 4: 293-300.
- Fang, Y.; Hart, E.R. 2000. Effect of cottonwood leaf beetle (Coleoptera: Chrysomelidae) larval population levels on *Populus* terminal damage. *Environmental Entomology*. 29: 43-48.
- Larson, P.R.; Isebrands, J.G. 1971. The plastochron index as applied to developmental studies of cottonwood. *Canadian Journal of Forest Research*. 1: 1-11.
- Nebeker, T.E.; Stone, W.D.; Beatty, T.K. 2006. Impact of herbivory by cottonwood leaf beetle on three selected cottonwood clones: year 2 results. In: Connor, K.F., ed. *Proceedings of the 13<sup>th</sup> biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 420-423.

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<sup>1</sup> County Forester, Mississippi Forestry Commission, Kiln, MS 39556; Research Associate and Professor, respectively, Mississippi State University, Department of Entomology and Plant Pathology, Mississippi State, MS 39762.

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# SPECIES SELECTION TRIALS AND SILVICULTURAL TECHNIQUES FOR THE RESTORATION OF BOTTOMLAND HARDWOOD FORESTS— A 10 YEAR REVIEW

Kenneth W. McLeod, Michael R. Reed, Barbara P. Moyer, and Thomas G. Ciravolo<sup>1</sup>

**Abstract**—From 1992 to 1994, species trials were initiated in the Fourmile Branch delta to investigate the best methods of re-establishing tree species in a severely disturbed, thermally affected stream delta. Treatments examined included planting stock type, habitat, tree shelters, root pruning, and competition controls. Survival of most species, as determined in 1994 or 1996 and 2003, changed little over the past decade and was not strongly affected by the treatments within a trial, except for root pruning. Trees in many treatments have grown tremendously, but individuals with no competition controls generally grew more slowly. For example, *Taxodium distichum* Richard has had a high survival rate, regardless of whether planted as bareroot or balled-and-burlapped saplings, and have grown to 8 to 12 m in height. *Quercus lyrata* Walter, *Carya aquatica* (Michaux f.) Nuttall, *Q. nuttallii* Palmer, and *Q. phellos* L. planted in later trials also had adequate survival rates and have grown to 5+ m. Low mortality rates after the initial 3 to 4 years suggests that these species are appropriate for restoration. In contrast, survival of *Nyssa aquatica* L. and *Fraxinus pennsylvanica* Marshall have continually declined over time.

## INTRODUCTION

Clewell and Lea (1989) noted that many extant wetland forest creation and restoration projects in the Southeastern United States were not being monitored. Hence the relative merits of different species and techniques were not being evaluated. In the past 15 years, many more creation and restoration projects have been initiated across the Southeast. Due to the extended length of time required for a forested wetland to develop, many current projects have not been planted long enough to determine their ultimate success or failure (Mitsch and Wilson 1996). The restoration project discussed here reports a series of species trials, planted from 1992 to 1994. Initial responses after 3 to 4 years were reported in McLeod (2000), McLeod and others (2000), McLeod and others (2001) and Reed and McLeod (1994). Five of these trials have been censused recently, and the longer term response is reported to provide data to hopefully improve the success of other restoration projects. The nomenclature and acronyms originally used in McLeod (2000) have been retained to minimize confusion. Each of the five trials reported had different objectives:

Trial VIII - determine the effects of transplant type and tree shelters on survival and growth of three tree species in stream and backwater habitats

Trial IX - determine the effects of acclimation and tree shelters on survival and growth of three tree species in stream and backwater habitats

Trial X - determine the effects of root pruning on survival and growth of three tree species planted in flooded, unconsolidated muck soil

Trial XI - determine the effects of herbaceous competition control methods on survival and growth of six tree species

Trial XII - determine the effects of willow removal on survival and growth of four tree species

Our goal was to re-evaluate the specific treatment effects and the overall project success at 10 to 12 years (7 to 9 years after the initial census).

## SITE DESCRIPTION

The restoration site (Fourmile Branch delta) was impacted over 30 years (1955 to 1985) by thermal effluent from a nuclear production reactor. Initial plant colonization was from wind-dispersed plant species [*Salix nigra* Marsh. (black willow) in wet sites and *Andropogon* spp. (broomsedge) and *Pinus taeda* L. (loblolly pine) in drier sites]. No soil seed bank existed due to the chronic thermal flooding. The site could not be mechanically contoured to fit a specific planting scheme. Hence all plantings were made in the existing early successional vegetation.

Hydrology of the delta has been highly variable due to variation in rainfall and management of the Savannah River by the U.S. Army Corps of Engineers. Any extensive and long duration flooding of the delta is a result of high water levels in the Savannah River. A more complete description of the site and its hydrology can be found in McLeod (2000).

## MATERIALS AND METHODS

### Trial VIII

In the winter of 1991/92, three different types of transplant units of *Fraxinus pennsylvanica* Marshall, *Nyssa aquatica* L., and *Taxodium distichum* Richard were planted in randomly chosen locations within either backwater or stream locations. Transplant types included: (1) balled and burlapped—BB, (2) hand-bagged—HB, and (3) bareroot seedlings—SBR. Commercial BB transplant units of *N. aquatica* were not available, so we placed bareroot seedlings in top soil within a burlap bag to make hand-bagged units. All types were planted in water so that the root collar would subsequently be in 0 to 30 cm of water at time of planting. Since the balled and burlapped and handbagged treatments were planted by placing the ball on the stream bottom, the root collar of these seedlings was elevated above the stream bottom, whereas the root collar of the bareroot seedlings was actually planted at the water/sediment interface. Comparison of these three types would permit an evaluation of the response to a common root collar

<sup>1</sup> Associate Research Ecologist, Research Coordinator, Research Technician, and Research Coordinator, respectively, Savannah River Ecology Laboratory, University of Georgia, P.O. Drawer E, Aiken, SC 29802.

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location in the water column. Bareroot stock was also planted in deeper water (30 to 60 cm of water). The response of this treatment (DBR) examines both a water depth effect with bare-root seedlings and a more practical comparison of planting in a stream location of a specific water depth. Half of the seedlings in each treatment were protected with tree shelters.

### Trial IX

Balled and burlapped *F. pennsylvanica* and *T. distichum* and hand-bagged *N. aquatica* seedlings were held for 60 days in water level with the root collar, in an attempt to acclimate the plants prior to outplanting into stream and backwater locations in the spring of 1992. They were planted so the root collar was 0 to 30 cm below the water surface at the time of planting. Half of the seedlings in each treatment were protected with tree shelters.

### Trial X

Root systems of bareroot seedlings of *F. pennsylvanica*, *N. aquatica*, and *T. distichum* were pruned to three levels prior to outplanting in a muck soil in the winter of 1991/92. Root pruning treatments were: (1) moderate - a bareroot seedling had all lateral roots in excess of 30 cm in length removed and the tap root was cut to a 30 cm length; (2) severe - a bareroot seedling had all lateral roots removed and the tap root was cut to a 30 cm length; and (3) cutting - the entire root system was removed by cutting at the root collar. These seedlings were planted by inserting the unit directly into the muck soil and supporting the seedling with a staked tree shelter.

### Trial XI

Bareroot seedlings of *N. aquatica*, *Quercus falcata* var. *pagodaefolia* Ell., *Q. lyrata* Walt., *Q. nuttallii* Palmer, *Q. phellos* L., and *T. distichum* were planted in tree shelters during the winter of 1992/93. Attempts were made to control the herbaceous vegetation within the plots by chemical or physical means in July 1993 and June 1994. Treatments included: (1) herbicide the whole plot—HW; (2) herbicide only the planting row—HR;

(3) control, no herbaceous control—C; (4) physical control by mowing and weedeating in the planting row only—PR; and (5) physical control by mowing and weedeating the whole plot—PW.

### Trial XII

In the winter of 1993/94, containerized seedlings of *Carya aquatica* (Michaux f.) Nuttall, *Q. laurifolia* Michaux, *Q. lyrata*, and *T. distichum* were planted in plots which had (1) an existing willow canopy—control; (2) the existing willow canopy that had been cut and removed from the plot—cut; and (3) an adjacent area which was dominated by herbs and grasses with no willow present—herb.

In all trials, survival was determined on a 1 to 2 week basis for the first growing season. Thereafter, survival and seedling height were usually determined in the autumn of each year for 3 to 4 years. In 2003, survival, height, and diameter at breast height (d.b.h.) were determined. Diameter and height were well correlated. Since height had been measured in the initial time period, before d.b.h. could be determined, height is reported to illustrate trends in early growth (1994 to 1996) and late growth (2003).

## RESULTS AND DISCUSSION

### Trial VIII

Survival of *T. distichum* was excellent regardless of transplant type in both backwater and stream locations over all 12 years (table 1). Tree shelters decreased herbivory but did not affect survival, except for bareroot seedlings planted in shallow water at the stream site. Water depth (shallow versus deep) did not affect bareroot seedling survival. Height of *T. distichum* was greater in the backwater than the stream location (table 2). After 3 growing seasons, *T. distichum* height was not affected by the presence of shelters or by transplant type, except for bareroot seedlings planted in deeper water. Neither transplant type nor shelter affected height after 12 years.

**Table 1—Trial VIII. Percent seedling survival in 1994 and 2003 after planting in the Fourmile Branch delta as affected by transplant type, location, and tree shelters**

Species Habitat - Shelter	Transplant type							
	BB		HB		SBR		DBR	
	1994	2003	1994	2003	1994	2003	1994	2003
<i>Fraxinus pennsylvanica</i>								
Backwater - no shelter	95	90	25	10	65	45	10	10
Backwater - shelter	100	90	30	10	100	95	00	00
Stream - no shelter	45	15	30	00	45	30	00	00
Stream - shelter	75	65	30	00	85	70	00	00
<i>Nyssa aquatica</i>								
Backwater - no shelter	—	—	65	15	60	00	60	05
Backwater - shelter	—	—	70	35	80	10	90	25
Stream - no shelter	—	—	50	25	35	10	25	05
Stream - shelter	—	—	75	30	75	10	65	20
<i>Taxodium distichum</i>								
Backwater - no shelter	100	100	100	100	95	95	100	100
Backwater - shelter	100	100	100	95	100	90	100	100
Stream - no shelter	100	100	95	90	55	45	100	100
Stream - shelter	100	100	100	100	100	95	100	100

BB = balled and burlapped; HB = handbagged; SBR = bareroot seedling planted in 0 to 30 cm of water; DBR = bareroot seedling planted in 30 to 60 cm of water.

**Table 2—Trial VIII. Seedling height (m) in 1994 and 2003 after planting in the Fourmile Branch delta as affected by transplant type, location, and tree shelters**

Species Habitat - Shelter	Transplant type							
	BB		HB		SBR		DBR	
	1994	2003	1994	2003	1994	2003	1994	2003
<i>Fraxinus pennsylvanica</i>								
Backwater - no shelter	3.2	9.7	2.0	8.4	2.9	12.0	1.3	1.8
Backwater - shelter	3.2	10.3	2.6	12.0	2.7	11.0	Dead	Dead
Stream - no shelter	1.2	8.6	2.1	Dead	1.6	8.8	Dead	Dead
Stream - shelter	2.4	7.3	2.3	Dead	2.3	8.9	Dead	Dead
<i>Nyssa aquatica</i>								
Backwater - no shelter	—	—	1.2	6.9	0.7	Dead	1.0	2.8
Backwater - shelter	—	—	1.8	9.9	1.2	2.9	1.2	2.3
Stream - no shelter	—	—	1.3	8.0	1.3	13.0	1.2	9.5
Stream - shelter	—	—	1.4	8.3	1.2	8.5	1.2	7.6
<i>Taxodium distichum</i>								
Backwater - no shelter	3.3	11.2	3.1	10.9	3.2	12.3	3.2	11.5
Backwater - shelter	3.2	11.2	3.2	10.2	3.1	11.5	3.0	10.0
Stream - no shelter	2.5	10.1	2.2	10.1	2.3	8.6	2.3	8.9
Stream - shelter	3.2	11.0	3.1	11.5	2.9	10.0	2.7	9.3

BB = balled and burlapped; HB = handbagged; SBR = bareroot seedling planted in 0 to 30 cm of water; DBR = bareroot seedling planted in 30 to 60 cm of water.

Survival of *N. aquatica* was good after 3 years but unacceptable after 12 years. Sheltered trees had greater survival than unsheltered trees. Poor survival was generally also true for *F. pennsylvanica* except for good survival of BB seedlings and sheltered bareroot stock planted in shallow water. *F. pennsylvanica* also did very poorly when planted in 30 to 60 cm of water.

### Trial IX

*T. distichum* did well when planted late in the spring following attempts to acclimate the seedlings, except for survival in 2003 of backwater sheltered seedlings (tables 3 and 4). Acclimation did not affect survival or growth of this species. Sheltered seedlings frequently grew taller than non-sheltered plants, while stream plants were frequently taller than backwater plants. Survival of *N. aquatica* and *F. pennsylvanica* were poor regardless of acclimation, shelter, or location.

### Trial X

Only *T. distichum* seedlings which had been moderately or severely root pruned survived well over the entire 12 years (table 5). Height of *T. distichum* was very good with heights of 9 to 11 m and d.b.h.s of 14 to 17 cm. Survival of *N. aquatica* was good for the first 3 years, but declined thereafter. These root pruning methods led to total mortality of *F. pennsylvanica*.

### Trial XI

*Q. lyrata* and *T. distichum* had the highest survival rates, followed by *Q. nuttallii* and *Q. phellos* (table 6). *N. aquatica* had good survival after 4 years but declined greatly thereafter. *Q. falcata* var. *pagodaefolia* had unacceptable survival after 4 years. Survival declined for all species over time but generally only slightly for the more suitable species and was not affected by the herbaceous competition control treatments. Plants were generally shorter in the control plots.

**Table 3—Trial IX. Percent seedling survival in 1994 and 2003 after planting in the Fourmile Branch delta as affected by acclimation, location, and tree shelters**

Species Habitat - Shelter	Acclimated			
	Yes		No	
	1994	2003	1994	2003
<i>Fraxinus pennsylvanica</i>				
Backwater - no shelter	00	00	00	00
Backwater - shelter	00	00	05	00
Stream - no shelter	16	05	20	00
Stream - shelter	53	47	35	25
<i>Nyssa aquatica</i>				
Backwater - no shelter	08	00	00	00
Backwater - shelter	69	00	70	00
Stream - no shelter	15	00	00	00
Stream - shelter	54	08	70	20
<i>Taxodium distichum</i>				
Backwater - no shelter	100	95	100	100
Backwater - shelter	95	35	100	55
Stream - no shelter	100	95	95	95
Stream - shelter	100	100	100	100

### Trial XII

Survival of *C. aquatica*, *Q. lyrata*, and *T. distichum* was good over the 10 years, but total mortality of *Q. laurifolia* occurred by the third year (table 7). Survival of the less affected species did not decline except in the plots with willows remaining, where all species declined. Survival of *T. distichum* was lower than the other two species and generally less than that observed in the other trials. This may be due to higher elevation plots used in this trial. The tallest plants were found in plots where the willows had been removed; the shortest plants occurred in the plots where willows shaded the seedlings. Reducing this shading might stimulate height growth of these seedlings.

**Table 4—Trial IX. Seedling height (m) in 1994 and 2003 after planting in the Fourmile Branch delta as affected by acclimation, location, and tree shelters**

Species Habitat - Shelter	Acclimated			
	Yes		No	
	1994	2003	1994	2003
<i>Fraxinus pennsylvanica</i>				
Backwater - no shelter	Dead	Dead	Dead	Dead
Backwater - shelter	Dead	Dead	3.0	Dead
Stream - no shelter	0.7	6.5	0.5	Dead
Stream - shelter	2.2	7.3	2.5	5.7
<i>Nyssa aquatica</i>				
Backwater - no shelter	0.8	Dead	Dead	Dead
Backwater - shelter	1.7	Dead	1.7	Dead
Stream - no shelter	1.1	Dead	Dead	Dead
Stream - shelter	1.6	12.3	1.3	9.8
<i>Taxodium distichum</i>				
Backwater - no shelter	1.6	5.2	1.6	5.2
Backwater - shelter	2.6	6.4	2.6	7.9
Stream - no shelter	2.0	8.8	1.7	7.7
Stream - shelter	2.9	10.0	2.9	10.0

**OVERALL OBSERVATIONS**

Treatments to control herbaceous and willow competition were not particularly effective in altering survival, but plants were generally shorter in control plots where competition was greatest. Planting of heavily root-pruned bareroot seedlings has limited applicability with only *T. distichum* doing well over the entire time period. While tree shelters did reduce herbivory, they did not generally affect survival or height growth.

The real key to successful restoration is using the most appropriate species for the particular habitat. *C. aquatica*, *Q. lyrata*, and *T. distichum* had overall survival in excess of 80 percent during the initial time interval (3 to 4 years since planting), while *Q. nuttallii*, *Q. phellos*, and *N. aquatica* had survival in excess of 50 percent (fig. 1). All of these species are good candidates for restoring this habitat, based on survival after 3 to 4 years. *F. pennsylvanica* had low overall survival but good survival in selected locations and may be carefully used for restoration. The remaining two species (*Q. falcata* var. *pagodaefolia* and *Q. laurifolia*) had low initial survival and should not be planted in this habitat.

Survival of numerous species in this study continued to be good 10 to 12 years after planting and are good candidates for

**Table 5—Trial X. Percent survival and height (m) in 1994 and 2003 after planting in the Fourmile Branch delta as affected by root pruning treatments. Planting location was a backwater, muck soil area. All seedlings were planted in tree shelters**

Species	Cutting		Severe		Moderate	
	1994	2003	1994	2003	1994	2003
Survival						
<i>Fraxinus pennsylvanica</i>	00	00	00	00	00	00
<i>Nyssa aquatica</i>	13	07	78	20	100	36
<i>Taxodium distichum</i>	33	33	100	93	100	100
Height						
<i>Nyssa aquatica</i>	1.3	8.2	1.3	6.0	1.3	6.8
<i>Taxodium distichum</i>	1.8	7.9	2.8	9.7	2.8	10.7

**Table 6—Trial XI. Percent survival and height (m) in 1996 and 2003 after planting in the Fourmile Branch delta as affected by herbaceous competition control treatments**

Species	HW		HR		C		PR		PW	
	1996	2003	1996	2003	1996	2003	1996	2003	1996	2003
Survival										
<i>Nyssa aquatica</i>	13	17	67	20	73	43	60	23	47	30
<i>Quercus falcata</i> <sup>a</sup>	10	13	10	13	20	13	03	00	27	20
<i>Q. lyrata</i>	97	97	77	70	83	80	80	73	80	77
<i>Q. nuttallii</i>	67	63	57	43	67	60	63	53	57	50
<i>Q. phellos</i>	50	43	50	50	67	63	67	63	37	37
<i>Taxodium distichum</i>	90	87	80	80	83	73	90	90	93	87
Height										
<i>Nyssa aquatica</i>	1.5	8.3	1.5	7.8	1.8	5.3	1.5	7.6	1.8	7.0
<i>Quercus falcata</i> <sup>a</sup>	1.2	3.9	1.6	6.5	1.3	7.8	1.0	Dead	1.6	7.2
<i>Q. lyrata</i>	3.1	7.8	2.9	7.7	2.6	6.4	2.8	7.5	2.8	7.7
<i>Q. nuttallii</i>	2.8	7.8	2.2	7.6	2.2	6.3	2.2	7.1	2.3	7.3
<i>Q. phellos</i>	2.1	8.3	2.5	7.7	2.0	6.5	1.9	6.6	2.4	7.4
<i>Taxodium distichum</i>	2.8	8.8	2.6	6.3	2.2	5.1	2.8	7.5	2.9	7.8

HW = whole plot treated with herbicide; HR = planting row treated with herbicide; C = not treated; PR = planting row mowed; PW = whole plot mowed.

<sup>a</sup> var. *pagodaefolia*

**Table 7—Trial XII. Percent survival and height (m) in 1996 and 2003 after planting in the Fourmile Branch delta as affected by willow control treatments**

Species	Cut		Control		Herb	
	1996	2003	1996	2003	1996	2003
<b>Survival</b>						
<i>Carya aquatica</i>	73	78	90	75	85	85
<i>Quercus laurifolia</i>	00	00	00	00	00	00
<i>Q. lyrata</i>	78	80	90	85	90	88
<i>Taxodium distichum</i>	75	68	95	85	70	68
<b>Height</b>						
<i>Carya aquatica</i>	1.5	5.8	1.5	4.4	1.6	5.4
<i>Q. lyrata</i>	1.2	4.3	1.1	3.1	1.2	4.4
<i>Taxodium distichum</i>	2.0	7.0	1.4	3.1	1.7	5.6

Cut = willows cut and removed; Control = willow canopy intact; Herb = herbaceous vegetation with no willow canopy.

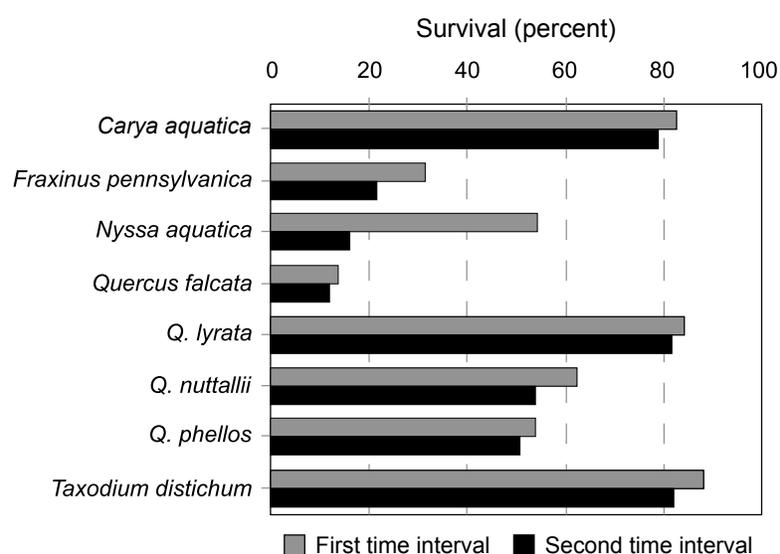


Figure 1—Mean survival (percent) of tree species from all 5 trials during the initial time interval (first 3-4 years) and secondary time interval (next 8-10 years).

restoration. However the continual decline in survival of *N. aquatica*, and to a lesser extent *F. pennsylvanica*, through the entire 10 to 12 year interval suggests that these species are unsuitable for restoration, at least in this habitat or under these conditions. Survival of *N. aquatica* was anticipated to be similar to *T. distichum*, due to their similar habitat requirements. Their dissimilar outcomes may be due to poorer nursery stock of *N. aquatica*, which has not had as much commercial horticultural interest as *T. distichum*. These results would also suggest that for at least seven of these species, survival after 3 to 4 years is indicative of future survival in bottomland/swamp forest restoration projects.

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#### LITERATURE CITED

- Clewell, A.F.; Lea, R. 1989. Creation and restoration of forested wetland vegetation in the Southeastern United States. In: Kusler, J.A.; Kentula, M.E., eds. Wetland creation and restoration: the status of the science, volume I: Regional reviews. EPA/600/3-89/038: 199-237.
- McLeod, K.W. 2000. Species selection trials and silvicultural techniques for the restoration of bottomland hardwood forests. *Ecological Engineering*. 15(Supplement 1): S35-S46.
- McLeod, K.W.; Reed, M.R.; Nelson, E.A. 2001. Influence of a willow canopy on tree seedlings establishment for wetland restoration. *Wetlands*. 21: 395-402.
- McLeod, K.W.; Reed, M.R.; Wike, L.D.; Nelson, E.A. 2000. Elevation, competition control, and species affect bottomland forest restoration. *Wetlands*. 20: 162-168.
- Mitsch, W.J.; Wilson, R.F. 1996. Improving the success of wetland creation and restoration with know-how, time, and self-design. *Ecological Applications*. 6: 77-83.
- Reed, M.R.; McLeod, K.W. 1994. Planting unconsolidated sediments with flood-tolerant species. In: Webb, F.J., ed. Proceedings of the 21<sup>st</sup> annual conference on wetlands restoration and creation. Tampa, FL: Hillsborough Community College: 137-146.

# EFFECTS OF LIGHT ACCLIMATION ON PHOTOSYNTHESIS, GROWTH, AND BIOMASS ALLOCATION IN AMERICAN CHESTNUT SEEDLINGS

G. Geoff Wang, William L. Bauerle, Byran T. Mudder<sup>1</sup>

## Poster Summary

American chestnut [*Castanea dentate* (Marshall) Borkh.] was a widely distributed tree species in the Eastern U.S., comprising an estimated 25 percent of native eastern hardwood forests. Chestnut blight eradicated American chestnut from the forest canopy by the 1950s, and now it only persists as understory sprouts. However, blight-resistant hybrids with approximately 94 percent American chestnut genetic inheritance are scheduled to be available in 2007. Given the economic and ecological importance of the species prior to the blight, great interest and support for the reintroduction is expected. Successful reintroduction will ultimately depend on a viable silvicultural system. However, little is known about the silvics of American chestnut. The objective of this experiment was to investigate light acclimation of American chestnut seedlings growing under a wide range of light conditions.

## METHODS

Pure American chestnut seeds were germinated and grown under well-watered conditions for 1 week. Ten seedlings were randomly assigned into each of 4 light treatments (100, 32, 12, and 4 percent of full sunlight) in a rainout shelter. Seedling height and root collar diameter were measured twice a month beginning on June 7, 2004. On August 2, 2004, all seedlings were destructively sampled and oven-dry mass of root, stem, and leaf, as well as specific leaf area were determined. After 2, 4, and 6 weeks of acclimation under each light treatment, net photosynthesis, leaf stomatal conductance, and transpiration rate were measured using a portable steady state gas-exchange system (CIRAS-I, PP Systems). In addition, the 10 seedlings growing under full sunlight were also used to determine the light response curve, based on which light compensation, light saturation, and maximum photosynthesis rate were determined. Analysis of variance followed by Bonferroni's multiple comparison was used to test the difference in diameter, height, biomass, biomass allocation, and physiological variables.

## RESULTS AND DISCUSSION

Maximum photosynthesis, light compensation, and light saturation were determined as 9.08, 29.5, and 203.50  $\mu\text{mol m}^{-2} \text{s}^{-1}$ , respectively. When measured under their acclimated light

environment, both net photosynthesis and water use efficiency significantly increased with the light level. Mortality due to light limitation was not found even in the 4 percent light, suggesting that American chestnut would survive when planted in the understory of a closed canopy forest. Height did not increase significantly in 4 percent light, while diameter significantly increased under all light levels. By not growing tall under light limitation, American chestnut decreased its height to diameter ratio, thus increasing light use efficiency. Differences in diameter and height were detected 15 days into the experiment and onward. At end of the experiment, seedling growth was significantly affected by light treatment, with the highest growth found in 100 percent light and the lowest growth found in 4 percent light. Root to shoot ratio was lower under 4 percent and 12 percent compared to 32 percent and 100 percent light treatments. Specific leaf area significantly decreased with light levels, with 100 percent < 32 percent = 12 percent > 4 percent. Smaller root to shoot ratio and greater specific leaf area indicated a high efficiency to capture light under shade conditions. Regardless of light level, American chestnut invests > 70 percent of its total biomass to above-ground growth. This allocation pattern is comparable to tulip poplar, red maple, and black gum but different from white oak and mockernut hickory, species that allocate < 35 percent to the aboveground.

## CONCLUSIONS

American chestnut quickly adapted to light limitation by changing its biomass allocation along the light gradient. The morphological and physiological acclimation to low light suggests that American chestnut is shade tolerant. Based on its shade-tolerance and strong response to canopy release, an underplanting-and-release or gap-phase regeneration approach would be feasible, and a clearcut-and-planting approach may not be necessary when reintroducing American chestnut back to its native range.

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<sup>1</sup> Associate Professor, Clemson University, Department of Forestry and Natural Resources, Clemson, SC 29634; Assistant Professor, Clemson University, Department of Horticulture, Clemson, SC 29634; and Graduate Student, Clemson University, Department of Forestry and Natural Resources, Clemson, SC 29634, respectively.

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# A COMPARISON OF TREE SHELTERS AND THEIR EFFECTS ON SEEDLING SURVIVAL AND GROWTH OF TWO BOTTOMLAND HARDWOOD SPECIES: FIRST-YEAR RESULTS

H. Christoph Stuhlinger, Jeffrey A. Earl,  
Rebecca A. Montgomery, and Buren B. DeFee II<sup>1</sup>

## Poster Summary

Tree shelters can aid hardwood establishment by improving seedling survival and growth. Shelters are translucent plastic tubes that act as mini-greenhouses by maintaining a higher humidity environment. Can less-costly shelters achieve the same improved results as more expensive shelters?

This study was established in February, 2004, at two 2.5-acre sites in Hempstead County (HC) and St. Francis County (SFC), AR, to compare three types of tree shelters installed on green ash (*Fraxinus pennsylvanica* Marsh.) and cherrybark oak (*Quercus pagoda* Raf.) seedlings. The HC site is a former hay field on a silty clay loam and was disked twice before planting. The SFC site is a former crop field on silt loam soils and was ripped (subsoiled) before planting. The study is a replicated randomized complete block design.

Tree seedlings enclosed in 4-foot-tall BLUE-X<sup>®</sup>, Protex<sup>®</sup>, or Tubex<sup>®</sup> tree shelters (12 feet by 12 feet spacing) were observed monthly during the growing season and compared to unsheltered controls with respect to survival and height growth. The BLUE-X<sup>®</sup> shelter (blue) consists of a flat Poly film and sleeve which must be assembled. The Protex<sup>®</sup> shelter (blue) comes flat and must be rolled into a cylinder and secured with eight tabs. The Tubex<sup>®</sup> shelter (green) comes as a tube ready to install. Each shelter is held upright with a 4-foot bamboo stake.

Average tree shelter establishment times (assembly plus installation) were longest for the Protex<sup>®</sup> shelters (2.4 minutes per shelter) and shortest for the Tubex<sup>®</sup> shelters (1.2 minutes per shelter). Costs of purchasing and establishing each shelter

were lowest for BLUE-X<sup>®</sup> (\$1.26) and highest for Tubex<sup>®</sup> (\$2.64). Shelters did not improve survival over unsheltered seedlings. Survival at SFC was 96 to 100 percent for all treatments. At HC, green ash survival was 98 to 100 percent, but cherrybark oak survival was only 79 to 85 percent. About 56 percent of the green ash control seedlings were browsed by deer at both sites, causing stunted growth but not mortality. Only a few cherrybark oaks (6 percent) were browsed. At both sites, height growth and emergence rate (when a seedling reached 4 feet in height) were greater for sheltered than unsheltered seedlings, but shelter type made little difference. Total heights at SFC averaged 4.1 feet for sheltered seedlings and 2.4 feet for controls. At SFC, 71 percent of the sheltered seedlings emerged, and 5 percent of the controls emerged. At HC, 11 percent of the sheltered seedlings emerged, compared to 0.6 percent of the controls. Some sheltered seedlings at SFC grew more than 0.5 foot per month. Sheltered seedlings more quickly outgrew weed competition and browse hazards. Protex<sup>®</sup> produced the greatest diameter growth. Further observation will reveal if the rapid height growth of sheltered seedlings will result in temporarily-reduced proportional diameter growth and if height growth will slow down after emergence.

GPS and GIS technology helped to illustrate spatial tree arrangement and to visually track treatment and intra-site differences. All three shelter types performed similarly regarding height growth. BLUE-X<sup>®</sup> shelters may provide the most cost-effective method of increasing early height growth in hardwoods.

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<sup>1</sup> University System Forest Manager, Program Technicians, and Assistant Professor, respectively, Arkansas Forest Resources Center, University of Arkansas at Monticello, Monticello, AR 71656.

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## **Hardwoods: Midstory Competition Control**

*Moderator:*

**DAVID LOFTIS**  
USDA Forest Service  
Southern Research Station



# LIGHT TRANSMITTANCE FOLLOWING MIDSTORY REMOVAL IN A RIPARIAN HARDWOOD FOREST

Bradford J. Ostrom and Edward F. Loewenstein<sup>1</sup>

**Abstract**—Midstory cover may negatively affect the growth of desirable oak reproduction. Where such cover exists, midstory control may be warranted prior to a regeneration harvest so that species that rely on large advance reproduction for regeneration can become established and grow into a more competitive position before overstory removal. Unfortunately, how midstory removals alter the light environment under a riparian hardwood canopy has not been quantified. To understand how midstory removal affects the light regime below the canopy, we measured light intensity following four levels of midstory control. The treatments consisted of the removal of none, 33 percent, 50 percent, or 100 percent of the midstory stems on 50 0.05-ha plots located within a riparian forest. The resulting light characteristics were then compared to published data on light requirements for particular species to determine whether midstory control alone is adequate to allow for the establishment and growth of a new cohort.

## INTRODUCTION

For many years, researchers have examined the problem of sustaining oak reproduction on mesic sites throughout the Southeastern United States. While this issue may be the result of a shift in the disturbance regime, problems with herbivory, or the extreme vegetative competition on these productive sites, one direct abiotic cause relates to the low light levels present in unmanaged, mesic forests (Lorimer 1993). The low light conditions found in these stands are problematic specifically because of the conservative growth strategy of oak reproduction. Oak seedlings are said to have a conservative growth strategy because they will oftentimes have slow initial height growth as true seedlings, instead allocating resources to develop a large root system. This strategy is ideal for the droughty sites that oaks will normally inhabit; their large root systems allow them to survive under moisture stress that might kill seedlings of other species. Additionally, having a large proportion of resources sequestered in the root system ensures that these seedlings are able to sprout back if the top dies due to moisture stress, predation, or is otherwise destroyed mechanically.

Whereas this early growth strategy is well-adapted to dry sites or sites with frequent disturbance, it is detrimental in undisturbed mesic forests; the light levels tend to be lower than might be expected on the drier sites where oak is usually found. Oak seedlings will begin to germinate regardless of the light conditions because of the resources stored in the cotyledon of the acorn. Once those resources are used, however, these seedlings will usually die because the light levels are not high enough for oak seedlings to produce sufficient amounts of photosynthate to compensate for respiration. On drier sites, light levels tend to be somewhat higher because of the lower degree of competition, which allows newly germinated oak seedlings to persist for a longer time without release. While the inclination would be to simply release those seedlings still surviving on mesic sites to allow them additional light to develop, the inability of these seedlings to produce sufficient height growth to remain competitive on these sites is a real problem. They cannot compete with fast-growing, shade intolerant species such as yellow-poplar that are common on

these sites, and they cannot survive for an extended period of time without increases in the light levels on these productive sites (Hodges and Gardiner 1993, Lorimer 1993).

With these problems in mind, silviculturists have struggled to develop management regimes that will enable them to maintain oak in these stands because of the value oak provides as a timber product and as a food source to wildlife. As indicated previously, in most cases clearcutting is not a viable method for regenerating oak on these sites. Similarly, single-tree selection as currently practiced does not appear to be a method that can be relied on to produce the light environment necessary for the maintenance or growth of oak reproduction on these sites (Della-Bianca and Beck 1985, Schlesinger 1976). Selection silviculture may yet prove to be a useful tool to address this problem; however, it has yet to be shown that it is economically feasible to maintain the amount of control needed to sustain oak reproduction in these stands using this method as currently practiced. Rather, the only silvicultural method that has yielded any real promise to date in terms of maintaining oak reproduction on mesic sites has been the shelterwood method, even though the results vary and sometimes a crop of desired reproduction fails to emerge (Loftis 1990, Schuler and Miller 1995). When successful, the shelterwood method is able to maintain oak reproduction because the canopy has been altered to the point where light conditions are not sufficient to allow the establishment of shade intolerant species but are high enough to allow oak seedlings already present to remain in a competitive position compared to other seedlings. In those instances where a shelterwood fails to maintain oak reproduction, the cause could be from a general lack of reproduction present prior to the implementation of the preparatory cut to cutting intensities not suited to providing the light environment needed to sustain oak reproduction in a competitive position (Schuler and Miller 1995).

While it would be inappropriate to propose cutting guidelines for use across all locations, some studies suggest that removing the midstory canopy tier while leaving the main canopy intact is necessary to promote growth of oak seedlings on high quality bottomland sites (Janzen and Hodges 1987, Lockhart

<sup>1</sup> Graduate Research Assistant and Assistant Professor, respectively, Auburn University, School of Forestry and Wildlife Sciences, 602 Duncan Drive, Auburn, AL 36849-5418.

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and others 1992). This level of canopy manipulation would not likely allow enough light to foster shade-intolerant reproduction, and if the targeted midstory stems are prevented from sprouting, it is reasonable to expect that oak reproduction could remain viable. Yet, the benefit of using midstory competition control as an initial cut of a shelterwood is most clearly seen in a study conducted in the southern Appalachian Mountains. In this study, Loftis (1990) demonstrates that northern red oak (*Quercus rubra* L.) advance reproduction will continue to grow under a continuous main canopy as long as the midstory has been treated. By removing the sub-canopy, it appears that the light environment below the main canopy is increased to the point that oak seedlings are able to maintain slow but positive growth. This study also demonstrates the realization that as site productivity increases, greater alterations to the canopy structure will be needed to ensure that light levels are high enough to produce the desired response in the oak reproduction present. Once these seedlings attain a size when they will not be out-competed once released by fast-growing yellow-poplar, the overstory can then be removed.

Given the positive response seen in the southern Appalachians following an effective control of the midstory competition, we wanted to evaluate how a similar treatment might perform in a riparian hardwood forest in the Southeastern United States. To accomplish this goal, we first wanted to quantify how various intensities of midstory competition control actually altered the light environment below the main canopy. Although midstory control has been shown to improve the growth of desired oak reproduction, the actual increase in light availability produced with these treatments has not been quantified. Given the conditions created by removing the midstory canopy tier, the next question we wanted to explore was how much removal is necessary to promote positive seedling growth of desirable species. These treatments can be labor-intensive so it makes sense, especially for a small landowner, to reduce the amount of treatment as much as possible. This question is one that we did not try to answer in the field study itself. Rather, we wanted to see how the light levels created compare with growth trends found in the literature to see what observations could be made from these comparisons. By demonstrating the actual effectiveness of these treatments in these riparian forests, we hope to continue the discussion on the feasibility of maintaining oak as a significant component in these stands.

## METHODS

The study site was located within the Blanton Creek Wildlife Management Area (WMA), GA, a 1,822-ha preserve located in the Piedmont physiographic region, and bordered on the west by the Chattahoochee River. The topography is undulating, with the uplands converted primarily to pine plantations, while the riparian zones and lowland areas are dominated by mixed hardwood forests. The riparian forests are reproductively mature and composed primarily of sweetgum (*Liquidambar styraciflua* L.), yellow poplar (*Liriodendron tulipifera* L.), and dogwood (*Cornus florida* L.). Red maple (*Acer rubrum* L.), Florida maple (*Acer barbatum* Michx.), boxelder (*Acer negundo* L.), two winged silverbell (*Halesia diptera* Ellis), ironwood (*Carpinus caroliniana* Walt.), winged elm (*Ulmus alata* Michx.), and various oaks (*Quercus* spp.) are also present. As a group, oaks comprise only a small portion of the stand, with water oak (*Q. nigra* L.) being the most common. Several invasive

exotic species are also present including Chinese privet (*Ligustrum sinense* Lour.), Japanese honeysuckle (*Lonicera japonica* Thunb.), kudzu [*Pueraria montana* (Lour.) Merr.], and microstegium [*Microstegium vimineum* (Trin.) A. Camus].

Along the east bank of Blanton Creek, located in the central portion of the management area, a transect line of 50 0.05-ha circular plots (12.62 m radius) was established in the early summer of 2003. The transect was laid out in a systematic fashion with 38 m separating each plot center (allowing for a 12.6 m buffer between plots). Each plot was randomly assigned one of four different cutting regimes. The 4 treatments consisted of a control (10 plots), a light removal [every third mid-story stem (10 plots)], a moderate removal [half of the midstory (15 plots)], and a complete midstory removal (15 plots). Vegetation < 1.37 m was not removed unless it posed a hazard to the cutting operation. Trees were felled with a chainsaw and all stems were left on site.

Light measurements were collected throughout the summer of 2004 beginning after full leaf expansion and concluding prior to leaf fall. Light quantity, the amount of photosynthetically active radiation (PAR), was measured with an AccuPar linear PAR/LAI ceptometer (Decagon Devices, Inc., Pullman, WA). A total of 12 readings were taken at 3 locations in each plot, each within 2 m of plot center and approximately 1.3 m above the ground. Each reading was an average of 80 sensors equally spaced along the 86.5-cm-long ceptometer. The ceptometer was pointed in the direction of the brightest light source so that the operator's shadow was not cast on the measurement sensors. Percent full sunlight was calculated based on PAR readings collected continuously at a weather station in an adjacent clearcut.

All PAR measurements were made under overcast conditions, usually during the late morning hours. Measuring PAR under clear skies often does not give an accurate description of average daily PAR levels due to the wide variation caused by direct radiation reaching the forest floor in the form of sunflecks (Messier and Puttonen 1995). However, studies have shown that instantaneous measurement of PAR made under completely overcast skies does provide a good representation of average daily growing season PAR levels (Messier and Puttonen 1995, Parent and Messier 1996). Data was collected from each plot at least three times during the growing season; average daily growing season PAR levels were calculated by averaging all readings. Data were analyzed with ANOVA as a completely randomized design. Tukey-Kramer analysis was used to test for differences between the treatments ( $\alpha = 0.05$ ).

## RESULTS

The analysis of the light intensity data shows a significant difference among midstory reduction treatments ( $p$ -value < 0.0001). As expected, there is an increase in PAR availability with increasing treatment intensity (fig. 1). The Tukey-Kramer analysis indicates that the one-third and one-half midstory removals did not significantly affect the light environment compared with that found in the uncut control plots. The control plots had average growing season PAR levels of 4.18 percent full sun, while the one-third and one-half removals had values of 5.02 percent and 6.52 percent respectively. The complete midstory removal significantly increased the light availability compared to the other treatments; PAR levels in the complete removal averaged 10.67 percent of full sun. The Tukey-Kramer

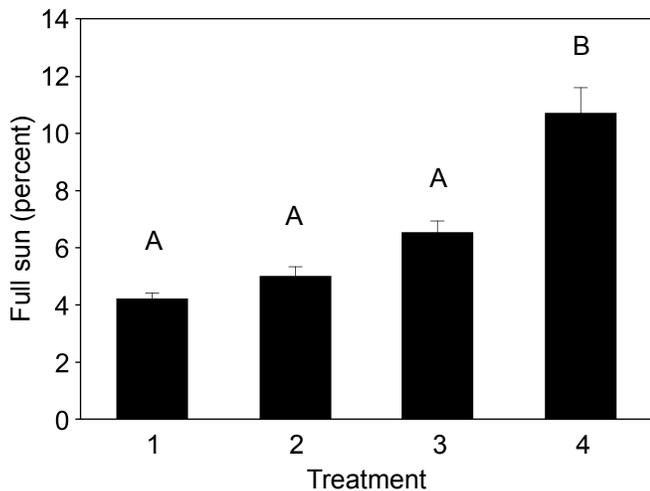


Figure 1—PAR levels below the main canopy increase with increasing midstory control intensity. Only the complete midstory removal (treatment 4) significantly improved light levels above those found in the uncut plots (treatment 1). The complete midstory removal results in an average daily growing season PAR level of 10.67 percent full sun.

test is fairly conservative. Had the analysis been done using LSD to examine differences among treatments, in addition to the complete midstory removal, the one-half midstory stem removal would also have been declared significantly different from the other treatments. This, however, is a case where statistical significance may not translate into biological significance. Given the low light conditions measured, it is unlikely that an increase of only 1.5 percent full sun would translate into a meaningful improvement in light conditions to seedlings growing in this environment.

The second portion of this study was to examine the literature in an attempt to predict how desirable reproduction might react to the light environments created by increasing levels of midstory removal. From past studies that report growth trends resulting from varying light levels, it is clear that the light environments created by midstory control in this stand are still well below what would be considered optimal conditions. Several studies indicate that the growth pattern for oak seedlings is best described by a parabolic curve; in many cases the growth realized in the lowest light levels tested was comparable to that seen under full sun conditions (Gardiner and Hodges 1998, Ziegenhagen and Kausch 1995). For cherry-bark oak (*Q. pagoda* Raf.) for example, it appears that the range of light conditions needed for maximum height growth is likely between 25 percent and 70 percent full sun (Gardiner and Hodges 1998). Gottschalk (1985) examined a larger gradient of light conditions and was able to determine that the optimal growth for northern red (*Q. rubra* L.) and black oak (*Q. velutina* Lam) was closer to 20 percent full sun. Similar results have been found by Ziegenhagen and Kausch (1995) and Crow (1992).

Based on these comparisons, it is evident that oak seedlings growing in the conditions created after a midstory removal would not likely increase significantly in size. When compared to the growth seen with higher PAR levels, the growth in these low light conditions is relatively poor. Indeed, the light levels

created in this study are barely included in the growth trend analysis; in most cases the conditions created in the complete midstory removal would be the lowest light level examined. Although the light levels created by midstory removal do not create conditions necessary for maximum seedling growth, the growth seen in these studies should not be equated to the actual growth that may occur following this treatment in riparian forests. Rather, since few of these studies were actually established in a forested setting, it is likely that varying moisture and nutrient availability, as well as competition, would impact the actual growth rates seen following the implementation of a midstory removal treatment. Thus, it is difficult to tell from the literature whether or not the light conditions created by removing the midstory will be enough to sustain oak seedlings in a similar forest type as the one studied. Despite the poor growth rates seen in low light conditions, Ziegenhagen and Kausch (1995) demonstrated that oak seedlings growing in 10 percent full sun conditions one year but 25 percent full sun conditions the second year were able to regain productive growth rates. Although working with pedunculate oak, this study shows that oak seedlings may become more competitive by gradually improving their light environment; this is the goal of midstory competition control. While the improved conditions resulting from the midstory control may still appear to be too poor to sustain oak reproduction, there is the example of Loftis' (1990) shelterwood which seems to indicate that some oak species can respond to the midstory control and the subsequent overstory removal.

## DISCUSSION

Hodges and Gardiner (1993) present an excellent illustration of the problem summarized in this study. They indicate that the range of light conditions favorable to oak seedling growth is related to the moisture availability of the site where the seedlings are growing, with the range being narrower on mesic sites compared to xeric sites (Hodges and Gardiner 1993). When this understanding of the relationship between the necessary light conditions for oak reproduction and site quality is placed within the shelterwood prescription detailed by Loftis (1990), it appears that the midstory removal used in the shelterwood prescription creates an understory environment that falls within the narrow range of suitable light conditions illustrated by Hodges and Gardiner (1993). In short, the conditions created by Loftis' (1990) shelterwood prescription are not suitable to the establishment and growth of fast-growing competitors such as yellow poplar but are sufficient to allow slow but steady growth by the desired oak reproduction already present on site. Because of these conditions, oak reproduction was able to maintain a competitive position below the main canopy. The hypothesis explored in this study was determining whether midstory treatments can create conditions that are favorable to oak reproduction on riparian sites.

It is apparent from the analysis presented above that the minor midstory removals did little to enrich the light environment below the main canopy; only the complete midstory removal appears to significantly improve the light environment in this riparian forest. Since the partial midstory removals failed to create conditions significantly different from the surrounding uncut stand, it is likely that these treatments are not sufficiently intense to promote oak seedling growth in this ecosystem. However, the question remains

whether a complete midstory removal creates conditions that promote development of the desired oak reproduction while controlling faster growing shade intolerant species. Although not quantified in this study, the conditions created (approximately 10 percent full sun) do not seem to be sufficient for the establishment of these species. Even so, we cannot yet determine whether these conditions are sufficient to promote oak development.

A review of the literature indicates that the light conditions created in this study are too low to maximize oak seedling growth. Further, greater mortality is expected under these conditions over time than would occur under an ideal light environment (Crow 1992). However, it is important to distinguish between creating conditions to maximize oak seedling growth and creating conditions that optimize oak seedling growth relative to the competition. As shown in Loftis (1990), relatively slow seedling growth is acceptable provided that the desired species remains in a competitive position prior to the overstory removal. If the desired species can be maintained and remain competitive to this point, then there is an increased likelihood that they will remain in the future stand. Since the main competitors in the low light conditions typified following a midstory removal are shade tolerant species, it is against these species that growth studies should be conducted. Chambers and Henkel (1989) did attempt to compare the height growth of several species including desirable oaks and common, less-desirable species over a range of light conditions created by partial cutting. Over the 2-year measurement period, however, this study fails to indicate whether the differences in heights between the oaks and the shade tolerant competitors are significant or not. By further exploration of these growth comparisons, researchers will be able to better determine whether the light conditions created by a midstory removal are sufficient to promote the development of desirable oak reproduction in riparian forests.

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## LITERATURE CITED

- Chambers, J.L.; Henkel, M.W. 1989. Survival and growth of natural and artificial regeneration in bottomland hardwood stands after partial overstory removal. In: Miller, J.H., ed. Proceedings of the fifth biennial southern silvicultural research conference. Gen. Tech. Rep. SO-74. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 277-283.
- Crow, T.R. 1992. Population dynamics and growth patterns for a cohort of northern red oak (*Quercus rubra*) seedlings. *Oecologia*. 91: 192-200.
- Della-Bianca, L.; Beck, D.E. 1985. Selection management in Southern Appalachian hardwoods. *Southern Journal of Applied Forestry*. 9(3): 191-196.
- Gardiner, E.S.; Hodges, J.D. 1998. Growth and biomass distribution of cherrybark oak (*Quercus pagoda* Raf.) seedlings as influenced by light availability. *Forest Ecology and Management*. 108: 127-134.
- Gottschalk, K. 1985. Effects of shading on growth and development of northern red oak, black oak, black cherry, and red maple seedlings. I. Height, diameter, and root/shoot ratio. In: Dawson, J.O.; Majerus, K.A., eds. Proceedings of the fifth central hardwood forest conference. Publication 85-05. Bethesda, MD: Society of American Foresters: 189-195.
- Hodges, J.D.; Gardiner, E.S. 1993. Ecology and physiology of oak regeneration. In: Loftis, D.L.; McGee, C.R., eds. Proceedings, oak regeneration: serious problems, practical recommendations. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 54-65.
- Janzen, G.C.; Hodges, J.D. 1987. Development of advanced oak regeneration as influenced by removal of midstory and understorey vegetation. In: Douglas, P.R., ed. Proceedings of the fourth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-042. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 455-461.
- Lockhart, B.R.; Hodges, J.D.; Guldin, J.M. 1992. Development of advanced cherrybark oak reproduction following midstory and understorey competition control and seedling clipping: 4-year results. In: Brissette, J.C., ed. Proceedings of the seventh biennial southern silvicultural research conference. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 109-115.
- Loftis, D.L. 1990. A shelterwood method for regenerating red oak in the Southern Appalachians. *Forest Science*. 36(4): 917-929.
- Lorimer, C.G. 1993. Causes of the oak regeneration problem. In: Loftis, D.L.; McGee, C.R., eds. Proceedings, oak regeneration: serious problems, practical recommendations. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 14-39.
- Messier, C.; Puttonen, P. 1995. Spatial and temporal variation in the light environment of developing Scots pine stands: the basis for a quick and efficient method of characterizing light. *Canadian Journal of Forest Research*. 25: 343-354.
- Parent, S.; Messier, C. 1996. A simple and efficient method to estimate microsite light availability under a forest canopy. *Canadian Journal of Forest Research*. 26: 151-154.
- Schlesinger, R.C. 1976. Sixteen years of selection silviculture in upland hardwood stands. Res. Pap. NC-125. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 6 p.
- Schuler, T.M.; Miller, G.W. 1995. Shelterwood treatments fail to establish oak reproduction on mesic forest sites in West Virginia 10 year results. In: Gottschalk, K.W.; Fosbroke, S.L.C., eds. Proceedings of the tenth central hardwood forest conference. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 375-387.
- Ziegenhagen, B.; Kausch, W. 1995. Productivity of young shaded oaks (*Quercus robur* L.) as corresponding to shoot morphology and leaf anatomy. *Forest Ecology and Management*. 72: 97-108.

# RESPONSE OF SUN-GROWN AND SHADE-GROWN NORTHERN RED OAK SEEDLINGS TO OUTPLANTING IN CLEARCUTS AND SHELTERWOODS IN NORTH ALABAMA

Callie Jo Schweitzer, Emile S. Gardiner, and David L. Loftis<sup>1</sup>

**Abstract**—The primary objective of this study was to determine if greenhouse light environment would affect outplanting success for northern red oak (*Quercus rubra* L.) in clearcuts and shelterwoods. In 2002, northern red oak seedlings were grown from acorns under full-ambient (sun) and half-ambient (shade) light conditions in a greenhouse. Seedlings grown under full sun conditions were significantly taller and had more leaves and more flushes than seedlings grown in shade. Root-collar diameter of sun-grown seedlings did not differ significantly from those of shade-grown seedlings. In February 2003, both sun-grown and shade-grown seedlings were outplanted in a clearcut and under an oak shelterwood. Three replicates of the oak shelterwood were created in November 2002 by using herbicide to selectively remove mid-canopy species; no gaps were created in the overstory canopy. Three clearcut plots were harvested in winter 2002. The clearcuts averaged 1 m<sup>2</sup>/ha residual basal area, 32 percent canopy cover, and photosynthetically active radiation was reduced to 30 percent less than above-canopy levels. Residual basal area for the shelterwood averaged 19 m<sup>2</sup>/ha, with 98 percent canopy cover and photosynthetically active radiation reduced by 86 percent. After one field growing season, sun seedlings outplanted in clearcuts had significantly greater basal diameter growth than either sun or shade seedlings planted in shelterwoods. Prior exposure to higher ambient light levels did not result in greater light use by outplanted seedlings.

## INTRODUCTION

Uncertainties in regenerating oaks in southern Cumberland Plateau forests are similar to other oak-dominated regions. Favorable conditions for regenerating oak can be created by employing a specific shelterwood formula (Dey and Parker 1996, Hannah 1987, Johnson and others 1989, Loftis 1990). However, the shelterwood method requires the presence of naturally occurring oaks, whose growth is stimulated through canopy manipulations. This method does not work if adequate advanced oak reproduction is lacking.

An alternative is to couple the shelterwood method with oak planting. Experimental silvicultural prescriptions for this coupling have focused on appropriate levels of overstory tree density, seedling standards and nursery practices, and various outplanting cultural treatments (Buckley and others 1998, Dey and Parker 1997, Gottschalk and Marquis 1983, Johnson 1984, Spetich and others 2004, Weigel 1999).

Mattsson (1997) provides a thorough review of conifer seedling quality assessment methods for predicting field performance, and many of these methods can be applied to hardwood seedlings. Dey and Buchanan (1995) provide a synthesis of research pertaining to nursery production and direct seeding of oaks, with specific guidelines for the production of high-quality stock. Numerous studies have shown that hardwood (particularly *Quercus*) seedling survival and shoot growth after transplanting depends on root system form and ability of the seedling to produce new roots (Barden and Bowersox 1989, Burdett and others 1983, Farmer 1975, Kormanik and others 1988, Rietveld and van Sambeek 1989, Sutton 1980). The next challenge is to show how silvicultural treatments affect the seedling environment and subsequently seedling physiology and growth.

We hypothesized that the light environment under which seedlings develop influences seedling field performance in the first year after outplanting. To test this, we grew northern red oak (*Q. rubra* L.) seedlings from acorns under two light levels and outplanted them under two stand conditions that produced different light regimes.

## METHODS

Northern red oak acorns were collected from the study sites in fall 2001. Collection amounts were low, and many acorns were small and visibly defective, so we discarded them and requested acorns from East Tennessee Nursery, Tennessee Department of Agriculture, Forestry Division. One thousand acorns from their wild seed collection were sent to us in January 2002 (courtesy of Paul Ensminger, Nursery Manager). Acorns were floated in water for 24 hours to increase their moisture content; floating and visibly unsound acorns were discarded. Sound acorns were stored in polyethylene bags at 3 °C for 30 to 45 days (Bonner and Vozzo 1987).

In February 2002, acorns were sown 4-cm deep, 1 acorn per pot, in 11-L pots filled with a 1:2:2 volume ratio of perlite, peat, and vermiculite. The resulting potted seedlings were grown in a greenhouse located on the Alabama Agricultural and Mechanical University campus, Normal, AL. Four hundred pots were sown to guarantee 150 seedlings for outplanting. Half of the pots were randomly selected and placed under black polypropylene shade fabric in the greenhouse (45 percent of full ambient sun = shade seedlings); the other half received full ambient greenhouse light (no supplemental light source used = sun seedlings). After germination, 150 sun seedlings and 150 shade seedlings were grown for 1 growing season. Pots were watered as needed to maintain ample soil moisture. Data loggers were placed under the shade fabric and

<sup>1</sup> Research Forester, USDA Forest Service, Southern Research Station, Ecology and Management of Southern Appalachian Hardwood Forests, Normal, AL 35762; Research Forester, USDA Forest Service, Southern Research Station, Center for Bottomland Hardwoods Research, Stoneville, MS 38776; and Project Leader, USDA Forest Service, Southern Research Station, Ecology and Management of Southern Appalachian Hardwood Forests, Asheville, NC 28806, respectively.

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on the open greenhouse table to record air temperature (°C), relative humidity (percent), and light intensity (lumens m<sup>-2</sup>).

Following one greenhouse growing season, seedling height and basal diameter were measured using a tape measure (nearest cm) and digital caliper (nearest mm). The total numbers of leaves and stem flushes were also recorded. Seedlings were moved outside the greenhouse in November 2002. A shade house was constructed for the shade seedlings using similar shade fabric, while sun seedlings were placed adjacent to the shade house in an open area.

Seedlings were outplanted in February 2003 on a site located on the southern Cumberland Plateau in Jackson County, AL. The site encompasses strongly dissected margins and sides of the plateau (the escarpment). Soils are characterized as deep to very deep, loamy, well-drained, and moderately fertile. Slopes range from 15 to 30 percent. Upland oak site index is 22.9-24.3, and yellow-poplar site index is 30.5 [height, in meters, at base age 50 years, Smalley Landtype 16, pleateau escarpment and upper sandstone slopes and benches-north aspect (Smalley 1982)]. For a detailed description of the site, see Schweitzer (2004).

Seedlings were outplanted under two stand conditions, a clearcut and a midstory removal shelterwood. Treatment units were 4 ha in area and were replicated three times. Clearcut harvesting was completed in winter 2002. An imazapyr herbicide, which was applied by the hack-and-squirt method, was used to deaden the midstory in the shelterwood treatment. The herbicide treatment was completed in fall 2001, prior to leaf-fall.

Outplanted northern red oak seedlings were spaced 0.5 m apart; 12 sun and 12 shade seedlings were planted in each clearcut and shelterwood plot. Plots were fenced, and competing vegetation was controlled mechanically. Seedling growth (height and diameter), survival, and light response were measured in June 2003 and September 2003. Net photosynthesis (μmol m<sup>-2</sup>s<sup>-1</sup>) of each sample leaf (four sample seedlings per light and outplanting treatment combination) was recorded at seven levels of photosynthetic photon flux density (PAR) (0, 50, 200, 400, 800, 1,200, and 1,600 μmol m<sup>-2</sup> s<sup>-1</sup>) with a portable photosynthesis system. Ambient light levels in each plot were recorded. Sixty light measures were collected for each plot in each sample month. During the growing season, one canopy

cover measurement was made within five points in each plot using a handheld spherical densitometer.

Photosynthetic light response data were modeled using methods and equations outlined by Givnish (1988) and applied to outplanted oak seedlings by Gardiner and others (2001). Analysis of variance for a randomized block design was used to quantify treatment differences; t-tests and Duncan's new multiple range test were used to separate means at α = 0.05 (SAS Institute 1990).

## RESULTS

### Greenhouse Environment and Seedling Response

During the months of June, July, August, and September 2002, northern red oak seedlings in the greenhouse were exposed to temperatures, relative humidities, and diurnal light availabilities given in table 1. Shade seedlings received an average of 46 percent as much ambient light as sun seedlings.

Sun seedlings (mean height 28.8 cm) were significantly taller than shade seedlings (mean height 21.4 cm) (*p* < 0.001). There was no difference in basal diameter. By September, the average numbers of leaves and stem growth flushes were significantly greater for sun seedlings (eight leaves compared to five leaves per shade seedling; 1.7 flushes per sun seedling compared to 1.0 flush per shade seedling). Survival was 100 percent for all seedlings. No data on photosynthesis were collected for seedlings while the seedlings were in the greenhouse.

### Outplanting Environment

Table 2 presents information about the conditions created by the shelterwood and clearcut treatments. Basal area of all trees ≥ 14.2-cm diameter at breast height was reduced more by clearcutting than by the shelterwood treatment. Herbicide was applied only in the shelterwood treatments, and most of the herbicide-treated trees were in the midstory. An average of 941 stems/ha were injected with herbicide, and the average tree diameter of treated trees was 7.5 cm. The 32 percent canopy cover recorded for the clearcuts resulted from stump-sprouting and rapid revegetation. This revegetation slightly reduced the amount of sunlight reaching the forest floor, but ambient light levels were significantly greater in the clearcuts than in the shelterwoods.

**Table 1—Temperature, relative humidity, and mean diurnal light availability (lumens m<sup>-2</sup>) for sun (full ambient light) and shade (45 percent ambient light) northern red oak seedlings grown in a greenhouse at Alabama Agricultural and Mechanical University, Normal, AL**

Environmental variable	Light treatment	Month			
		June	July	August	September
Temperature (°C)	Sun	25.9	27.2	25.8	23.9
	Shade	25.2	26.8	25.9	23.8
Relative humidity (%)	Sun	27.9	27.1	28.6	27.0
	Shade	50.7	47.9	31.5	32.3
Light	Sun	179.5	208.9	131.6	119.0
	Shade	89.5	108.2	91.4	59.7

**Table 2—Stand conditions for outplanting plots, Jackson County, AL**

Variable	Shelterwood	Clearcut
Pretreat BA/ha <sup>a</sup> (m <sup>-2</sup> )	27	25
Posttreat BA/ha (m <sup>-2</sup> )	19	1
BA retained (%)	70	5
Canopy cover (%)	98	32
Full sunlight at 1.37 m (%)	14	69
Light intensity average (μmol m <sup>-2</sup> s <sup>-1</sup> )	128	1096
Light intensity range (μmol m <sup>-2</sup> s <sup>-1</sup> )	19 – 1057	123 – 1827

BA = basal area.

<sup>a</sup> BA = basal area of all trees ≥ 14.2 cm at 1.37 m aboveground.

### Response of Outplanted Seedlings

Following one growing season in the greenhouse, seedlings were outplanted in the field in the winter of 2003. Table 3 details the survival and growth of outplanted seedlings. Survival was high for all outplanted seedlings; competition was controlled mechanically and the outplanting site fenced. After one field-growing season, sun seedlings outplanted in clearcuts had significantly greater basal diameter growth than both sun and shade seedlings planted in shelterwoods. There were no treatment-to-treatment differences in height growth.

### Photosynthetic Response to Light

Full leaf-out for all seedlings was completed by mid-April 2003. In mid-June, photosynthetic light response of northern red oak leaves was similar for all seedlings, regardless of greenhouse light environment or outplanting condition (fig. 1). Dark respiration rates were 33 percent greater for clearcut sun and shade seedlings than for shelterwood sun and shade seedlings; no other light responses differed from treatment to treatment in mid-June (table 3).

There were two distinct light response curves for photosynthesis in September (fig. 2). At PAR of 800 and above, photosynthetic rates for seedlings in clearcuts were significantly

greater than those for shelterwood seedlings. Dark respiration was the only light response variable that did not differ significantly from treatment to treatment (table 4). Clearcut shade seedlings had significantly greater gross photosynthetic rate at light saturation, greater PAR required for half gross photosynthetic rate at light saturation, greater light compensation point, and greater quantum yield than shade shelterwood seedlings. Sun seedlings in clearcuts had significantly greater gross and net photosynthetic rate than sun shelterwood seedlings. In clearcuts, sun seedlings had a significantly greater light compensation point than shade seedlings; in shelterwoods, sun seedlings had significantly lower gross photosynthetic rate and higher quantum yield than shade seedlings.

### DISCUSSION

Prior exposure to higher ambient light levels (sun seedlings) did not result in greater light use for outplanted seedlings in the following growing season. Outplanting light conditions significantly affected physiological response, as net photosynthetic rate was greater for clearcut than shelterwood seedlings. Light saturation and light compensation point were significantly less for shelterwood seedlings. Mean ambient light intensity (128 μmol m<sup>-2</sup>s<sup>-1</sup>) under shelterwoods was below

**Table 3—Survival, growth, and photosynthetic characteristics of northern red oak seedlings measured on sun and shade seedlings outplanted on shelterwood and clearcut plots, June 2003, Jackson County, AL**

Variable	Clearcut		Shelterwood	
	Sun seedlings	Shade seedlings	Sun seedlings	Shade seedlings
Survival (%)	97a	92a	97a	100a
Diameter growth (mm)	3a	2ab	2b	1c
Height growth (cm)	1a	1a	1a	1a
P <sub>g-sat</sub> (μmol m <sup>-2</sup> s <sup>-1</sup> )	6.95a	6.71a	5.86a	5.67a
P <sub>n-sat</sub> (μmol m <sup>-2</sup> s <sup>-1</sup> )	3.72a	3.74a	3.94a	4.04a
R <sub>d</sub> (μmol m <sup>-2</sup> s <sup>-1</sup> )	2.81a	2.66a	1.11b	1.25b
Q <sup>a</sup>	0.03a	0.04a	0.04a	0.04a
LCP (μmol m <sup>-2</sup> s <sup>-1</sup> )	80.4a	50.5a	50.1a	25.5a
K (μmol m <sup>-2</sup> s <sup>-1</sup> )	99.9a	75.7a	286.4a	133.4a

P<sub>g-sat</sub> = gross photosynthesis at light saturation; P<sub>n-sat</sub> = net photosynthesis at light saturation; R<sub>d</sub> = dark respiration rate; Q = quantum yield; LCP = light compensation point; K = light needed to attain one-half of P<sub>g-sat</sub>.

Means in a row followed by the same letter do not differ at the 0.05 probability level.

<sup>a</sup> (μmol CO<sub>2</sub> m<sup>-2</sup>s<sup>-1</sup>/μmol photon m<sup>-2</sup>s<sup>-1</sup>).

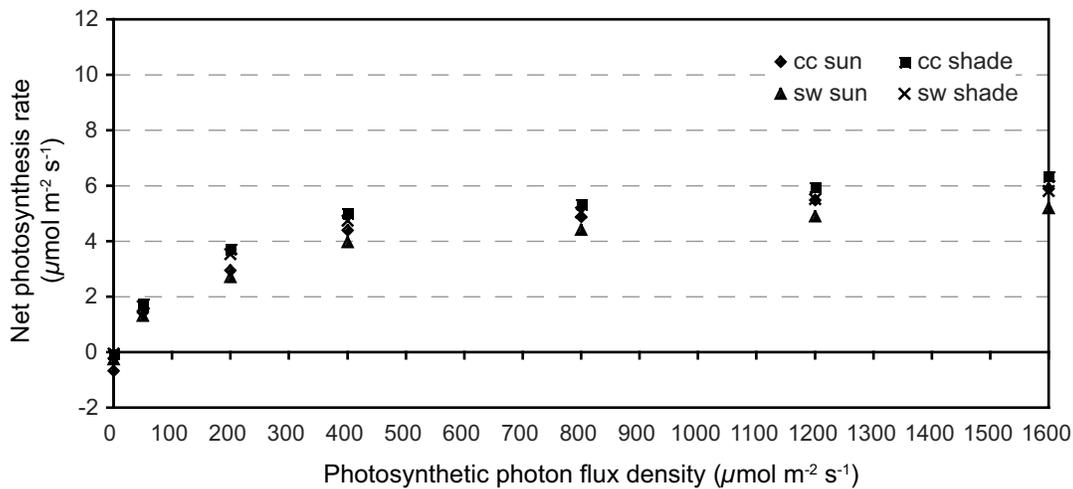


Figure 1—June 2003 photosynthetic light response of northern red oak seedlings raised under two light regimes (sun = full sunlight; shade = 45 percent full sunlight) and outplanted under two silvicultural prescriptions (cc = clearcut; sw = shelterwood).

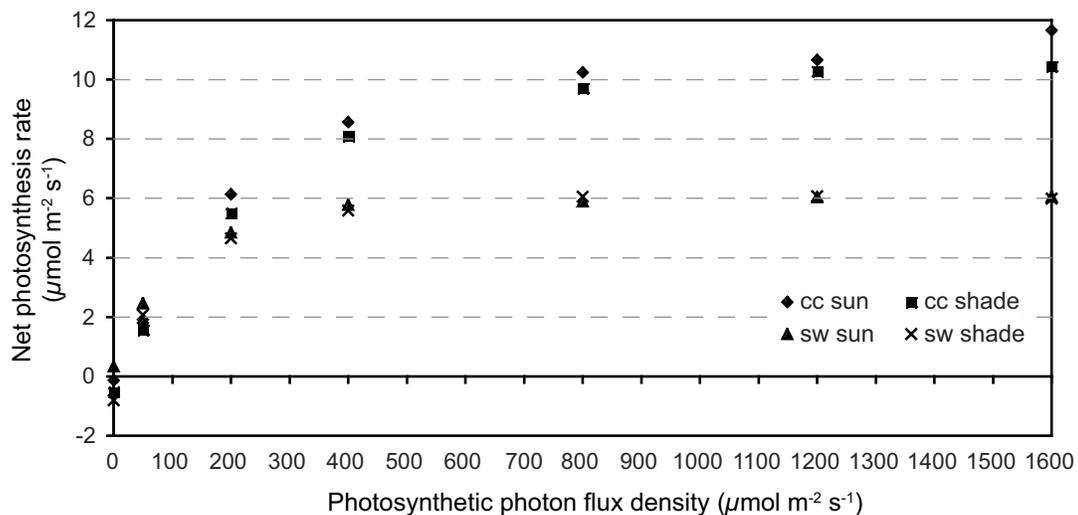


Figure 2—September 2003 photosynthetic light response of northern red oak seedlings raised under two light regimes (sun = full sunlight; shade = 45 percent full sunlight) and outplanted under two silvicultural prescriptions (cc = clearcut; sw = shelterwood).

the average light saturation level recorded for those seedlings ( $131 \mu\text{mol m}^{-2}\text{s}^{-1}$ ).

Response mechanisms behind the observations in this study can only be postulated, as seedlings were not destructively sampled for intensive study. Root biomass may be more sensitive to light environment than leaf or stem biomass (Gottschalk 1987). Higher leaf area in low light may allow seedlings to harvest light more effectively; however, higher leaf areas may be more reflective of growth mechanisms than of acclimation to low-light environments (Groninger and others 1996). Quantum yield has been shown to increase in shade-grown plants, allowing more efficient energy transfer from light-harvesting chlorophyll to photosystem II (Demmig and Bjorkman 1987). Gardiner and others (2001) found no difference in quantum yield or leaf area for Nuttall oak (*Quercus nuttallii* Palm.) seedlings grown in full and 43 percent of full sun. In

our study, shade seedlings grown in shelterwoods had greater quantum yield than shade seedlings in clearcuts and sun seedlings in shelterwoods, suggesting a response towards increased efficiency.

## CONCLUSIONS

Species that adapt rapidly to their environment may have a competitive advantage in habitats with changing light intensities. Efforts to increase outplanting success for oak seedlings should continue to emphasize competition control and the importance of high-quality seedlings. Results from this study suggest that outplanted northern red oak seedlings are plastic in their photosynthetic response and are able to acclimate to changing light conditions. No immediate gain was incurred by subjecting these seedlings to low light prior to outplanting.

**Table 4—Survival, growth, and photosynthetic characteristics of northern red oak seedlings measured on sun and shade seedlings outplanted on shelterwood and clearcut plots, September 2003, Jackson County, AL**

Variable	Clearcut		Shelterwood	
	Sun seedlings	Shade seedlings	Sun seedlings	Shade seedlings
Survival (%)	97a	92a	97a	100a
Diameter growth (mm)	3a	2ab	2b	1c
Height growth (cm)	2a	-1a	3a	-2a
$P_{g-sat}$ ( $\mu\text{mol m}^{-2}\text{s}^{-1}$ )	13.08a	13.69a	6.64c	7.47b
$P_{n-sat}$ ( $\mu\text{mol m}^{-2}\text{s}^{-1}$ )	11.01a	10.63ab	5.60c	6.38bc
$R_d$ ( $\mu\text{mol m}^{-2}\text{s}^{-1}$ )	0.41a	0.97a	0.68a	0.76a
$Q^a$	0.07ab	0.05b	0.06b	0.09a
LCP ( $\mu\text{mol m}^{-2}\text{s}^{-1}$ )	5.31b	19.33a	10.33ab	8.79b
K ( $\mu\text{mol m}^{-2}\text{s}^{-1}$ )	189.4ab	245.1a	91.33bc	68.3c

$P_{g-sat}$  = gross photosynthesis at light saturation;  $P_{n-sat}$  = net photosynthesis at light saturation;  $R_d$  = dark respiration rate;  $Q$  = quantum yield; LCP = light compensation point; K = light needed to attain one-half of  $P_{g-sat}$ .

Means in a row followed by the same letter do not differ at the 0.05 probability level.

<sup>a</sup> ( $\mu\text{mol CO}_2 \text{ m}^{-2}\text{s}^{-1} / \mu\text{mol photon m}^{-2}\text{s}^{-1}$ ).

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## LITERATURE CITED

- Barden, C.J.; Bowersox, T.W. 1989. The effect of root pruning treatments on red oak seedling root growth capacity. In: Rink, G.; Budelsky, C.A., eds. Proceedings of the seventh central hardwood forest conference. Gen. Tech. Rep. NC-132. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 115-119.
- Bonner, F.T.; Vozzo, J.A. 1987. Seed biology and technology of *Quercus*. Gen. Tech. Rep. SO-66. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 21 p.
- Buckley, D.S.; Sharik, T.L.; Isebrands, J.G. 1998. Regeneration of northern red oak: positive and negative effects of competitor removal. *Ecology*. 78(1): 65-78.
- Burdett, A.N.; Simpson, D.G.; Thompson, C.F. 1983. Root development and plant establishment success. *Plant and Soil*. 71: 103-110.
- Demmig, B.; Bjorkman, O. 1987. Comparison of the effect of excessive light on chlorophyll fluorescence (773K) and photon yield of  $O_2$  evolution in leaves of higher plants. *Planta*. 171: 171-184.
- Dey, D.C.; Buchanan, M. 1995. Red oak (*Quercus rubra* L.) acorn collection, nursery culture and direct seeding: a literature review. Forest Research Information Paper 122. Sault Ste. Marie, ON: Ontario Ministry of Natural Resources: Ontario Forest Research Institute. 46 p.
- Dey, D.C.; Parker, W.C. 1996. Regeneration of red oak (*Quercus rubra* L.) using shelterwood systems: ecophysiology, silviculture and management recommendations. Forest Research Information Paper 126. Sault Ste. Marie, ON: Ontario Ministry of Natural Resources: Ontario Forest Research Institute. 59 p.
- Dey, D.C.; Parker, W.C. 1997. Overstory density affects field performance of underplanted red oak (*Quercus rubra* L.) in Ontario. *Northern Journal of Applied Forestry*. 14(3): 120-125.
- Farmer, R.E. 1975. Growth and assimilation rate of juvenile northern red oak: effects of light and temperature. *Forest Science*. 21(4): 373-381.
- Gardiner, E.S.; Schweitzer, C.J.; Stanturf, J.A. 2001. Photosynthesis of Nuttall oak (*Quercus nuttallii* Palm.) seedlings interplanted beneath an eastern cottonwood (*Populus deltoids* Bartr. ex Marsh) nurse crop. *Forest Ecology and Management*. 149: 283-294.
- Givnish, T.J. 1988. Adaptation to sun and shade: a whole-plant perspective. *Australian Journal of Plant Physiology*. 15: 63-92.
- Gottschalk, K.W. 1987. Effects of shading on growth and development of northern red oak, black oak, black cherry and red maple seedlings: II. Biomass partitioning and prediction. In: Hays, R.L.; Woods, F.W.; DeSelm, H., eds. Proceedings of the sixth central hardwood forest conference. Knoxville, TN: [Publisher unknown]: 99-110.
- Gottschalk, K.W.; Marquis, D.A. 1983. Survival and growth of planted red oak and white ash as affected by residual overstory density, stocking size, and deer browsing. In: Muller, R.N., ed. Proceedings of the fourth central hardwood forest conference. Gen Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 125-140.
- Groninger, J.W.; Seiler, J.R.; Peterson, J.A.; Kreh, R.E. 1996. Growth and photosynthetic responses of four Virginia Piedmont tree species to shade. *Tree Physiology*. 16: 773-778.
- Hannah, P.R. 1987. Regeneration methods for oaks. *Northern Journal of Applied Forestry*. 4(2): 97-101.
- Johnson, P.S. 1984. Responses of planted northern red oak to three overstory treatments. *Canadian Journal of Forest Research*. 14(4): 536-542.
- Johnson, P.S.; Jacobs, R.D.; Martin, J.A.; Godel, E.G. 1989. Regenerating northern red oak: three successful case histories. *Northern Journal of Applied Forestry*. 6(4): 174-178.
- Kormanik, P.P.; Ruehle, J.L.; Muse, H.D. 1988. Frequency distributions of seedlings by first-order lateral roots: a phenotypic or genotypic expression. In: Proceedings of the 31<sup>st</sup> northeastern forest tree improvement conference. University Park, PA: Pennsylvania State University: 181-187.

- Loftis, D.L. 1990. A shelterwood method for regenerating red oak in the Southern Appalachians. *Forest Science*. 36(4): 917-929.
- Mattsson, A. 1997. Predicting field performance using seedling quality assessment. *New Forests*. 13: 227-252.
- Rietveld, W.J.; van Sambeek, J.W. 1989. Relating black walnut planting stock to field performance. In: Rink, G.; Budelsky, C.A., eds. *Proceedings of the seventh central hardwood forest conference*. Gen. Tech. Rep. NC-132. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 162-169.
- SAS Institute. 1990. *SAS user's guide: statistics*. Version 6. 4<sup>th</sup> ed. Cary, NC: SAS Institute. 584 p.
- Schweitzer, C.J. 2004. First year response of an upland hardwood forest to five levels of overstory tree retention. In: Connor, K.F., ed. *Proceedings of the 12<sup>th</sup> biennial southern silviculture research conference*. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 287-291.
- Smalley, G.W. 1982. Classification and evaluation for forest sites on the Mid-Cumberland Plateau. Gen. Tech. Rep. SO-38. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 123 p.
- Spetich, M.A.; Dey, D.C.; Johnson, P.S.; Graney, D.L. 2004. Success of underplanting northern red oaks. In: Spetich, M.A., ed. 2004. *Upland oak ecology symposium: history, current conditions, and sustainability*. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 206-211.
- Sutton, R.F. 1980. Planting stock quality, root growth capacity, and field performance of 3 boreal conifers. *New Zealand Journal of Forest Science*. 10: 54-71.
- Weigel, D.R. 1999. Oak planting success varies among ecoregions in the central hardwood region. In: Stringer, J.W.; Loftis, D.L., eds. *Proceedings of the 12<sup>th</sup> central hardwood forest conference*. Gen. Tech. Rep. SRS-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 9-16.

# INITIAL RESPONSE OF UNDERPLANTED YELLOW POPLAR AND CHERRYBARK OAK SEEDLINGS TO FOUR LEVELS OF MECHANICAL MIDSTORY REMOVAL

John M. Lhotka and Edward F. Loewenstein<sup>1</sup>

**Abstract**—Midstory removal has been suggested as a possible enhancement strategy to develop seedling pools in stands lacking vigorous advanced oak (*Quercus* spp.) reproduction. However, for successful implementation, silviculturists must understand the differential growth responses of oak and its competitors to conditions created by midstory removal. To further quantify the competitive dynamics between cherrybark oak (*Q. pagoda* Raf.) and yellow-poplar (*Liriodendron tulipifera* L.), this study was designed to assess the initial height growth responses of these species to four levels of midstory removal and to understory vegetation control. The study was installed within a riparian corridor located in western Georgia, and treatments were completed in the fall of 2003. One-year data suggests cherrybark oak height increment was not significantly increased by any level of midstory removal. In contrast, yellow-poplar growth was significantly greater in the removal treatments and was highest under full midstory removal. Results also show that the height growth of cherrybark oak was significantly higher and yellow-poplar was significantly lower within understory control treatment. Overall, data suggest that underplanted yellow-poplar may have initial height growth advantage over cherrybark oak following midstory removal.

## INTRODUCTION

Historically, both even- and uneven-aged methods have been used to regenerate oak (*Quercus* spp.). Unfortunately, the success of these treatments varies greatly across regions, and regeneration failure is not uncommon regardless of the method employed. In many situations, clear-cutting has resulted in forest conditions that favor the development of intolerant species such as yellow-poplar over oak (Beck and Hooper 1986). This pattern can be explained by species-specific growth strategies and resource allocation of oak and its associated species (Kolb and others 1990). At the other end of the silvicultural spectrum, application of single-tree selection has often favored the development of shade-tolerant species over more desired intolerant and mid-tolerant species (Della-Bianca and Beck 1985). The flexible nature of the shelterwood method has shown the most promise in successful natural regeneration of oak in both upland and bottomland systems (Hodges and Janzen 1987, Loftis 1983). The residual forest cover present with the shelterwood prior to final removal provides conditions that sustain continued oak growth but does not create optimal growing conditions for fast-growing intolerants (Loftis 1990).

The absence of favorable advance reproduction and the presence of a dense shade tolerant midstory in many mature upland and bottomland oak stands are major issues contributing to the oak regeneration problem. The development of these multi-stratum forest canopies has been linked to microclimatic conditions that inhibit the developmental potential of oak and other shade-intolerant reproduction (Heitzman and others 2004, Lorimer and others 1994, Zaczek and others 2002). Research has suggested that both mechanical and chemical control of midstory canopy layers can be employed to enhance the development of existing oak reproduction within a shelterwood system (Janzen and Hodges 1985, Lockhart and others 2000, Loftis 1990). In stands without the desired natural reproduction, underplanting has been suggested as a method to enhance reproduction pools (Spetich and others

2002, Weigel and Johnson 2000). The inclusion of activities that increase the number, size, and competitive position of oak seedlings is critical because the presence of large advance reproduction prior to overstory removal is crucial for successful oak regeneration (Crow 1988, Larsen and Johnson 1998, Sander 1972).

Given the demonstrated relationship that oak tend to be out-competed by shade-intolerant species under open conditions and by shade-tolerant species under dense canopy cover, it seems that the essential problem surrounding the design of silvicultural operations to favor oak seedling development is understanding how the interaction between residual canopy structure and understory microclimate influences species-specific growth rates. Because of differential growth strategies, intolerant species such as yellow poplar will outgrow oak in high resource conditions. Therefore, structural manipulations must create conditions that inhibit the development of this source of competition, while still providing sufficient resources for survival and growth of oak (Johnson and others 1989). In a generalized view, treatments must find an optimized range that favor oak development over more shade-intolerant or tolerant species. More specifically, midstory treatments must be designed to culture oak reproduction but also must consider the response of potential competition to residual forest structure. The objective of this study was to quantify the differential response between oak and a shade-intolerant competitor to varying levels of midstory removal. Specifically, we assessed first year growth of underplanted yellow-poplar (*Liriodendron tulipifera* L.) and cherrybark oak (*Q. pagoda* Raf.) to four levels of midstory removal and two levels understory vegetation control.

## PROCEDURES

### Site Description

The study was conducted within a riparian forest corridor on the Blanton Creek Wildlife Management Area located in Harris

<sup>1</sup> Graduate Research Assistant and Assistant Professor, respectively, Auburn University, School of Forestry and Wildlife Sciences, 602 Duncan Drive, Auburn University, AL 36849-5418.

County, GA. This site is considered part of the Lower Piedmont physiographic region of western Georgia. The corridor's overstory is primarily composed of yellow poplar and sweetgum (*Liquidambar styraciflua* L.). Water oak (*Q. nigra* L.), green ash (*Fraxinus pennsylvanica* Marsh.), and boxelder (*Acer negundo* L.) are also present but serve as minor components. A dense midstory is present across much of the area and is dominated by flowering dogwood (*Cornus florida* L.), two-winged silverbell (*Halesia diptera* Ellis.), muscledwood (*Carpinus caroliniana* Walt.), and ironwood [*Ostrya virginiana* (Mill.) K. Koch]. The flora occupying the area's understorey include Japanese honeysuckle (*Lonicera japonica* Thunb.), Nepal grass [*Microstegium vimineum* (Trin.) A. Camus], and blackberry (*Rubus* spp.).

### Design and Analysis

Fifty, 0.05 ha (12.62-m-radius) circular plots were installed within those areas of the Blanton Creek riparian corridor that were at least 38 m wide. These plots were systematically located along a transect bisecting the riparian corridor and were placed with at least 38 m separating plot centers. It was essential that the plots be located within existing closed canopy forest; therefore, specific criteria were evaluated to prevent plots from being placed within or adjacent to a forest gap. Forest gaps were defined for the purpose of plot establishment as openings in the forest canopy > 0.025 ha in size. If a plot fell adjacent to a gap, the plot center was moved an additional 12.6 m along the same transect to allow for a buffer between the plot and the gap. Similarly, if a plot fell within in forest gap, the center was moved an addition 25 m to provide sufficient buffer. Finally, if a plot fell within a section of the riparian corridor area that was < 38 m wide, the plot was relocated 38 m further along the transect.

To assess how different levels of midstory cover influence initial seedling growth, the 50 plots were randomly assigned 1 of 4 midstory removal treatments. These treatments include: (1) uncut - no trees were removed; (2) Light - removed 1/3 of all midstory trees; (3) Moderate - removed 1/2 of all midstory trees; and (4) Heavy - removed all midstory trees. Midstory trees were defined as those stems not present in the dominant/co-dominant canopy layer. Midstory removals were completed in the summer/fall of 2003 using directional chainsaw felling. Tree bole and top material were left on site and were cut-up to speed decomposition. No vegetation < 1.4 m in height was removed unless it created a hazard during the felling operation.

During November and December, 2003, 12 yellow-poplar and cherrybark oak 1-0 containerized seedlings were systematically planted in pairs on each of the 50 plots. The seedlings were planted approximately 15 inches apart using a gas-powered auger and were watered following planting. Because of known problems with deer browse in Piedmont forests, seedling pairs were protected using 28 by 48 inch circular wire cage enclosures (Romagosa and Robison 2003). The enclosures were secured using two bamboo stakes driven into the ground.

After planting, half of each plot was randomly selected to receive the understory competition control treatment. Due to the systematic planting design, six seedling pairs received the competition treatment on each plot. This understory control was conducted in June of 2004 and included hand-weeding

within each cage and application of Roundup® Pro (3 percent solution) surrounding each cage.

Pre- and post-growing season total height (cm) was measured in the spring and fall of 2004, respectively. Split-plot analysis of variance (ANOVA) was used to test for differences in height increment between treatments by species. Understorey competition control was the split-plot factor within a whole-plot factor (midstory removal) completely randomized design. A mixed models approach was used for this ANOVA, because the whole-plot error term is random in nature (Steel and others 1997). Following non-significant interaction and significant omnibus test ( $\alpha=0.05$ ), pair-wise comparisons were completed using the Tukey-Cramer method (Neter and others 1996). Height increment for yellow-poplar was natural-log transformed for the ANOVA analysis to stabilize non-constant variance. However, untransformed data are presented to facilitate interpretation and understanding of the results.

### RESULTS

Cherrybark oak and yellow-poplar differ with regard to height increment response following midstory removal and understory competition control treatments. A pattern of increasing cherrybark oak height increment was seen with increasing midstory removal. However, analysis showed no significant difference ( $p = 0.1460$ ) among the four levels of removal (table 1). Conversely, yellow-poplar height increment differed among the midstory treatments ( $p < 0.001$ ) and increased with increasing removal. The three levels of removal had significantly larger height increments than did the no removal treatment. The complete removal was significantly greater than the one-third ( $p = 0.0241$ ) or one-half removal ( $p = 0.0084$ ). However, growth increment for one-third and one-half midstory removal did not differ from one another ( $p = 1.000$ ). Finally, yellow-poplar's height increment was greater than cherrybark oak within all levels of removal.

Response to understory competition control also differed between species. Application of herbicide/weeding treatment resulted in significantly greater ( $p = 0.0328$ ) cherrybark oak height increment than did the no control treatment (table 1).

**Table 1—Least-square mean height increment for cherrybark oak (CBO) and yellow poplar (YP) by treatment**

Treatment	Height increment ( $\pm$ SE) <sup>a</sup>	
	CBO	YP
----- cm -----		
Whole-plot factor		
No midstory removal	5.35 <sup>A</sup> (1.265)	9.04 <sup>A</sup> (1.093)
1/3 midstory removal	6.34 <sup>A</sup> (1.265)	6.90 <sup>B</sup> (1.094)
1/2 midstory removal	7.69 <sup>A</sup> (0.920)	6.86 <sup>B</sup> (1.075)
Full midstory removal	8.67 <sup>A</sup> (0.920)	7.80 <sup>C</sup> (1.075)
Split-plot factor		
No understory control	6.61 <sup>A</sup> (0.630)	8.60 <sup>A</sup> (1.049)
Weeding/herbicide application	8.04 <sup>B</sup> (0.630)	25.23 <sup>B</sup> (1.049)

<sup>a</sup> Means followed by the same letter within a factor indicates no significant difference ( $\alpha=0.05$ ).

In contrast, yellow-poplar's height growth was significantly lower ( $p = 0.0182$ ) in herbicide/weeding treatment when compared with no understory competition control (table 1).

## DISCUSSION

Much research has focused on developing treatments to address the problem of successfully regenerating oak in both upland and bottomland systems. Complex interactions of biotic and abiotic factors are known to influence the stochastic nature of oak germination and establishment (Gribko and others 2002, Sork and others 1993), but development of established reproduction may be directly affected through silvicultural operations. Sander (1972) highlighted the need for developing large oak reproduction, which are more likely to survive than are smaller seedlings that are in competition with associated species. Following this sage advice, development of vigorous oak seedlings has been the focus of many management strategies. In highly productive oak ecosystems, midstory control has been suggested as a method to enhance oak development prior to the final removal harvests in a shelterwood system (Hodges and Janzen 1987, Loftis 1990). This pre-release development is crucial because of the height growth differential that can occur between oak its intolerant competitors in high resource environments (Beck and Hooper 1986, Kolb and others 1990, Walters 1963). Gardiner and Hodges (1998) have also suggested that cherrybark oak may exhibit greater height growth in moderate light environments than in full sun. Loftis (1990) demonstrated that it is possible to create conditions that inhibit intolerant competitors, such as yellow-poplar, while at the same time favoring oak development. To take advantage of differential growth strategies, researchers have suggested midstory control as a method to increase height development and competitive advantage of cherrybark oak (Janzen and Hodges 1985, Lockhart and others 2000).

First-year height increment data suggest that planted yellow-poplar has the potential to outgrow cherrybark oak following all levels of midstory removal (table 1). In the complete midstory removal treatment, mean height increment for yellow poplar was approximately 38 cm, which was 29 cm greater than the height growth of cherrybark oak. From a management prospective, this pattern highlights the importance of competitor response to residual structure.

It is possible that the initial height growth patterns observed in this study may not be representative of the response in naturally occurring advanced reproduction. It is suggested that residual effects of nursery practice may be influencing the study's initial height growth patterns. This notion is supported by past research that indicates nursery conditions and practices can influence seedling morphology (Howell and Harrington 2004, Zaczek and others 1993) and potential growth response following outplanting (Dey and Parker 1997, Spetich and others 2002). In other words, it is possible that the observed height growth may have been more influenced by growth and carbohydrate storage in the previous year within the nursery bed than by current conditions at the planting site. In addition, field observations suggest that natural establishment of yellow-poplar may be inhibited by the current understory environmental conditions. This is supported by the fact that the study area has a large overstory component of

yellow-poplar and thus an adequate supply of seed (Beck and Della-Bianca 1981) but has little naturally established poplar reproduction present. Therefore, data and observation suggest that while yellow-poplar may be able to respond if already present in the understory, the conditions created by midstory removal may not stimulate germination and establishment.

Regarding the competitive capacity of oak, it should be noted that past studies have documented lag periods of 2 or more years prior to height growth response of cherrybark oak (Gardiner and Hodges 1998, Lockhart and others 2000). Also, other factors such as the timing and intensity of overstory removal and species-specific mortality trends in the seedling populations could affect the future dynamics of these seedlings. For all of these reasons, the long-term competitive advantage of either species cannot truly be assessed at this time, but their respective developmental patterns will continue to be observed.

A final management implication that should be addressed is the effect of understory vegetation control on height growth. For yellow-poplar, the competition control treatment resulted in a significantly smaller height increment when compared to no understory control. Due to obvious foliar injury evident within several of the study's plots, it seems likely that this difference is a function of herbicide damage caused by spray drift and species-specific sensitivity to glyphosate. In cherrybark oak, the application of weeding/herbicide resulted in a statistically significant increase in height growth. However, given that the total difference in growth was < 3 cm, it is questionable whether this difference is biologically significant. Again, interacting factors such as nursery practices and initial growth delay of cherrybark oak have the potential to mask the influence of this treatment.

## CONCLUSIONS

The results from 1-year height growth data suggest that established yellow-poplar may have the potential to create a competitive problem for cherrybark oak following midstory removal. While first year data is undoubtedly insufficient to predict long-term competitive dynamics, this study does highlight the importance of considering establishment and growth of intolerant competition when implementing midstory removal to enhance oak development. Finally, because understory conditions created by these midstory removals seem to promote positive height growth of shade-intolerant yellow-poplar, it is suggested that these same environmental conditions may also benefit the development of the more tolerant cherrybark oak following the lag period in height growth commonly seen with this species.

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## LITERATURE CITED

- Beck, D.E.; Della-Bianca, L. 1981. Yellow-poplar: characteristics and management. Agric. Handb. 583. Washington, DC: U.S. Department of Agriculture, Forest Service. 91 p.
- Beck, D.E.; Hooper, R.M. 1986. Development of a southern Appalachian hardwood stand after clearcutting. Southern Journal of Applied Forestry. 10: 168-172.
- Crow, T.R. 1988. Reproductive mode and mechanisms for self-replacement of northern red oak *Quercus rubra* - a review. Forest Science. 34(1): 19-40.
- Dey, D.C.; Parker, W.C. 1997. Morphological indicators of stock quality and field performance of red oak (*Quercus rubra* L.) seedlings underplanted in a central Ontario shelterwood. New Forests. 14: 146-156.
- Della-Bianca, L.; Beck, D.E. 1985. Selection management in southern Appalachian hardwoods. Southern Journal of Applied Forestry. 9(3): 191-197.
- Gardiner, E.S.; Hodges, J.D. 1998. Growth and biomass distribution of cherrybark oak (*Quercus pagoda* Raf.) seedlings as influenced by light availability. Forest Ecology and Management. 108: 127-134.
- Gribko, L.S.; Schuler, T.M.; Ford, W.M. 2002. Biotic and abiotic mechanisms in the establishment of northern red oak seedlings: a review. Gen. Tech. Rep. NE-295. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 18 p.
- Heitzman, E.; Shelton, M.G.; Grell, A. 2004. Species composition, size structure, and disturbance history of an old-growth bottomland hardwood-loblolly pine *Pinus taeda* L. forest in Arkansas, USA. Natural Areas Journal. 24(3): 177-187.
- Hodges, J.D.; Janzen, G.C. 1987. Studies on the biology of cherrybark oak: recommendations for regeneration. In: Phillip, D.R., ed. Proceedings of the fourth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 133-139.
- Howell, K.D.; Harrington, T.B. 2004. Nursery practices influence seedling morphology, field performance, and cost efficiency of containerized cherrybark oak. Southern Journal of Applied Forestry. 28(3): 152-162.
- Janzen, G.C.; Hodges, J.D. 1985. Influence of midstory and understory vegetation removal on the establishment and development of oak regeneration. In: Shoulders, E., ed. Proceedings of the third biennial southern silvicultural research conference. Gen. Tech. Rep. SO-54. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 273-278.
- Johnson, P.S.; Jacobs, R.D.; Martin, A.J.; Godel, E.D. 1989. Regenerating northern red oak: three successful case histories. Northern Journal of Applied Forestry. 6: 174-178.
- Kolb, T.E.; Steiner, K.C.; McCormick, L.H.; Bowersox, T.W. 1990. Growth response of northern red oak and yellow poplar seedlings to light, soil moisture and nutrients in relation to ecological strategy. Forest Ecology and Management. 38: 65-78.
- Larsen, D.R.; Johnson, P.S. 1998. Linking the ecology of natural oak regeneration to silviculture. Forest Ecology and Management. 106: 1-7.
- Lockhart, B.R.; Hodges, J.D.; Gardiner, E.S. 2000. Response of advance cherrybark oak reproduction to midstory removal and shoot clipping. Southern Journal of Applied Forestry. 24(1): 45-50.
- Loftis, D.L. 1983. Regenerating southern Appalachian mixed hardwood stands with the shelterwood method. Southern Journal of Applied Forestry. 7: 212-217.
- Loftis, D.L. 1990. A shelterwood method for regenerating red oak in the Southern Appalachians. Forest Science. 36(4): 917-929.
- Lorimer, C.G.; Chapman, J.W.; Lambert, W.D. 1994. Tall understory vegetation as a factor in the poor development of oak seedlings beneath mature stands. Journal of Ecology. 82: 227-237.
- Neter, J.; Kutner, M.H.; Nachtshein, C.J.; Wasserman, W. 1996. Applied linear statistical models. New York, NY: McGraw-Hill, Inc. 1408 p.
- Romagosa, M.A.; Robison, D.J. 2003. Biological constraints on the growth of hardwood regeneration in upland Piedmont forests. Forest Ecology and Management. 175: 545-561.
- Sander, I.L. 1972. Size of oak advanced reproduction: key to growth following harvest cutting. Res. Pap. NC-79. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 6 p.
- Sork, V.L.; Bramble, J.; Sexton, O. 1993. Ecology of mast-fruiting in three species of North America deciduous oaks. Ecology. 74(2): 528-541.
- Spetich, M.A.; Dey, D.C.; Johnson, P.S.; Graney, D.L. 2002. Competitive capacity of *Quercus rubra* L. planted in Arkansas' Boston Mountains. Forest Science. 48(3): 504-517.
- Steel, R.G.D.; Torrie, J.H.; Dickey D.A. 1997. Principles and procedures of statistics a biometrical approach. New York, NY: McGraw-Hill. 666 p.
- Walters, R.S. 1963. Past growth of yellow-poplar and oak reproduction key to future. Res. Pap. CS-4. Columbus, OH: U.S. Department of Agriculture, Forest Service, Central States Forest Experiment Station. 6 p.
- Weigel, D.R.; Johnson, P.S. 2000. Planting red oak under oak/yellow-poplar shelterwoods: a provisional prescription. Gen. Tech. Rep. NC-210. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 16 p.
- Zaczek, J.J.; Groninger, J.W.; Sambeek, J.W.V. 2002. Stand dynamics in old-growth hardwood forest in Southern Illinois, USA. Northern Journal of Applied Forestry. 22(3): 211-219.
- Zaczek, J.J.; Steiner, K.C.; Bowersox, T.W. 1993. Performance of northern red oak planting stock. Northern Journal of Applied Forestry. 10(3): 105-110.

# SURVIVAL AND GROWTH OF UNDERPLANTED NORTHERN RED OAK ON MESIC SITES IN EASTERN TENNESSEE: TWO-YEAR RESULTS

Matthew G. Olson, Wayne K. Clatterback, and Scott E. Schlarbaum<sup>1</sup>

**Abstract**—As part of a replicated oak regeneration study initiated at the University of Tennessee's Oak Ridge Forestry Experiment Station, 180 northern red oak (*Quercus rubra* L.) seedlings were allocated equally among three no-cut control stands, which provided an opportunity to chart the survival and growth of understory planted oak seedlings across several growing seasons (2002 and 2003). Seedling survival decreased from 58 percent in 2002 to 43 percent in 2003, while average seedling growth dropped from 15.42 cm in 2002 to -8.52 cm in 2003. Logistic regression found that first-year survival was related to three initial seedling attributes: shoot length, root collar diameter, and number of first-order lateral roots. Two-year survival was significantly related to shoot length ( $p < 0.05$ ). The only significant relationship found for growth was between first-year growth and shoot length with  $R^2 = 0.29$  and a  $p < 0.0001$ . An exploratory analysis on a subset of seedlings ( $n = 30$ ) relating survival and growth to neighborhood structure found overstory and understory structure to have significant effects on first-year survival, while only overstory structure had an effect on first-year growth and 2-year survival.

## INTRODUCTION

Regenerating oak on mesic sites may require foresters to adopt a more pluralistic approach. The success of traditional prescriptions for regenerating oak, like the shelterwood method, are contingent on the presence of large advance reproduction prior to harvest. This assumption is often violated on mesic sites, where oak saplings are conspicuously absent from the understory. Artificial regeneration can partially offset the problem of regenerating oak on mesic sites by bolstering oak density in the understory but may require other silvicultural treatments in order to be successful. Planting oak in conjunction with cutting is a promising composite method that simultaneously increases the abundance of oak reproduction while creating a more favorable light environment for new oak development.

A critical decision is whether to plant before or after harvest. There are advantages and disadvantages associated with pre-harvest and post-harvest planting that should be considered. The pre-harvest option avoids planting in and around logging residue; however, seedlings are likely to experience logging-related damage during harvest (Olson and others 2004). Although seedlings start in a high light environment when planted after harvest, environmental fluctuations associated with open conditions can stress seedlings during acclimation from nursery to field conditions. Another issue with planting is the timing between planting and cutting. In the case of pre-harvest planting, waiting too long to harvest can lead to low survivorship, eliminating seedlings before they have a chance to restock the new stand.

The primary objective of this study was to document 2 years of survival and growth of planted northern red oak in the understories of mesic, closed canopy stands. A second objective was to relate planted seedling survival and growth to neighborhood structure.

## STUDY SITES

Study sites are located at the University of Tennessee's Forestry Experiment Station in Oak Ridge, TN. The experiment station is in the Ridge and Valley Physiographic Province. Soils underlying the study sites are classified as variants of the Fullerton series, which are Typic Paleudults derived in cherty, dolomitic limestone residuum (Moneymaker 1981). This area supports a mixed-species assemblage typical of the southern portion of the Central Hardwood Region, composed primarily of upland oak species (*Quercus* spp.), yellow poplar (*Liriodendron tulipifera* L.), red and sugar maple (*Acer rubrum* L. and *A. saccharum* Marsh., respectively), hickory species (*Carya* spp.), and miscellaneous hardwoods.

## METHODS

### Study Background and Design

This research is based on a larger harvest/regeneration study evaluating natural and artificial regeneration. The original experiment was a randomized block design, because of inherent topographic and edaphic variability of the study site. The harvest treatment consisted of five levels of overstory removal and a no-cut control, which were replicated three times.

Seedlings used were 1-0 bare-root northern red oak grown in 2001 at the Flint River Nursery, GA. In April, 2002, a total of 1,080 seedlings were planted with shovels. Sixty seedlings were planted in each overstory treatment unit on a spacing of 20 feet by 20 feet. This study focuses on the survival and growth of underplanted northern red oak in the three control units.

### Data Collection

All 180 seedlings in control units were visited at the end of the 2002 and 2003 growing seasons to determine survival and measure height growth. Survival was determined by identifying new twigs with fresh buds and leaf scars. Growth was derived by measuring shoot length and subtracting this value from the initial shoot length measure made prior to planting in 2002.

<sup>1</sup> Graduate Assistant, Department of Forest Ecosystem Science, University of Maine, 5755 Nutting Hall, Orono, ME 04469-5755; and Associate Professor and James R. Cox Professor of Forest Genetics, respectively, Department of Forestry, Wildlife, and Fisheries, University of Tennessee, 274 Ellington Plant Sciences Building, Knoxville, TN 37996-4563.

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The exploratory analysis relating neighborhood structure to survival and growth was based on 10 seedlings selected in each of the 3 control units (n=30). The neighborhood of each seedling was delineated and quantified using the point-quarter method with the planted seedling acting as plot center. Neighboring vegetation was tallied separately into overstory ( $\geq 5$  cm d.b.h.) and understory ( $> 1.4$  m tall,  $< 5$  cm d.b.h.) categories according to size. The distance from plot center and d.b.h. of neighboring vegetation were recorded, which were used to derive basal area and stem density values.

### Statistical Analysis

**Methods**—All analyses relating planted seedling survival and growth to initial seedling attributes and neighborhood structure were performed using logistic and simple linear regression, respectively, with SAS software. All testing was performed at the 5 percent level.

**Variables**—The variables used to represent initial seedling attributes were shoot length (SL), root-collar diameter (RCD), and number of first-order lateral roots (FOLR), which were measured prior to planting in 2002. Total basal area (BA), density (Den), and basal area of nearest neighbor (BA-NN) were calculated for both understory and overstory neighborhood components. The basal area and density of overstory and understory were combined to get a total basal area (TBA) and density (TDen).

## RESULTS

### Overall Survival and Growth

First-year and 2-year survival of planted oak seedlings was 58 percent and 43 percent, respectively. Shoot growth averaged 15.42 cm in the first year and -8.52 cm after 2 years.

### Seedling Attributes and Survival and Growth

Significant relationships between first-year survival and all seedling attributes were detected according to logistic regression (table 1). In all three models, slopes were positive, suggesting positive relationships between seedling attributes and first-year survival. The only significant explanatory variable of 2-year survival was shoot length. Once again, the relationship between survival and shoot length after 2 years was positive. The low  $R^2$ -values make interpretability more

tenuous; however, a pattern of low  $R^2$ -values is typical of logistic regression (Saxton 2002). After the second growing season (2003), the only significant attribute-related growth trend was a negative relationship with shoot length yielding an  $R^2$  of 0.29 (table 1).

### Neighborhood Effects

The average total density and basal area of seedling neighborhoods were 1,892.8 stems/ha and 0.49  $m^2$ , respectively. For overstory neighborhood (stems  $\geq 5$  cm d.b.h.), average density, basal area, and basal area of nearest neighbor were 428.7 stems/ha, 0.45  $m^2$ , and 0.15  $m^2$ , respectively. For the understory (stems  $< 5$  cm d.b.h.), neighborhood structure consisted of an average density of 1,464.1 stems/ha, average basal area of 0.03  $m^2$ , and an average nearest neighbor basal area of 0.005  $m^2$ .

First-year survival was significantly related to overstory density, understory density, total density, and basal area of overstory nearest neighbor (table 2). In all cases, first-year survival response to these factors was negative. Only basal area of nearest neighbor in the overstory was a significant predictor of 2-year survival, which also yielded a negative relationship.

The only significant growth responses detected were between first-year growth and overstory basal area ( $R^2 = 0.43$ ) and total basal area ( $R^2 = 0.35$ ).

## DISCUSSION

Overall, the pattern of survival and growth after 2 years indicated that seedling condition was on the decline. The drop in survival from 58 percent after the first growing season to 43 percent after 2 years suggests that conditions in the understory are likely having a negative effect on planted oak seedlings. Further evidence of poor understory response is the shift from growth in the first season (15.42 cm) to dieback (-8.52 cm) during the second. Although Dey and Parker (1997) observed 90 percent survival in a similar study, they found growth of underplanted red oak after 2 years was negligible to negative. The observation of shoot growth during the first year is deceiving without any indication of shoot vigor, since many of the seedlings exhibited etiolated growth. Etiolated growth is a compensatory response to a limiting light environment and,

**Table 1—Regression results of 1-year and 2-year survival and growth of underplanted northern red oak predicted by 3 initial seedling attributes: shoot length (SL), root-collar diameter (RCD), and number of first-order lateral roots (FOLR). The values shown from left to right are: R-square, p-value in parentheses, and slope sign for significant relationships only**

Response	Initial seedling attribute		
	SL	RCD	FOLR
Survival			
1-year	0.09 (0.001) +	0.03 (0.04) +	0.12 (<0.0001) +
2-year	0.11 (0.005) +	0.02 (0.35)	0.09 (0.06)
Growth			
1-year	0.29 (<0.0001) -	0.003 (0.63)	0.035 (0.1)
2-year	0.05 (0.07)	0.017 (0.25)	0.04 (0.09)

**Table 2—Regression results of 1-year and 2-year survival and growth of underplanted northern red oak predicted from 3 overstory, understory and combined overstory and understory structural attributes. For overstory and understory, basal area (BA), density (Den), and basal area of the nearest neighbor (BA-NN) were used. The combined analysis used total basal area (TBA) and total density (Tden). The values shown from left to right are: R-square, p-value in parentheses, and slope sign for significant relationships only**

		Neighborhood attribute		
	Response	BA	Den	BA-NN
Overstory	Survival			
	1-year	0.037 (0.31)	0.1 (0.03) -	0.13 (0.02) -
	2-year	0.018 (0.43)	0.032 (0.085)	0.11 (0.034) -
	Growth			
	1-year	0.43 (0.002) -	0.09 (0.26)	0.0007 (0.9)
	2-year	0.009 (0.72)	0.0004 (0.94)	0.02 (0.6)
Understory	Survival			
	1-year	0.08 (0.056)	0.18 (0.02) -	0.05 (0.15)
	2-year	0.032 (0.32)	0.09 (0.054)	0.01 (0.47)
	Growth			
	1-year	0.1 (0.17)	0.022 (0.53)	0.07 (0.27)
	2-year	0.03 (0.54)	0.003 (0.85)	0.002 (0.86)
Total				
	Survival			
	1-year	0.004 (0.23)	0.14 (0.026) -	
	2-year	0.02 (0.38)	0.043 (0.07)	
	Growth			
	1-year	0.35 (0.007) -	0.07 (0.3)	
2-year	0.005 (0.78)	0.002 (0.9)		

therefore, is symptomatic of poor light conditions (Taiz and Zeiger 1998). This suggests that planted oaks were light-limited. However, the effect of light on oak seedling survival and growth in this study is speculative without any measure of light to test these relationships.

The positive relationships between all seedling attributes and first-year survival represents a pattern of improved survival for the larger outplanted seedlings. If this survivorship pattern holds true, then one way to increase the success of planting northern red oak would be to select only the largest seedlings. However, the negative relationship between first-year growth and shoot length suggests that larger seedlings grew less than smaller seedlings during the first year. A combination of increasing survival and diminishing growth with increasing seedling size during the first growing season represents a survival-growth trade-off. According to the survival-growth trade-off, underplanting smaller seedlings will lead to increased growth but lower survival. Conversely, a higher proportion of large seedlings are expected to survive to year 2, yet will add less growth during the first growing season.

Neighborhood analysis revealed that both overstory and understory factors had a significant impact on survival of planted northern red oak in the first year. The literature on oak recruitment failure is replete with examples suggesting understory competition is a primary limiting factor (Abrams 1992,

Lorimer 1994). This study illustrates that the understory environment is partly a product of overstory structure and, therefore, overstory attributes affect the performance of plants in the understory. Canham and Burbank (1994) found resource availability varied spatially beneath multi-species canopies and that resource heterogeneity corresponded with variation in overstory structure and composition. Although only neighborhood structure was evaluated in this study, it is plausible that planted oak performance was influenced by neighborhood composition in the diverse mixed-species stands sampled.

A consistent trend across all analyses of survival and growth was deterioration of relationships by the end of 2 years. This observation, along with the result of low survival and seedling dieback, suggests that underplanted northern red oak seedlings are declining irrespective of seedling attributes and stand conditions. If current trends continue, there will not be a reliable component of planted oak to restock larger size classes in the future.

#### SILVICULTURAL IMPLICATIONS

If enrichment planting is to be used to establish and develop oak reproduction in stands similar to those included in this study, then underplanting without further treatment may not be the best option. A cutting restricted to the smaller diameter classes in a manner reminiscent of a thinning-from-below or low thinning may admit adequate light for understory oak

growth, while retaining enough overwood to prevent the development of shade-intolerant competition, such as yellow poplar (Loftis 1990). Harvesting after underplanting, however, is not a perfect remedy. Olson and others (2004) found that harvest-induced damage to seedlings, whether complete or partial cutting, was severe enough to diminish or decimate oak planting stock. Therefore, the viability of pre-harvest planting needs to be weighed against the post-harvest option in order to determine the planting strategy best suited for a particular situation.

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## LITERATURE CITED

- Abrams, M.D. 1992. Fire and the development of oak forests. *BioScience*. 42(5): 346-353.
- Canham, C.D.; Burbank, D.H. 1994. Causes and consequences of heterogeneity in forests: interspecific variation in light transmission by canopy trees. *Canadian Journal of Forest Research*. 24: 337-349.
- Dey, D.C.; Parker, W.C. 1997. Overstory density affects field performance of underplanted red oak (*Quercus rubra* L.) in Ontario. *Northern Journal of Applied Forestry*. 14(3): 120-125.
- Loftis, D.L. 1990. A shelterwood method for regenerating red oak in the southern Appalachians. *Forest Science*. 30(1): 3-22.
- Lorimer, C.G. 1994. Causes of the oak regeneration problem. In: Loftis, D.L.; McGee, C.E., eds. *Oak regeneration: serious problems, practical recommendations*. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 14-39.
- Moneymaker, R.H. 1981. Soil survey of Anderson County, Tennessee. U.S. Department of Agriculture, Soil Conservation Service, and Tennessee Agricultural Experiment Station. Washington, DC: Government Printing Office. 165 p. plus maps.
- Olson, M.G.; Clatterbuck, W.K.; Schlarbaum, S.E. 2004. Mechanical damage incurred by underplanted northern red oak following six overstory treatments: first-year results. In: Connor, K.F., ed. *Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 551-554.
- Saxton, A.M. 2002. Design and analysis for biological research with SAS software. Knoxville, TN.: Graphic Creations. 469 p.
- Taiz, L.; Zeiger, E. 1998. *Plant physiology*, second edition. Sunderland, MA: Sinauer Associates, Inc., Publishers. 791 p.

# RELEASE OF SUPPRESSED OAK ADVANCE REGENERATION

Dylan Dillaway and Jeffrey W. Stringer<sup>1</sup>

**Abstract**—Oaks are not consistently regenerating on intermediate- and high-quality sites due to the lack of well-developed advance regeneration. Studies of northern red oak (*Quercus rubra* L.) seedling cohorts have shown that when grown under well-developed canopies and mid-stories, height growth is suppressed, and seedling mortality increases with time resulting in a sparsely populated bank of low-vigor advance regeneration. A mid-story removal treatment has been shown to improve vigor of northern red oak and cherrybark oak (*Q. pagoda* Raf.) regeneration in advance of a harvest. However, this treatment has not been widely tested, and indicators of advance regeneration vigor, such as height/age relationships, have not been defined for a number of important oak species. This study profiled the developmental characteristics of white and black oak (*Q. alba* L. and *Q. velutina* Lam.) seedlings growing under dense over-stories and mid-stories in central Kentucky and reports the initial growth response of these seedlings to a mid-story removal.

## INTRODUCTION

Advance regeneration is defined as regeneration that is present prior to a regeneration event. For oaks (*Quercus* spp.), this encompasses a range of tree sizes and ages, from first-year seedlings to saplings that possess a wide range of vigor and growth potentials. Characterizing and managing this diverse pool of advance regeneration is difficult.

Advance regeneration is required to successfully regenerate oak. The intermediate- to shade-intolerance of oaks (Hodges and Gardiner 1992) and the dieback and resprouting nature of oaks (Johnson 1992) helps develop cohorts of advance regeneration. However, intermediate treatments are required to improve the competitive vigor of oak advance regeneration (Loftis 1983). Seedling sprouts and true seedlings perform differently under a wide range of light levels at the time of release (Lockhart and others 1999). We hypothesize that as the length of suppression in dense shade progresses, seedlings have less associated vigor and will not respond to a release treatment as well as seedlings that have been suppressed for shorter periods. This could have direct implications on when intermediate treatments, such as mid-story removal, should be performed relative to the establishment of oak cohorts.

Loftis (1992) has shown that a cohort of northern red oak (*Q. rubra* L.) seedlings at 12 years attained a height of > 1 foot. It was also shown that this cohort of seedlings exhibited a 90 percent mortality rate by year 12. However, little is known about the demographics of other oak seedling populations. It is critical to have seedlings with a height of > 4.5 feet at the time of a regeneration treatment in order for these seedlings to be competitive (Sander 1972). Treatments have been proposed that allow seedlings to achieve this stature without stimulating the growth of competing species (Johnson 1980, Loftis 1983). However, the optimum timing of this treatment relative to cohort age is unknown.

Describing populations of advance regeneration requires an understanding of the growth habits of oak seedlings. Oak seedlings have a conservative growth strategy, favoring root growth over shoot growth even when presented with improved

growing conditions (Abrams 1998, Hodges and Gardiner 1992). Often seedlings die back and resprout and have been shown to perform differently when exposed to silvicultural treatments (Lockhart and others 1999). Understanding the nature of advance regeneration root systems and predicting below-ground biomass may be important to understanding the nature of their response. Many above ground features of a seedling can provide estimates of the condition and developmental stage of a root system (Johnson 1992). Due to the conservative growth strategy of oak seedlings, their well-developed root system may provide for a more timely response to release (Hodges and Gardiner 1992). Larger root systems may also have larger carbohydrate reserves for a seedling to tap upon release (Hodges and Gardiner 1992). This paper will outline some of the characteristics of white oak (*Q. alba* L.) and black oak (*Q. velutina* Lam.) seedling populations in upland oak stands in central Kentucky that have direct implications toward assessing advance regeneration vigor and will also provide some first-year growth response information on released advance regeneration.

## STUDY SITES

Study sites were located on Berea College Forest in Madison County, KY, in the Knobs physiographic region located on the western edge of the Cumberland Plateau. Four stands containing a range of cohorts of black oak and white oak advance regeneration were selected for study. All stands have a mixed oak over-story with a significant white oak component. Site indices for these stands range from 73 to 82, with a mean of 78. Before treatment, basal area ranged from 100 to 115 square feet. The mid-story and under-story of these stands were dominated by red maple (*Acer rubrum* L.), sugar maple (*A. saccharum* Marshall), beech (*Fagus sylvatica* L.), and minor components of other species. In each stand, two 0.5 acre tracts were delineated for study (treatment and control).

## METHODS

In January, 2004, 30 black oak and 120 white oak seedlings were excavated from the study sites. Seedlings were bagged, labeled, and immediately put on ice. In the lab, all seedling

<sup>1</sup> Research Assistant and Associate Professor, respectively, University of Kentucky, Department of Forestry, 213 T.P. Cooper Building, Lexington, KY 40546-0073.

roots were rinsed in a water bath, photographed, and measured. Seedling tops were separated from the root system at the root collar. Measurements taken on the seedling top include: root collar diameter, length of all growth flushes or nodes, total height, and number of flushes (top age).

Root ages of white oak were measured 1 inch below the root collar by counting annual rings. It was not possible to accomplish this with black oak roots, and no root ages were obtained for this species. Length, root diameter (diameter 1 inch below root collar), wet mass, and dry weight were measured on all root systems. Two sections of root (root collar to 1 inch below root collar, and 1 inch below root collar to 2 inches below root collar) were sectioned, flash frozen in liquid nitrogen, and put in a  $-80^{\circ}\text{C}$  freezer. These were then analyzed for carbohydrate levels (data not presented in this paper).

Seedlings were classified into two groups: true seedlings and seedling sprouts. This was accomplished using comparisons of the top age (number of nodes or growth flushes) and the root age (number of growth rings 1 inch below the root collar). Seedlings that had the same top age and root age were classified as a true seedling, and seedlings that expressed a discrepancy between top age and root age (root age > top age) were classified as seedling sprouts.

All seedlings sampled were growing in an intact canopy setting. After this initial excavation of seedlings, a mid-story removal was implemented. This was accomplished by removing approximately 20 percent of the total stand basal area with a chainsaw and immediately spraying the stumps with 100 percent Roundup Pro<sup>®</sup>. Stems were removed starting with the 1 inch size class and moving up through diameter classes until the 20 percent target was achieved. A 25-foot buffer was installed around the treated growth and yield plot. In addition to the excavated seedlings, 400 seedlings of white oak, black oak, northern red oak, and red maple were tagged and measured (basal diameter, height, number of nodes, and length of last internode).

### STATISTICAL ANALYSES

Analysis of variance (ANOVA) was used to test for significant differences between the seedling sprout characteristics and the true seedling characteristics. These variables include root mass, root diameter, root length, root age, seedling height, root collar diameter, and number of nodes (top age). ANOVA was also used to detect growth differences between treatments and among species. All comparisons were analyzed at  $\alpha = 0.05$ .

### RESULTS

In the four stands that were profiled for this study, 55 percent of the seedlings sampled were true seedlings and 45 percent were seedling sprouts. Both seedlings and seedling sprouts encompassed a wide range of age. True seedlings averaged 6 years for both top age and root age (fig. 1). The average root age of seedling sprouts was approximately 9 years, while the average top age was 6 years (fig. 2). While root ages differed between seedlings and seedling sprouts, ages of tops were similar.

The mean height of seedling sprouts and true seedlings rarely surpass 1 foot in intact canopy settings in central Kentucky (fig. 3). While internode length was similar for true seedlings

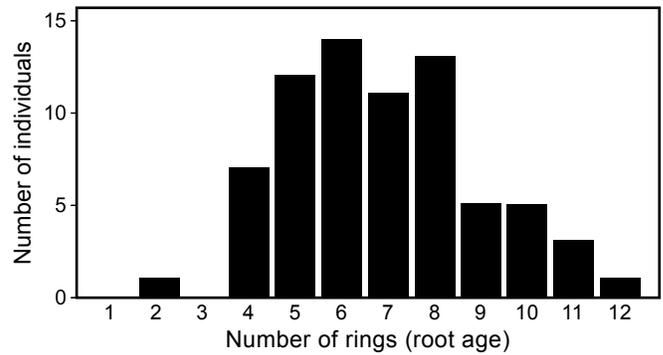


Figure 1—Age distribution of true white oak seedlings grown under intact canopies.

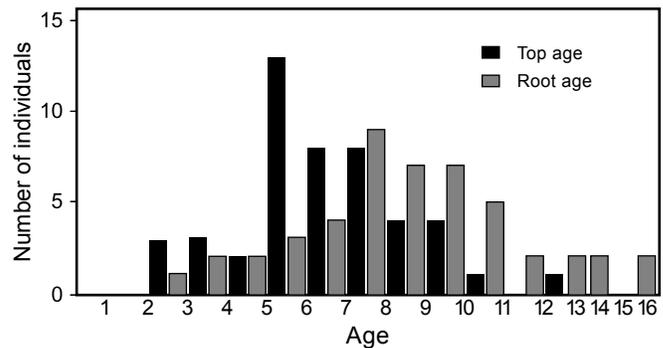


Figure 2—Age distribution of white oak seedling sprouts (top age and root age) grown under intact canopies.

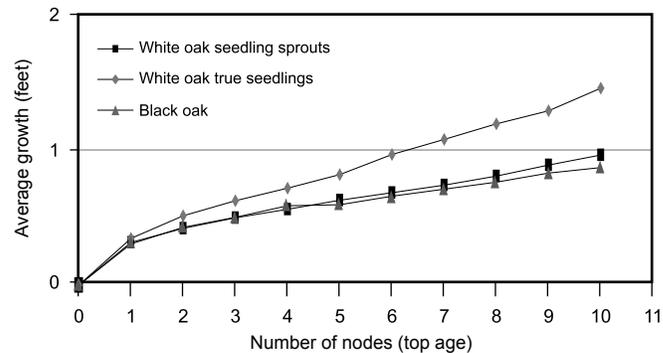


Figure 3—Average height growth of white oak seedling and seedling sprouts and black oak advance regeneration over time under intact canopies as indicated by internode length.

of white oak and black oak seedlings, white oak seedling sprouts had a significantly greater height at node 10. Due to the inability to obtain a root age from the black oak seedlings, we were unable to further classify the black oak into seedling sprouts and true seedlings. The performance of the black oak seedlings and the white oak true seedlings, under an intact canopy, is similar to the results reported by Loftis (1992) for northern red oak in the southern Appalachians.

Although we could not distinguish between one flush and multiple-flush years, it is rare for oak seedlings to have multiple flushes in a growing season in central Kentucky. From field observations, over-story oaks in central Kentucky tend

to exhibit a multiple flush every 3 to 5 years as a result of above-average rainfall. However, this multiple flush phenomenon occurs less often in suppressed seedlings growing in intact canopy settings. During the experimental period, higher-than-average rainfall resulted in 2 to 3 growth flushes of canopy oak trees. However, monitored oak seedlings only flushed once. This lends credibility to the age estimation from node counts. Regardless, the seedlings and seedling sprouts monitored in this study fell short of the minimum height requirements needed to successfully compete after a regeneration harvest, and improvement in oak seedling height through the application of a mid-story removal is warranted.

### INITIAL GROWTH RESPONSE

Seedlings and seedling sprouts of white oak, black oak, northern red oak, and red maple were monitored in order to assess the initial growth response to a mid-story removal. Initial response varied by species. All species of oak advance regeneration showed no height growth response to a mid-story removal. However, northern red oak and black oak had significantly better height growth in intact canopy conditions and also in a mid-story removal setting than white oak (fig. 4). There was no height growth difference between northern red oak and black oak. White oak had significantly less height growth in the mid-story removal setting than that of the control. This initial response to increased light levels is not unexpected due to oak's conservative growth strategy. There was a significant increase in basal diameter in the mid-story removal treatment over that of the control plot at all sites and across all species of oak seedlings (fig. 5). This suggests that as these oak seedlings are exposed to higher light intensities,

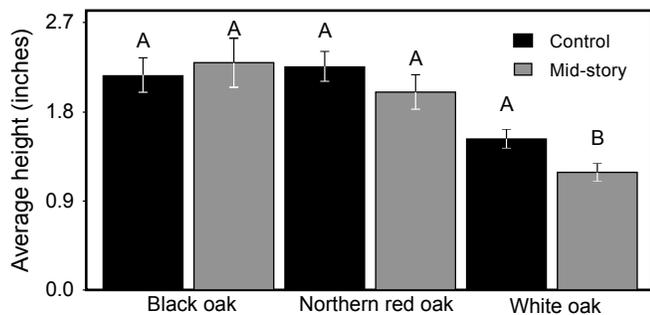


Figure 4—Advance regeneration height growth in 2004 by treatment and species. Letters represent significant differences between treatments ( $p < 0.05$ ) using ANOVA.

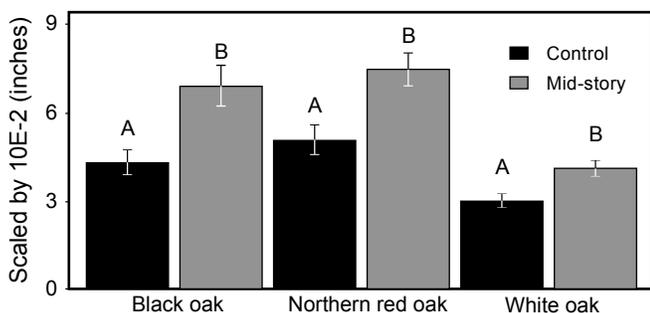


Figure 5—Basal diameter growth of advance oak regeneration by species and treatment. Letters represent significant differences between treatments ( $p < 0.05$ ) using ANOVA.

they shift the allocation of photosynthate to root growth while maintaining height growth at pre-treatment levels. This trend also is not unexpected due to oak's conservative growth strategy. There was no significant difference in basal diameter growth among oak species.

### RED MAPLE RESPONSE

Red maple seedlings did respond to increased light levels in both height and basal diameter growth. Red maple height growth in the mid-story removal areas was significantly greater than that of the control seedlings. Red maple seedlings also grew significantly more than white oak seedlings in both an intact canopy setting and in the mid-story removal plots. Figure 6 shows increased height growth of red maple compared to that of white oak.

These data indicate that red maple is out-growing white oak in height under intact canopies and in response to a mid-story removal. Red maple also exhibited the same significant increase in basal diameter growth as the oak seedlings when exposed to a mid-story removal. Basal diameter growth was significantly greater in the mid-story removal plots than the control plots (fig. 7).

### CONCLUSIONS

Black oak seedlings and true white oak seedlings in central Kentucky upland oak stands follow a similar trend reported for northern red oak in North Carolina (Loftis 1992). Advance

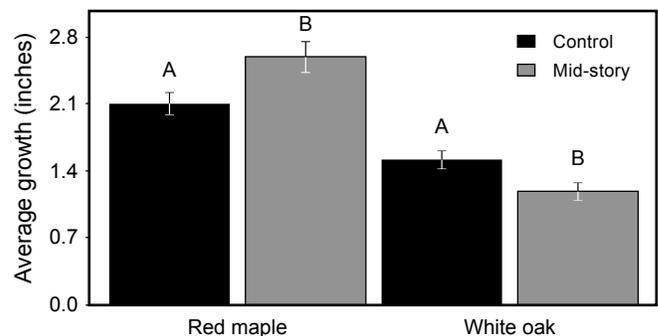


Figure 6—Red maple vs. white oak height growth response by treatment. Letters represent significant differences between treatments ( $p < 0.05$ ) using ANOVA.

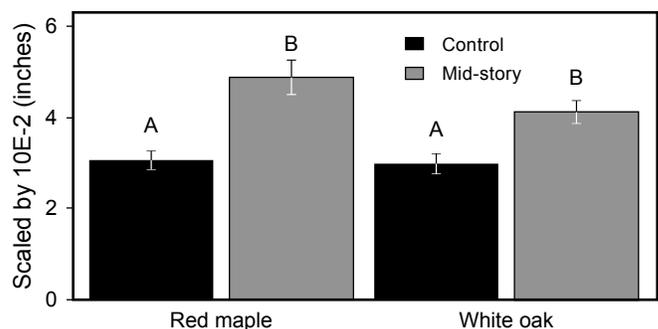


Figure 7—Red maple and white oak basal diameter growth by treatment. Letters represent significant differences between treatments ( $p < 0.05$ ) using ANOVA.

regeneration growing under intact canopies rarely attain a height > 1 foot. Results show that application of a mid-story removal significantly increases basal diameters of all oak species investigated. This indicates a positive response in tree vigor to this treatment that will ultimately result in a seedling or seedling sprout that has greater potential for rapid height growth when challenged with a full canopy release. However, red maple was also able to capitalize in both height and basal diameter growth in the first season following treatment implementation. This may pose problems over the life of this treatment making multiple under-story cleanings a necessity.

#### LITERATURE CITED

- Abrams, M.D. 1998. The red maple paradox: what explains the widespread expansion of red maple in eastern forests? *Bioscience*. 48: 355-364.
- Hodges, J.D.; Gardiner, E.S. 1992. Ecology and physiology of oak regeneration. In: Loftis, D.L.; Mcgee, C.E., eds. Oak regeneration: serious problems, practical recommendations. Symposium proceedings. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 54-65.
- Johnson, R.L. 1980. New ideas about regeneration of hardwoods. Proceedings hardwood committee's symposium on hardwood regeneration. Atlanta, GA. Southeastern Lumber Manufacturers Association: 17-19.
- Johnson, P.S. 1992. Sources of oak reproduction. In: Loftis, D.L.; Mcgee, C.E., eds. Oak regeneration: serious problems, practical recommendations. Symposium proceedings. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 112-131.
- Lockhart, B.R.; Hodges, J.D.; Gardiner, E.S. 1999. Response of advance cherrybark oak reproduction to mid-story removal and shoot clipping. *Southern Journal of Applied Forestry*. 24(1): 45-50.
- Loftis, D.L. 1983. Regenerating red oak on productive sites in the southern Appalachians: a research approach. Proceedings of the second biennial southern silviculture research conference. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 144-150.
- Loftis, D. 1992. Regenerating northern red oak on high quality sites in the southern Appalachians. In: Loftis, D.L.; Mcgee, C.E. Oak regeneration: serious problems, practical recommendations. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 202-210.
- Sander, I.L. 1972. Size of advance reproduction: key to growth following harvest cutting. Res. Pap. NC-79. St. Paul, MN: U.S. Department of Agriculture, Forest Service. 6 p.

# REGENERATION RESPONSE TO MIDSTORY CONTROL FOLLOWING LONG-TERM SINGLE TREE SELECTION MANAGEMENT OF SOUTHERN APPALACHIAN HARDWOODS

Jason R. Lewis, John W. Groninger, and David L. Loftis<sup>1</sup>

**Abstract**—Sustainability of the single tree selection system in the mixed hardwood forests of the southern Appalachians is compromised by insufficient recruitment of oak species. In 1986, portions of a stand at Bent Creek Experimental Forest that have been under single tree selection management since 1945 were subjected to a midstory herbicide treatment in an effort to improve the competitive status of oak species. Regeneration density of oak species and red maple, the primary competitor species, were measured in the treated stand and an untreated control in 2003. The results of this study suggest the potential for oak recruitment has been increased by the herbicide treatment.

## INTRODUCTION

In the southern Appalachian Mountains, single tree selection may be implemented to balance esthetic and timber production concerns. Long-term use of this system on productive sites may lead to decreased dominance of oak species in younger age classes at the expense of shade tolerant tree species. Red maple, in particular, has been widely observed to increase in dominance in partially cut stands (Abrams 1998). Red maple seedlings and saplings may form a subcanopy to the exclusion of oak and other less shade tolerant tree species. Midstory control with herbicides has been implemented in Appalachian hardwoods stands with short-term evidence of success in promoting the growth of shade intolerant species (Kochenderfer and others 2001). However, the long-term impact of this treatment has not been reported.

The objective of this study was to evaluate the effects of a single midstory herbicide treatment on the development of regeneration in a Southern Appalachian hardwoods forest under long-term single tree selection management.

## METHODS

### Site History

The treated and untreated compartments in this study are part of the farm woodlots at the Bent Creek Experimental Forest near Asheville, NC. The farm woodlots were installed in 1945 in order to examine the economic returns from periodic small harvests (Della-Bianca and Beck 1985). Most of the early harvests were improvement cuts with large numbers of defective or poorly formed trees being removed (McGee 1970).

Throughout the 1960s and 1970s, the site was managed exclusively under the single tree selection system. All cuts were made to adhere to de Liocourt's diameter distribution for unevenaged stands (McGee 1970). Little attention was paid to the species composition of the regeneration. The last harvest of overstory trees occurred in 1983. In 1986, an experiment was installed to improve the species composition of the regeneration by creating better growth conditions for oak species. The experiment was conducted on two compartments,

each roughly 30 acres in size with similar soils and slope position (Beck and Della Bianca 1985). One compartment received an herbicide treatment of the undesirable midstory species while the other remained untreated.

### Data Collection and Analysis

Regeneration was sampled in fall, 2003. Thirty 0.01-acre plots were established in each compartment for a total of 60 plots. Trees were identified by species, and height was measured for all individuals between 1- and 20-feet tall. Diameter was determined on all individuals > 1.0 inches d.b.h.

Shannon's index of diversity and means for regeneration data were calculated for each sample plot. Treatment differences in diversity and regeneration density were evaluated using a t-test with  $\alpha < 0.05$ .

## RESULTS AND DISCUSSION

The herbicide treatment generally improved the competitive status of oak saplings relative to red maple. Oak density was significantly greater than that of red maple in the 1-, 2-, and 3-inch diameter classes in the herbicide treatment (figs. 1 and 2). Red maple density was reduced by the herbicide treatment, with significant differences recorded in the 2- and 3-inch d.b.h. classes. Total oak sapling density was low, however, even in the treated stand, averaging 30 trees per acre in the 1-, 2-, and 3-inch size classes combined.

Among individuals in the  $\leq 10$  feet height classes, no significant treatment differences were detected in the number of oak or red maple stems (figs. 3 and 4). However, a trend toward higher numbers was evident in the herbicide treatment for oaks in the  $\geq 4$  feet size class and for red maple in all size classes. Red maple density was generally higher than oak in all but the smallest height classes.

Shannon's index of diversity was unaffected by the herbicide treatment, averaging 1.72 and 1.68 for the treated and untreated sites, respectively.

<sup>1</sup> Graduate student and Associate Professor, respectively, Department of Forestry, Southern Illinois University Carbondale, Carbondale, IL 62901; and Project Leader, USDA Forest Service, Southern Research Station, Bent Creek Experimental Forest, Asheville NC 28804.

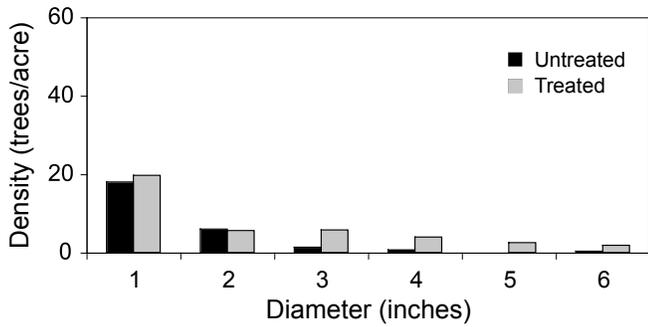


Figure 1—Oak species density response to midstory herbicide control by diameter class.

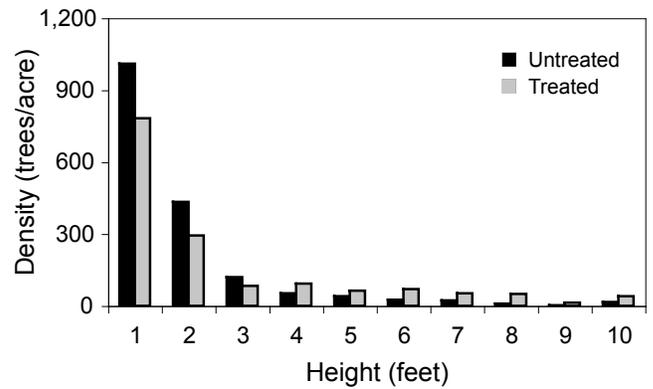


Figure 3—Oak species density response to midstory herbicide control by height class.

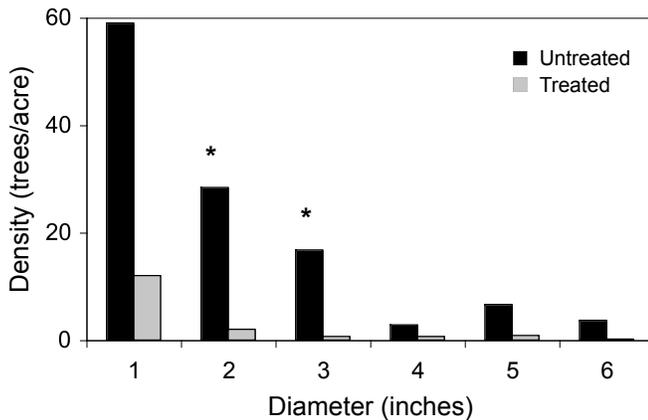


Figure 2—Red maple density response to midstory herbicide control by diameter class. Significant treatment differences within a diameter class are indicated by an asterisk.

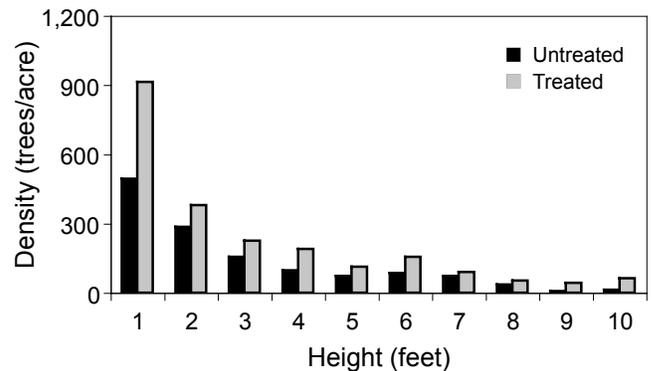


Figure 4—Red maple density response to midstory herbicide control by height class.

## CONCLUSIONS

The herbicide treatment improved the competitive status of oak species relative to red maple. However, red maple remained a common component of the seedling and sapling size classes. Follow-up midstory treatments or overstory removal could allow larger oak stems to approach overstory status. Under this scenario, oak recruitment would be more likely to occur in the treated stand. In the absence of further midstory or canopy disturbance, the competitive status of oak is likely to decline at the expense of the more shade tolerant red maple. The cessation of overstory removal treatments since 1983 is inconsistent with typical single tree selection management scenarios and may be at least in part responsible for dampening the tree growth response to the herbicide treatment.

## LITERATURE CITED

- Abrams, M.D. 1998. The red maple paradox. *Bioscience*. 48: 355-365.
- Della-Bianca, L.; Beck, D.E. 1985. Selection management in southern Appalachian hardwoods. *Southern Journal of Applied Forestry*. 9: 191-196.
- Kochenderfer, J.D.; Zedaker, S.M.; Johnson, J.E. [and others]. 2001. Herbicide hardwood crop tree release in central West Virginia. *Northern Journal of Applied Forestry*. 18: 46-54.
- McGee, C.E. 1970. Regeneration of the Bent Creek farm woodlot. Office Report. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Bent Creek Experimental Forest. 19 p.

## **Growth and Yield**

*Moderators:*

**DAVID LARSEN**  
University of Missouri

and

**TOM LYNCH**  
Oklahoma State University



# USE OF A GENERALIZED SIGMOID GROWTH FUNCTION TO PREDICT SITE INDEX FOR UNMANAGED LOBLOLLY AND SLASH PINE PLANTATIONS IN EAST TEXAS

Dean W. Coble and Young-Jin Lee<sup>1</sup>

**Abstract**—A generalized sigmoid growth function was used in this study to model site index (SI) for unmanaged or low-intensity managed loblolly pine (*Pinus taeda*, L.) and slash pine (*Pinus elliottii*, Engelm.) plantations in east Texas. Schnute's growth function was fit to 11,367 and 5,040 height-age observations of loblolly and slash pine, respectively. These data were collected over a 20-year period from unmanaged pine plantations located across the east Texas region as a part of the East Texas Pine Plantation Research Project (ETPPRP). The fit model was used to derive SI equations (25-year index age). The SI equations apply to unmanaged or low-intensity managed loblolly and slash pine plantations in east Texas ranging in age from 5 to 40 years. They can also serve as a baseline for SI estimation of intensively managed pine plantations.

## INTRODUCTION

Forestland in east Texas occupies about 12.1 million acres (Miles 2005). Of this area, 2.9 million acres are classified as pine plantations, with about 2.7 million acres (90 percent) of this total on private land. Estimation of the productivity of these plantations is vitally important to forecasting future wood fiber yields. Site index (SI) is the most common measure used to assess a site's productivity (Clutter and others 1983). Sigmoid growth functions have been used for decades to predict SI (Pienaar and Turnbull 1973). The Chapman-Richards (Chapman 1961, Richards 1959) and Von Bertalanffy (Von Bertalanffy 1951) functions represent two sigmoid functions commonly used as guide curves to develop anamorphic families of site curves (Clutter and others 1983). Schnute (1981) generalized these sigmoid growth functions, with specific application to fish growth. This function is highly flexible in that it can represent many aspects of biological growth, such as asymptotic growth or the lack thereof. In fact, many widely used growth functions, such as the Chapman-Richards and Logistic growth functions, are special cases of Schnute's growth function. The Schnute growth function has found application in forestry for modeling individual tree diameter and basal area growth (Bredenkamp and Gregoire 1988, Yuancai and others 1997), stand density and yield (Zhang and others 1993), and individual tree height-diameter (Peng and others 2001, Zhang 1997). However, to the best of our knowledge, the Schnute growth function has not been applied in the development of SI curves.

The purpose of this study was to use the Schnute growth function to develop a family of anamorphic SI curves for loblolly pine and slash pine in east Texas. These new curves were then compared to existing site curves for loblolly and slash pine in east Texas.

## METHODS

### Background Information – Chapman-Richards Growth Function

The Chapman-Richards growth function is based on the first-order ordinary differential equation:

$$\frac{dY}{dt} = \alpha Y^\beta - \gamma Y \quad (1)$$

or

$$\frac{dY}{dt} + \gamma Y = \alpha Y^\beta$$

where

Y = size of organism

t = time

$\frac{dY}{dt}$  = growth of organism

$\alpha Y^\beta$  = anabolic growth (e.g., photosynthesis)

$\gamma Y$  = catabolic growth (e.g., respiration)

Equation (1) is a Bernoulli equation that can be solved with traditional methods (Grossman and Derrick 1988):

$$Y(t) = \phi \left( 1 - e^{-\theta(t-t_0)} \right)^{\frac{1}{1-\beta}} \quad (2)$$

where

Y(t) = size of organism at time t

$t_0$  = time zero or beginning time

$$\phi = \left( \frac{\alpha}{\gamma} \right)^{\frac{1}{1-\beta}}$$

$$\theta = \gamma(1 - \beta)$$

all other variables defined above.

A more familiar formulation of equation (2) is the empirical 3-parameter Chapman-Richards growth function:

$$Y(t) = b_0 \left( 1 - e^{-b_1(t-t_0)} \right)^{b_2}, \quad (3)$$

where

$b_i$  = regression parameters to be estimated

all other variables are defined as before.

<sup>1</sup> Associate Professor of Forest Biometrics, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, Texas, 75962; and Assistant Professor of Forestry, College of Industrial Science, Kongju National University, Chungnam, Korea, respectively.

**Background Information –  
Schnute Growth Function**

The Schnute growth function is based on two first-order ordinary differential equations:

$$\frac{dY}{dt} = YZ \text{ and } \frac{dZ}{dt} = -Z(a - bZ)$$

where

Z = growth rate

a, b = constants

all other variables defined as before.

Thus,  $\frac{dY}{dt}$  states that the change in size (i.e., growth) is a function of size, Y, and the growth rate, Z; and,  $\frac{dZ}{dt}$  states

that the change in the growth rate, Z, is a linear function of Z. Together, they give the second-order ordinary differential equation that describes the acceleration of growth:

$$\frac{d^2Y}{dt^2} = \frac{dY}{dt}(-a + (1-b)Z)$$

where

all variables are defined above.

Solution of this second-order differential equation gives:

$$Y(t) = \left( y_1^b + (y_2^b - y_1^b) \frac{1 - e^{-a(t-\tau_1)}}{1 - e^{-a(\tau_2-\tau_1)}} \right)^{1/b} \quad (4)$$

where

Y(t) = size of organism at time t

y<sub>1</sub>, y<sub>2</sub> = size of organism at τ<sub>1</sub> and τ<sub>2</sub> (to be estimated via regression)

τ<sub>1</sub>, τ<sub>2</sub> = ages at time 1 and 2 (e.g., old and young)

a, b = constants to be estimated via regression ≠ 0.

Equation (4) is based on acceleration of growth, not just growth as in other models such as Chapman-Richards. Depending on the values of a and b, equation (4) takes on different forms, where some are asymptotic and others are non-asymptotic. In any event, each case is a limiting form of one function. The Chapman-Richards, Von Bertalanffy, Gompertz, Exponential, and Logistic growth functions represent special cases of certain limiting forms, all found by algebraic tinkering of the Schnute function. This study is concerned with Schnute's Case 1 [a ≠ 0, b ≠ 0, equation (4)], because site curves are typically asymptotic.

**Guide Curve Development –  
Chapman-Richards Growth Function**

The guide curve method is used to develop anamorphic SI curves (Clutter and others 1983). This method first specifies SI in terms of a mathematical function. In this study, SI is defined as the average height of the 10 tallest trees at the index age of 25 years. For the Chapman-Richards growth function (equation 3), this can be expressed as:

$$S = b_0 \left( 1 - e^{-b_1(t_{IA} - t_0)} \right)^{b_2}$$

where

S = SI in feet

t<sub>IA</sub> = index age = 25 years

t<sub>0</sub> = time zero = 0

all other variables defined as before.

Then, solve for b<sub>0</sub>:

$$b_0 = S \left( 1 - e^{-b_1(t_{IA} - t_0)} \right)^{-b_2}$$

Substituting this into equation (3) gives:

$$H = S \left( \frac{1 - e^{-b_1(t)}}{1 - e^{-b_1(t_{IA})}} \right)^{b_2} \quad (5)$$

and then solving for S gives

$$S = H \left( \frac{1 - e^{-b_1(t_{IA})}}{1 - e^{-b_1(t)}} \right)^{b_2} \quad (6)$$

where

H = Y(t) = average height of the tallest 10 trees in feet at time t

all other variables are defined as before.

Equations (5) and (6) represent a family of anamorphic SI curves described by the Chapman-Richards growth function.

**Guide Curve Development –  
Schnute Growth Function**

The methodology outlined in the preceding section was used to develop anamorphic SI curves described by the Schnute growth function, equation (4). First, define the guide curve:

$$S = \left( y_1^b + (y_2^b - y_1^b) \frac{1 - e^{-a(t_{IA} - \tau_1)}}{1 - e^{-a(\tau_2 - \tau_1)}} \right)^{1/b}$$

Then, solve for y<sub>2</sub><sup>b</sup>:

$$y_2^b = y_1^b + \left( S^b - y_1^b \right) \frac{1 - e^{-a(\tau_2 - \tau_1)}}{1 - e^{-a(t_{IA} - \tau_1)}}$$

Substituting this expression in equation (4) gives:

$$H = \left( y_1^b + \left( S^b - y_1^b \right) \frac{1 - e^{-a(t - \tau_1)}}{1 - e^{-a(t_{IA} - \tau_1)}} \right)^{1/b} \quad (7)$$

and then solving for S gives,

$$S = \left( y_1^b + \left( H^b - y_1^b \right) \frac{1 - e^{-a(t_{IA} - \tau_1)}}{1 - e^{-a(t - \tau_1)}} \right)^{1/b} \quad (8)$$

where

all variables are defined as before.

Equations (7) and (8) represent a family of anamorphic SI curves described by the Schnute growth function.

## Data Analysis

Currently, 124 permanent plots are located in loblolly pine plantations, and 56 plots are located in slash pine plantations throughout east Texas. The ETPPRP study area covers 22 counties across east Texas (Lenhart and others 1985). Generally, the counties are located within the rectangle from 30 to 35 north latitude and 93 to 96 west longitude. Each plot consists of two subplots: one for model development and one for model evaluation. A subplot is 100 x 100 feet in size, and a 60-foot buffer separates the subplots. All planted pine trees are permanently tagged and numbered. Only the model development plots were used in this study. The average height of the 10 tallest site trees and the total age of the plantation were used to represent height and age in the functions. The 10 tallest trees per plot were considered site trees if they met the following criteria: (1) free of damage, (2) no forks, and (3) no presence of stem fusiform rust [*Cronartium quercuum* [Berk.] Miyabe ex Shirai f. sp. *Fusiforme*]. A total of 11,367 height-age observations for loblolly pine and 5,040 height-age observations for slash pine (table 1) were used to fit equation (4). PROC NLIN in SAS version 9.1 was used to run the analyses.

## RESULTS

Equation (4) was fit to the loblolly and slash pine data to produce the coefficients for equations (7) and (8). All coefficients were significantly different from zero (table 2), and the residual plots did not reveal any unusual heteroscedasticity problems (plots not shown). Note that  $\tau_1$  and  $\tau_2$  were fixed at the values of the youngest and oldest ages, while  $a$ ,  $b$ ,  $y_1$ , and  $y_2$  were estimated by SAS. The SAS code fragment used to fit the Schnute model is provided in the appendix. The coefficient values from table 2 were used in equation (8) to produce site curves for loblolly pine (fig. 1) and slash pine (fig. 2). These curves range in SI from 40 to 90 feet (index age = 25 years), and they apply to plantations that range from 5 to 40 years of age.

The Schnute guide curves differ significantly from those of Lenhart and others (1986). For loblolly pine, the Schnute curve was higher than Lenhart and others' curve for all ages (fig. 3). For slash pine, the Schnute curve was higher for ages > 15 years (fig. 4). Since the Chapman-Richards growth function (equation 3) is a special case of the Schnute growth function (equation 4), the Schnute guide curve equations can be converted to the same functional form as those of Lenhart and others, so that the coefficients can be compared using a one-sample t-test. To find asymptotic height,  $b_0$ , of the Chapman-Richards function for loblolly pine, insert parameter values into the Schnute function and let  $t \rightarrow \infty$ :

**Table 1—Descriptive statistics for the ETPPRP loblolly and slash pine development plots, where age = total age (years) of plantation and height = average height (feet) of the 10 tallest site trees on a plot**

Species	Variable	N	Standard			
			Mean	deviation	Minimum	Maximum
Loblolly	Age	11,367	14	7	1	37
	Height	11,367	44	21	1	101
Slash	Age	5,040	14	7	1	33
	Height	5,040	43	21	2	97

**Table 2—Parameter estimates and fit statistics of loblolly and slash pine guide curves (equation 4)**

Species	Parameter	Parameter estimate	Standard error	Lower 95% confidence interval	Upper 95% confidence interval	Root MSE
						feet
Loblolly	$y_1$	0.99476	0.36757	0.27432	1.71520	7.3
	$y_2$	80.92198	0.48019	79.98081	81.86315	
	$a$	0.08036	0.00342	0.07366	0.08706	
	$b$	0.68232	0.04006	0.60380	0.76084	
	$\tau_1$	1	—	—	—	
	$\tau_2$	37	—	—	—	
Slash	$y_1$	3.14282	0.44793	2.27034	4.02622	6.7
	$y_2$	82.25850	0.66399	80.95708	83.55992	
	$a$	0.07747	0.00554	0.06661	0.08833	
	$b$	0.52098	0.06477	0.39403	0.64793	
	$\tau_1$	1	—	—	—	
	$\tau_2$	33	—	—	—	

— = na.

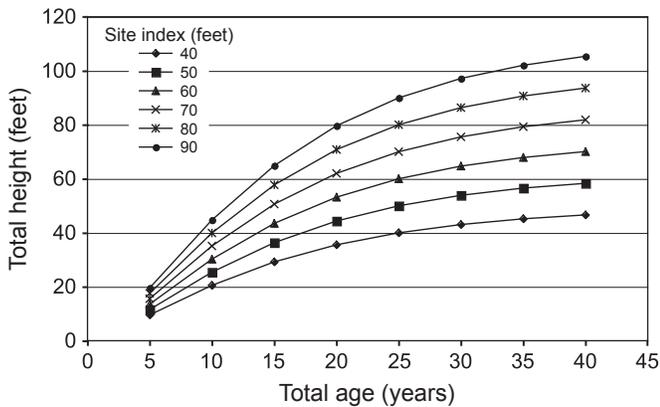


Figure 1—Site index curves (index age = 25 years) for unmanaged loblolly pine plantations in east Texas.

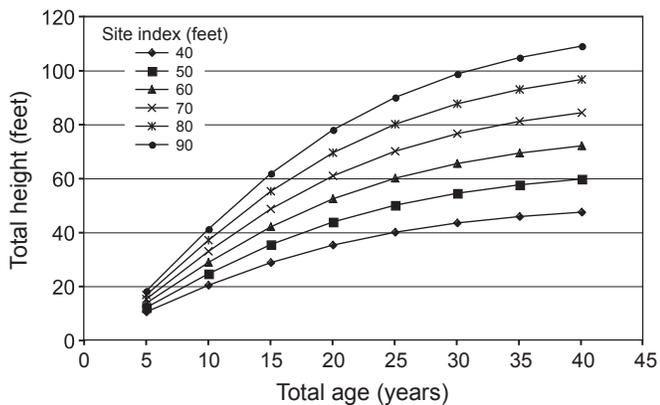


Figure 2—Site index curves (index age = 25 years) for unmanaged slash pine plantations in east Texas.

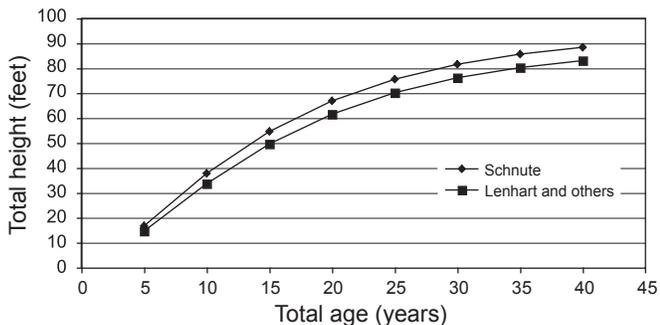


Figure 3—Comparison between the new Schnute guide curve and the Lenhart and others (1985) guide curve for loblolly pine.

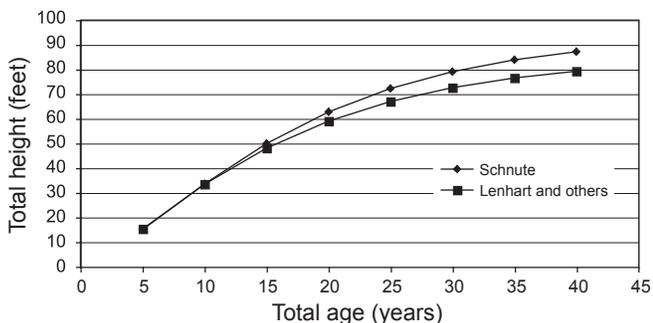


Figure 4—Comparison between the new Schnute guide curve and the Lenhart and others (1985) guide curve for slash pine.

$$b_0 = (0.99476^{0.68232} + (80.92198^{0.68232} - 0.99476^{0.68232}) \left( \frac{1 - 0}{1 - e^{-0.08036(37-1)}} \right)^{1/0.68232})^{1/0.68232} = 87.6214 \quad (8)$$

Similarly, find the values for the other two coefficients:

$$b_1 = a = 0.08036, \text{ and}$$

$$b_2 = 1 / b = 1 / 0.08036 = 1.4656.$$

Thus, the Chapman-Richards guide curve function derived from equation (4) for loblolly pine is:

$$\text{Height} = 87.6214 * (1 - e^{-0.08036 * (\text{Age}-0)})^{1.4656}.$$

The same procedure applied to equation (4) for slash pine gives:

$$\text{Height} = 94.4730 * (1 - e^{-0.07747 * (\text{Age}-0)})^{1.9195}.$$

The t-test revealed that the  $b_2$  coefficient for the loblolly pine equation is significantly different ( $p < 0.0001$ ) than that of Lenhart and others (1986). Furthermore, the  $b_0$  and  $b_2$  coefficients for the slash pine equation are significantly different than those of Lenhart and others (1986)  $p = 0.0149$  and  $p < 0.0001$ , respectively. These results further support the claim that Lenhart and others' guide curves are significantly lower than the Schnute guide curves. This leads to an underestimation of average height for the trees in this dataset, which will underestimate SI. Thus, the new Schnute SI equations/curves represent an improvement over those of Lenhart and others (1986). The additional height-age data now available from older stands that encompass the index age of 25 years are most likely responsible for the improvement in SI estimation by the new Schnute SI curves.

## CONCLUSIONS AND RECOMMENDATIONS

The Schnute growth function can be applied to many forestry prediction problems: diameter and basal area growth, height-age, density, yield, and SI. The Schnute growth function can also be used as a guide curve to develop a family of anamorphic SI curves, either in its original form (equation 4) or in the Chapman-Richards form (equation 3). This study provides new SI curves and equations for unmanaged or low-intensity managed loblolly and slash pine plantations in east Texas. These new curves are an improvement over Lenhart and others (1986) because in this study, height-age data for model fitting encompass the 25-year index age.

## ACKNOWLEDGMENTS

This study would not be possible without the East Texas Pine Plantation Research Project (ETPPRP). We are indebted to the people that have worked to collect the data over the years, and we are grateful for the long-term sponsorship from the following organizations: Temple-Inland, International Paper, and Stephen F. Austin State University.

## LITERATURE CITED

- Bredenkamp, B.V.; Gregoire, T.G. 1988. A forestry application of Schnute's generalized growth function. *Forest Science*. 34(3): 790-797.
- Chapman, D.G. 1961. Statistical problems in population dynamics. In: Neyman, J., ed. *Proceedings of the fourth Berkeley symposium on mathematical statistics and probability*. Vol. 4. Berkeley, CA: University of California Press: 153-186.
- Clutter, J.L.; Fortson, J.C.; Pienaar, L.V. [and others], 1983. *Timber management: a quantitative approach*. New York, NY: John Wiley and Sons. 333 p.
- Grossman, S.I.; Derrick, W.R. 1988. *Advanced engineering mathematics*. New York, NY: Harper Collins Publishers, Inc. 1089 p.
- Lenhart, J.D.; Hunt, E.V., Jr.; Blackard, J.A. 1985. Establishment of permanent growth and yield plots in loblolly and slash pine plantations in East Texas. In: Shoulders, E., ed. *Proceedings of the third biennial southern silvicultural research conference*. Gen. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Research Station: 436-437.
- Lenhart, J.D.; Hunt, E.V., Jr.; Blackard, J.A. 1986. Site index equations for loblolly and slash pine plantations on non-old-fields in East Texas. *Southern Journal of Applied Forestry*. 10(2): 109-112.
- Miles, P.D. 2005. FIA Mapmaker Web Application version 1.7. St. Paul, MN, U.S. Department of Agriculture, Forest Service, North Central Research Station. <http://www.ncrs2.fs.fed.us/4801/fiadb/>.
- Peng, C.; Zhang, L.; Liu, J. 2001. Developing and validating nonlinear height-diameter models for major tree species of Ontario's boreal forests. *Northern Journal of Applied Forestry*. 18(3): 87-94.
- Pienaar, L.V.; Turnbull, K.J. 1973. The Chapman-Richards generalization of Von Bertalanffy's growth model for basal area growth and yield in even-aged stands. *Forest Science*. 19(1): 2-22.
- Richards, F.J. 1959. A flexible growth function for empirical use. *Journal of Experimental Botany*. 10: 290-300.
- Schnute, J. 1981. A versatile growth model with statistically stable parameters. *Canadian Journal of Fisheries and Aquatic Sciences*. 38: 1128-1140.
- Von Bertalanffy, L. 1951. *Theoretische biologie*. (Band II). Franke, Bern. 403 p.
- Yuancai, L.; Marques, C.P.; Macedo, F.W. 1997. Comparison of Schnute's and Bertalanffy-Richards' growth functions. *Forest Ecology and Management*. 96(3): 283-288.
- Zhang, L. 1997. Cross-validation of non-linear growth functions for modelling tree height-diameter relationships. *Annals of Botany*. 79(3): 251-257.
- Zhang, L.; Moore, J.A.; Newberry, J.D. 1993. Estimating asymptotic attributes of forest stands based on bio-mathematical rationales. *Ecological Applications*. 3(4): 743-748.

## APPENDIX

The following SAS code fragment was used to estimate coefficients in equation (4) for loblolly pine:

```
PROC NLIN DATA = LOB_HTAGE_PAIRS OUTEST = TEST;
  MODEL HEIGHT = (B0**B2 + (B1**B2 - B0**B2) * ( (1-EXP(-B3 * (AGE-1))) / (1-EXP(-B3 * (37-1))) )) ** (1 / B2);
  PARMs B0 = 5.0
        B1 = 50.0
        B2 = 0.8
        B3 = 0.05;
```

# FAMILY AND SPACING AFFECT STEM PROFILE OF LOBLOLLY PINE AT AGE 19

Joshua P. Adams, Samuel B. Land, Jr., and Thomas G. Matney<sup>1</sup>

**Abstract**—Profile measurements were taken on a stratified sample of 19-year-old trees from 8 North Carolina families and a commercial Mississippi-Alabama check established at 3 spacings (5 x 5, 8 x 8, and 10 x 10 feet). Measurements were first fitted on a single profile equation using multiple-regression. Data were also segregated by family, spacing, and family-by-spacing and fitted on the equation. These new model types were tested using the reduction-sum-of-squares principle. Stem volumes were calculated using the different model types and compared. A significant decrease of error was obtained from the reduction-sum-of-squares method, indicating that accuracy of stem-volume estimation can be increased by accounting for family and spacing in the profile equation.

## INTRODUCTION

Many species have natural form deviations due to age, butt-swell, silvicultural treatments, dominance, site, stand density, and heredity (Bügen and Münch 1929, Liu and Keister 1978). Deviations in form have been observed in pines by Baldwin and others (2000) and Allen (1993). These papers attributed form variation to different levels of competition. However, some variation is attributed to genetics. McLaughlin (1998) found significant differences in taper below d.b.h. between families of loblolly pine.

Many studies have favored selection on height for genetic improvement in growth and yield (Foster 1986, Gwaze and others 1997, McKeand 1988), while others have favored selection on diameter (Kusnander and others 1998, White and Hodge 1992). The Western Gulf Forest Tree Improvement Cooperative incorporates some measure of profile in their selection by basing selection on juvenile per-acre volume (Raley and others 2003). However, they use a common stem form for all families. The selection on height, diameter, or common form leaves no means to account for stem profile variation that may be present among families.

This study investigates variation in stem profile among families at age 19 and discusses the importance that these differences may have on selection gains. Because selection is practiced at early ages, juvenile traits are explored for correlations with profile differences. More accurate family selection and volume prediction may be possible by accounting for family-specific stem profiles.

## METHODS

Containerized seedlings of eight open-pollinated families in North Carolina (NC) and one open-pollinated "genetic check" (bulk seed lot) from east-central Mississippi (MS) and west-central Alabama (AL) were provided by Weyerhaeuser Company. The 8 families were selected based on 12-year-old progeny tests to represent ideotypes of fast growth with small crowns (NC1 and NC8), fast growth with large crowns (NC4 and NC7), slow growth with small crowns (NC3 and NC6), and slow growth with large crowns (NC2 and NC5).

Seedlings were planted from April 22 to May 7, 1985, at two sites on the John Starr Memorial Forest (Mississippi State University school forest) in Winston County, MS. The experimental design consisted of a randomized complete block design with four replications at each site. The two sites were an old field and a cutover-and-site-prepared area. Treatments were arranged in split-split plots, where each rep was split into 3 spacings (5 x 5, 8 x 8, and 10 x 10 feet). Each spacing was split into a mixed family plot and a pure family plot. The pure family plot contained nine subplots, each having one family or the check. A single or double border row was planted around each subplot. The interior trees of each pure family subplot covered an equal area of 0.0367 acre. Survival, d.b.h., and total height were measured at ages 5, 9, 13, and 17 years. Crown length was measured at ages 9, 13, and 17.

Two trees from each 1-inch diameter class from each family in each spacing were selected for sampling. Selected trees had no major defects or fusiform galls (*Cronartium quercuum* f. sp. *Fusiforme*), and they could not be in the border rows. A partial profile of the stem was used for development of profile equations. Lee (2002) showed that full profiles and partial profiles were statistically the same at the 0.05 significance level. Measurements of diameter and height were taken with a caliper and tele-Relaskope at stump height (approximately 0.5 feet), 2 feet, d.b.h., midpoint between base of live crown and d.b.h., base of live crown, midpoint between base of live crown and top of the tree, and top of the tree.

Heights and diameters of the 361 sampled trees were fitted with regression on 2 third-degree polynomials conditioned through d.b.h. to characterize profiles. The data were first fitted on a general model that used all sampled trees. Then, data were segregated by family, spacing, family-by-spacing, ideotype, and ideotype-by-spacing and fit as separate models. The subset models were tested against the general model using the reduction sum of squares method described by Graybill (1961).

A computer program was written to apply the general model profile and subset model profiles onto age 17 height and d.b.h. measurements for all non-border trees > 4.5 inches d.b.h. Cubic foot volumes for every 4-foot segment of the stem, up

<sup>1</sup> Graduate Student and Professors, respectively, Mississippi State University, Department of Forestry, Mississippi State, MS 39762.

to a 3-inch top, were calculated using Smalian's volume formula. These 4-foot-segment volumes were summed for the tree to closely estimate the tree's actual volume.

Profile equations for different family-by-spacing combinations were applied to a tree with the same d.b.h. and height to illustrate the effects of profile differences on diameters at various heights up the tree. Tree volumes calculated with the general model and the family-by-spacing model profiles were compared with juvenile traits (tree height, survival, crown length, and crown ratio). Correlations between family means for juvenile traits and family means for 17-year tree volume (calculated both by the general profile and by the family-by-spacing specific profiles) were tested using Kendall's distribution-free test for independence (Kendall and Gibbons 1990).

## RESULTS AND DISCUSSION

Error (deviations of predicted from actual tree volume) was significantly reduced by inclusion of family-specific and spacing-specific profiles in the general model. This demonstrated that a single model does not adequately describe the range of profiles due to differences among the three spacings, eight families and check. The family-by-spacing model was compared to partial models adjusted for families only and spacings only. This full model significantly reduced error over those partial models.

The "reduction-sum-of-squares" method tests the adequacy of a broad (full) equation versus a more specific subset. Many profile models within a subset may not be different, and only a few extreme forms that are not fit by a general model may be the cause of significant error reduction. Pair-wise comparisons were conducted to test for profile differences between individual families in a spacing. Extreme families were selected based on the pair-wise tests, and their profiles are shown in figures 1 through 3.

There were family differences in profile within each spacing. Even in the tight 5 x 5 spacing, where uniformity was greatest, family NC6 had a profile where the stem diameter was larger at greater heights in the tree than the check or NC2 (fig. 1). This family, NC6, would therefore have more stem volume per tree than the check or NC2 for trees with the same d.b.h. and height. While there were also differences found in butt and crown taper, most merchantable volume is taken from the lower bole of the tree below the live crown. In all spacings, profiles differed between 10 to 30 feet up the bole. Therefore, differences in stem profile caused volume estimation to vary greatly among families. Stem volumes for trees (with the same d.b.h. and height) representing different families ranged from 4.48 to 5.50 cubic feet in the 5 x 5 spacing, 8.88 to 10.00 cubic feet in the 8 x 8 spacing, and 11.61 to 13.24 cubic feet in the 10 x 10 spacing.

Ideotype classifications were investigated as a method for grouping families to limit the number of different profiles needed. Both the ideotype model and the ideotype-by-spacing model significantly reduced error when compared to the general model. The ideotype-by-spacing model was compared to the family-by-spacing model. Out of 12 ideotype-by-spacing combinations, 5 profiles adequately described the 2 families contained by the classification. Adequate ideotype x spacing profiles were found for the 5 x 5 and 10 x 10 fast growth/large

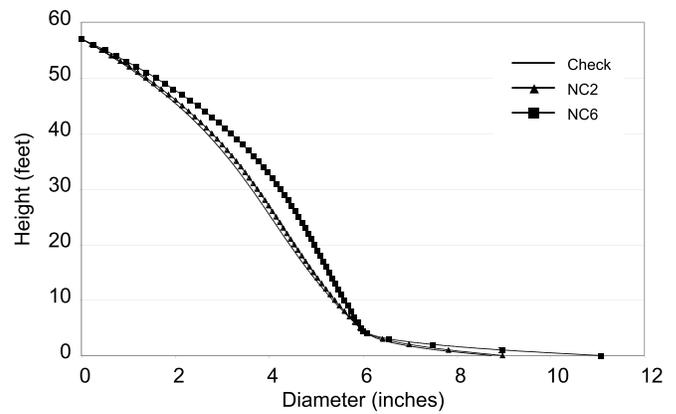


Figure 1—Profile based on a common tree height and d.b.h. of the two extreme families and check in the 5 x 5 spacing.

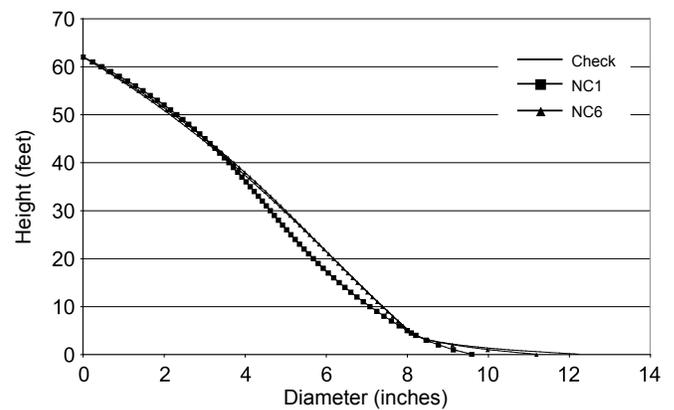


Figure 2—Profile based on a common tree height and d.b.h. of the extreme families and check in the 8 x 8 spacing.

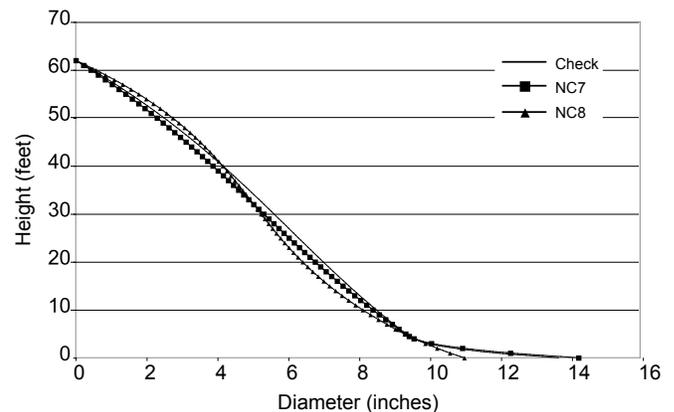


Figure 3—Profile based on a common tree height and d.b.h. of the two extreme families and check in the 10 x 10 spacing.

crown combinations, the 10 x 10 slow growth/small crown combination, and the 8 x 8 and 10 x 10 slow growth/large crown combinations. Other ideotype-by-spacing profiles did not sufficiently describe both families within the ideotype. These results indicate that the ideotype classifications used in the present study do not adequately account for all factors which affect stem profile. One trait not captured by these ideotypes is “competitive ability” (the ability to survive after crown closure), and number of trees per acre at age 17 years will affect profile.

Crown ratio, survival percentage, crown length, and tree height were juvenile traits shown to be significantly correlated with change in profile by Kendall’s Test for independence. Quantification of profile was done through application of the family-by-spacing model to a tree from each family with the same d.b.h. and height. Changes in volume could then be attributed to changes in profile. These volume estimates were tested against juvenile traits for correlations. All juvenile traits were weakly and negatively correlated with profiles that produce more volume. Traits with the strongest correlations were 9 year crown ratio in the 5 x 5 spacing, 13 year survival percentage in the 8 x 8 spacing, and 17 year tree height in the 10 x 10 spacing. “Kendall’s Correlation Values” for these were -0.25, -0.39, and -0.37 respectively.

Taper is the change in diameter between two points on the stem, while profile refers to the entire geometrical shape of the stem. Two extreme forms of stem profile are the “frustrum of a paraboloid” and the “frustrum of a neiloid” (figs. 4 and 5). Both of these could have the same taper but would differ in volume. The frustrum of a paraboloid produces greater volumes than the frustrum of a neiloid. Thus, taper differences (or absence of difference) among families may not be a good measure of stem volume differences, because one family may have a neiloid profile and another family may have a paraboloid profile.

Survival, crown length, crown ratio, and total tree height were positively correlated with the neiloid profile. As survival increases, competition for available resources increases. This causes growing emphasis to be on height and crown development rather than on diameter growth. The bole will be smaller with a form resembling the frustrum of a neiloid. On the other hand, when profiles were fitted on families with shorter heights or less survival such as those found in the slow growth ideotype, more taper was localized in the crown area. This caused the form of the bole to resemble the frustrum of a paraboloid. Thus, if height and d.b.h. are kept constant for all families in

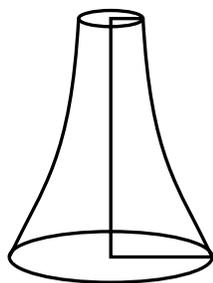


Figure 4—Frustrum of a Neiloid.

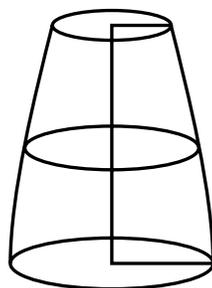


Figure 5—Frustrum of a Paraboloid.

the correlations, profiles modeled on shorter families and profiles modeled on families with less survival produce greater stem volume per tree. This is an artifact of the forced condition that the trees from all families were the same height and d.b.h. In real life, what this indicates is that slow-growing, poor-survival families will not be as far below the fast-growth, high-survival families in stand volume at age 17 as expected.

Of the traits tested, height was of great interest because of its importance in early selection for tree improvement. However, if correlations between height and greater-volume-producing profiles are negative, height’s use as a selection tool may not produce as much gain as expected. Age 9 height was tested for its ability to predict mean tree volume at age 17 before and after specific profiles were applied (table 1).

If families were selected based on mean height at age 9, the 2 tallest families would have 1 percent taller dominant height at age 17 than the average of the 8 families and 2.9 percent greater dominant height than the age 17 heights of the 2 shortest families (identified at age 9). Also, selection based on age 9 height resulted in the 2 “top” families still outperforming the 2 “worst” families by +2.5 percent in mean tree volume at age 17, when the same general profile was used on all families. However, these two “top” families had a -2.6 percent smaller mean-tree volume than the average of the eight families when the general profile was used. After applying the family-by-spacing profiles, mean-tree volume of the top two families for age 9 height was even further below that of the other families, -6.7 percent of the average for all eight families and -4.5 percent of the mean for the two worst families. The 2 best families for height at age 9 had the 2 smallest mean-tree stem volumes at age 17. This is a result of family differences in survival at age 17 (competitive ability). The 2 top families for height at age 9 also had the greatest survival (and thus density) at age 17. Higher density resulted in smaller d.b.h.s and neiloid profiles, which gave smaller mean-tree volumes for these two families. Inclusion of the neiloid profiles accentuated the deficit in mean-tree volume. This is illustrated in the column of table 1 labeled “General minus Family”. The general profile was more paraboloid than the neiloid profiles of NC1 and NC4, so the general model overestimated the mean-tree volume of those two families. The implication is that survival of the selected families must be sufficiently greater than the survival of the other families to compensate for the smaller mean-tree volume and give a greater volume per acre. That improvement in survival must be even greater than what would be calculated if mean-tree volumes from the general model were used.

The effects of neiloid versus paraboloid profiles on accuracy of family estimates for mean-tree volume are illustrated in the right four columns of table 1. Using the general model, families NC1 and NC4 would both have their volumes over-predicted (neiloid profiles). On the other hand, NC2, NC3, NC5, and NC6, all in the slow-growth ideotype with paraboloid profiles, would have their volumes underestimated from -4.1 percent to -7.6 percent by a general profile. Differences between the two volume calculations demonstrate that estimates of gains in volume per acre from family selection may not be as great as predicted from a general profile model, because volumes from high-surviving families (neiloid profiles) are over-predicted and volumes from low-surviving families (paraboloid profile) are under-predicted.

**Table 1—Effect of family differences in stem profiles on tree-volume estimates at age 17 in a loblolly pine test in northeast Mississippi**

Family	Family means <sup>a</sup>				Mean tree volume(cubic feet) at age 17			
	Age 9 height	Age 17			General profile <sup>b</sup>	Family-spacing profile <sup>c</sup>	General minus family	Error
		Dom ht	dbh	Surv.				
	<i>feet</i>	<i>feet</i>	<i>inches</i>	<i>%</i>				<i>%</i>
NC1	35.5	63.1	7.8	85	8.13	8.11	+0.02	+0.3
NC2	34.8	62.3	7.9	69	8.48	9.02	-0.54	-6.0
NC3	34.2	61.7	8.0	64	4.26	8.94	-0.68	-7.6
NC4	35.8	62.7	7.9	78	8.25	8.08	+0.17	+2.1
NC5	33.5	61.8	7.7	74	8.16	8.50	-0.35	-4.1
NC6	34.0	60.4	7.6	66	7.82	8.42	-0.61	-7.2
NC7	35.1	63.4	7.9	74	8.62	8.79	-0.17	-1.9
NC8	35.4	63.3	8.0	66	9.22	9.42	-0.19	-2.0
Avg. All Fams.	34.8	62.3	7.9	72	8.40	8.64	-0.24	-2.7

Percent Gain [Best two families at age 9 (=NC1&4)] compared to:

(1) Avg. all fams (%)	+2.5	+1.0	-0.6	+13.2	-2.6	-6.7
(2) Worst two fams at age 9 (%) (=NC5&6)	+5.6	+2.9	+2.6	+16.43	+2.5	-4.5

<sup>a</sup> Based on all trees measured at ages 9 and 17 (not just sample trees).

<sup>b</sup> Based on profile derived from all 321 trees sampled. This is a general profile for the site (across all families and spacings). Volume per tree is calculated by applying the family means at ages 17 to this general profile.

<sup>c</sup> Based on profiles derived for each family-by spacing combination. Volume per tree is calculated by applying the spacing-by-family means at ages 17 to the specific family-by-spacing profile.

## CONCLUSIONS

Selection of families generally occurs at ages before stem profile can be considered for selection. However, stem profile differences were present at age 19. Both spacings and families had profile variation not adequately described by a general model. Profile equations were developed for each family within each spacing. This family-by-spacing model was better at describing the different profiles than models adjusted for spacings or families independently. Profile differences were shown to occur throughout the stem. Difference in family profile caused stem volume to vary in all spacings. These differences between families increased with wider spacing. Ideotype classification was tested and found to better describe profiles than the general equation. However, when the ideotype-by-spacing model was compared to the family-by-spacing model, only 42 percent of the ideotype-by-spacing combinations adequately described both families within the class.

Profiles resembling the frustrum of a paraboloid give greater stem volume per tree. These paraboloid profiles were negatively correlated with survival, height, crown length, and crown ratio. Selection for increased values of these traits results in profiles that resemble the frustrum of a neiloid and reduce individual-tree volume. While this latter profile may be desirable for better quality later in the tree's life, stem volume per tree will be less than may be expected from projections using a general, more paraboloid profile.

Selection of the top two families (of eight) based on their age 9 height did not translate into gains in tree volume over the

average of the eight when general profile was used. Application of the fully-adjusted profile model for family and spacing even caused the "top" families' mean stem volume per tree to fall below the "worst" families. This calls into question the use of height as the only criteria for making selection. While height may warrant use due to its high heritability and age-age correlations, a selection criteria that incorporates more comprehensive stand dimensions would be more promising. Selection based on juvenile per-acre volume as implemented by the Western Gulf Forest Tree Improvement Cooperative is an example of this. However per-acre volume would still be prone to error if a common profile is assumed for all families. This error is demonstrated by volume projections, using a general model, that overestimate two families and under estimate the other families in the current study.

Profile differences among families and spacings should be considered for selection programs that desire to improve yield. Growth-and-Yield models should be refined for these differences to better handle today's deployment of improved families in single-family blocks. However, development of models for each family in each spacing can be arduous. Ideotype classifications may be used to supplant use of individual-family models. However, the ideotypes tried in this study were not adequate for classifying family differences in profiles, and some measure of "competitive ability" must be incorporated. Profile models, specific to spacing and family, will aid in more accurate selection and help minimize overestimation of stand volume in fast-growth, high-survival families and underestimation of stand volume in slow-growth, low-survival families.

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## LITERATURE CITED

- Allen, P.J. 1993. Stem profile and form factor comparisons for *Pinus elliotii*, *Pinus caribaea* and their F1 hybrid. *Australian Forestry*. 56: 140-144.
- Baldwin, C.V.; Peterson, K.D.; Clark, A., III. [and others]. 2000. The effects of spacing and thinning on stand tree characteristics of 38 year old loblolly pine. *Forest Ecology and Management*. 137: 91-102.
- Busgen, M.; Munch, E. 1929. *The structure and life of forest trees*. Thompson, T., translator. New York: John Wiley & Sons, Inc. 436 p.
- Foster, G.S. 1986. Trends in genetic parameters with stand development and their influence on early selection for volume growth in loblolly pine. *Forest Science*. 32: 944-959.
- Graybill, F.A. 1961. *An introduction to linear statistical models*. New York, NY: McGraw-Hill. 463 p.
- Gwaze, D.P.; Wooliams, J.A.; Kanowski, P.J. 1997. Optimum selection age for height in *Pinus taeda* L. in Zimbabwe. *Silvae Genetica*. 40: 162-176.
- Kendall, M.G.; Gibbons, J.D. 1990. *Rank correlation methods*. 5<sup>th</sup> ed. London: Arnold. 260 p.
- Kusnander, D.; Galway, N.W.; Hertzler, G.L.; Butcher, T.B. 1998. Age trends in variance and heritabilities for diameter and height in Maritime Pine (*Pinus pinaster* Ait.) in western Australia. *Silvae Genetica*. 47: 136-141.
- Lee, G.S. 2002. Standing tree weights of loblolly pine at the first delivery point and comparable volume functions. Mississippi State University, Department of Forestry. 38 p. Master's thesis.
- Liu, C.J.; Keister, T.D. 1978. Southern pine stem form defined through principal component analysis. *Canadian Journal of Forestry Research*. 8: 188-197.
- McKeand, S.E. 1988. Optimum age for family selection for growth in genetic tests of loblolly pine. *Forest Science*. 34: 400-411.
- McLauchlin, B.C. 1998. Family and deployment effect on twenty-two year stand development of loblolly pine. Mississippi State University, Department of Forestry. 73 p. Master's thesis.
- Raley, E.M.; Gwaze, D.P.; Byram, T.D. 2003. An evaluation of height as an early selection criterion for volume and predictor of site index gain in the western gulf. In: McKinley, C.R., ed. *Proceedings of the 27<sup>th</sup> southern forest tree improvement conference*. Southern Forest Tree Improvement Committee Publication 49: 45-55.
- White, T.L.; Hodge, G.R. 1992. Test design and optimum age for parental selection in advanced generation progeny tests in slash pine. *Silvae Genetica*. 41: 252-262.

# PREDICTING THE PAST: A SIMPLE REVERSE STAND TABLE PROJECTION METHOD

Quang V. Cao and Shanna M. McCarty<sup>1</sup>

**Abstract**—A stand table gives number of trees in each diameter class. Future stand tables can be predicted from current stand tables using a stand table projection method. In the simplest form of this method, a future stand table can be expressed as the product of a matrix of transitional proportions (based on diameter growth rates) and a vector of the current stand table. There are cases where the reverse information is needed, i.e. predicting the past instead of the future. Examples of these scenarios include estimating timber damages and retroactively establishing the tax basis of timber that was earlier inherited or purchased. This study focused on procedures used to predict past stand tables from current stand tables and past diameter growth rates. The reverse stand table projection method can be an effective approach to predict the past when not much information is available. Its main drawback is that it has low tolerance for poor estimates of past diameter growth rates, which can result in prediction of negative numbers of trees for some diameter classes.

## INTRODUCTION

Forest managers often have to project a stand into the future so that they can evaluate various management alternatives. In some cases, however, there is a need to project a stand backward in time, i.e. to predict the past instead of the future. Examples of these scenarios include estimating timber damages and retroactively establishing the tax basis of timber that was earlier inherited or purchased. In the former scenario, the stand is projected backward to a point in time before the damage and then grown forward to the present using “regular” diameter growth rates obtained by sampling nearby unaffected stands. The difference between observed and predicted current volumes in this case is an estimate of the timber damage that the stand sustained.

Stand tables give number of trees for each diameter class. Although complicated stand table projection algorithms have been developed (Cao and Baldwin 1999a, 1999b; Nepal and Somers 1992; Pienaar and Harrison 1988), the simplest form of stand table projection requires only a stand table and information on diameter growth rates (which can be obtained from increment cores sampled throughout the stand). The objective of this study was to develop procedures for predicting past stand tables from current stand tables and past diameter growth rates.

## STAND TABLE PROJECTION

Table 1 shows an example of applying the simple stand table projection method to a hypothetical forest stand. The growth-index ratio (Avery and Burkhart 2002) or movement ratio (Husch and others 2003), which is defined as the ratio of diameter growth and diameter class interval, controls the movement of trees during the growth period. For example, trees in the 6 inch class grew an average of 2.4 inches, resulting in a growth-index of 1.2 (table 1). Therefore, 20 percent of these trees moved up 2 diameter classes, whereas 80 percent of them moved up 1 class. The growth-index ratio of the 10 inch class was 0.9, denoting that 90 percent of trees in this diameter class moved up 1 class, and the rest stayed in that class. Current number of trees in each diameter class is obtained by summing up values along the path indicated by the arrows (Husch and others 2003).

Results from table 1 can be obtained via matrix manipulations. The growth-index ratios from table 1 are used to form matrix *A* [equation (1)], which is a 5x4 matrix of transitional proportions. The first column of *A* shows what happened to trees that were in the 6 inch diameter class: no trees remained in the 6 inch class, 80 percent moved up to the 8 inch class, 20 percent moved up to the 10 inch class, and no trees moved up to the 12 inch and 14 inch classes. Likewise,

**Table 1—Simple stand table projection of a hypothetical stand**

DBH class	10-yr DBH growth	Growth-index ratio	Past stand table	Current stand table	Number trees moving up		
					No change	1 class	2 classes
----- inches -----					--- number ---		
6	2.4	1.2	313	0	0 ← 250	63	
8	2.2	1.1	229	250 ← 0	206 ← 250	23	
10	1.8	0.9	134	282 ← 13	121 ← 206	0	
12	1.6	0.8	70	158 ← 14	56 ← 121	0	
14				56 ← 0			

<sup>1</sup> Professor and Gilbert Fellow, respectively, School of Renewable Natural Resources, Louisiana State University Agricultural Center, Baton Rouge, LA 70803.

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the next three columns deal with trees originally from the 8, 10, and 12 inch classes, respectively.

$$A = \begin{matrix} & \begin{matrix} \text{From} \\ 6'' & 8'' & 10'' & 12'' \end{matrix} \\ \begin{matrix} \text{To} \\ 6'' \\ 8'' \\ 10'' \\ 12'' \\ 14'' \end{matrix} & \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.8 & 0 & 0 & 0 \\ 0.2 & 0.9 & 0.1 & 0 \\ 0 & 0.1 & 0.9 & 0.2 \\ 0 & 0 & 0 & 0.8 \end{bmatrix} \end{matrix} \quad (1)$$

If  $\underline{x}$  = a 4 x 1 column vector of past number of trees and  $\underline{y}$  = a 5 x 1 column vector of current number of trees, then  $A$ ,  $\underline{x}$ , and  $\underline{y}$  are related as follows:

$$A\underline{x} = \underline{y} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.8 & 0 & 0 & 0 \\ 0.2 & 0.9 & 0.1 & 0 \\ 0 & 0.1 & 0.9 & 0.2 \\ 0 & 0 & 0 & 0.8 \end{bmatrix} \begin{bmatrix} 313 \\ 229 \\ 134 \\ 70 \end{bmatrix} \begin{matrix} 6'' \\ 8'' \\ 10'' \\ 12'' \end{matrix} = \begin{bmatrix} 0 \\ 250 \\ 282 \\ 158 \\ 56 \end{bmatrix} \begin{matrix} 6'' \\ 8'' \\ 10'' \\ 12'' \\ 14'' \end{matrix} \quad (2)$$

## REVERSE STAND TABLE PROJECTION

### Principle

In the reverse stand table projection problem, the objective is to find the vector of the past stand table ( $\underline{x}$ ) given the current stand table ( $\underline{y}$ ) and the matrix of transitional proportions ( $A$ ). Assuming that the stand progressed through time following (2), then the vector  $\underline{x}$  is solved as follows:

$$A^T A \underline{x} = A^T \underline{y} \quad (3)$$

$$\underline{x} = (A^T A)^{-1} A^T \underline{y} \quad (4)$$

or

$$\underline{x} = \left( \begin{bmatrix} 0 & 0.8 & 0.2 & 0 & 0 \\ 0 & 0 & 0.9 & 0.1 & 0 \\ 0 & 0 & 0.1 & 0.9 & 0 \\ 0 & 0 & 0 & 0.2 & 0.8 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.8 & 0 & 0 & 0 \\ 0.2 & 0.9 & 0.1 & 0 \\ 0 & 0.1 & 0.9 & 0.2 \\ 0 & 0 & 0 & 0.8 \end{bmatrix} \right)^{-1} \begin{bmatrix} 0 \\ 250 \\ 282 \\ 158 \\ 56 \end{bmatrix} \begin{matrix} 6'' \\ 8'' \\ 10'' \\ 12'' \\ 14'' \end{matrix} = \begin{bmatrix} 313 \\ 229 \\ 134 \\ 70 \end{bmatrix} \begin{matrix} 6'' \\ 8'' \\ 10'' \\ 12'' \end{matrix} \quad (5)$$

Equation (5) demonstrates that the past stand table can be obtained from the current stand table. The problem is that the matrix of transitional proportions,  $A$ , is derived from the true average diameter growth rates of the stand (population) and is therefore unknown. It is necessary to obtain a sample to estimate the average diameter growth rate for each diameter class. These growth rates are used to produce growth-index ratios and consequently matrix  $B$ , which is an estimate of  $A$ . As an example, the following matrix of transitional proportions was derived from sampled diameter growth rates:

$$B = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.95 & 0 & 0 & 0 \\ 0.05 & 0.85 & 0.05 & 0 \\ 0 & 0.15 & 0.95 & 0.15 \\ 0 & 0 & 0 & 0.85 \end{bmatrix} \quad (6)$$

Equation (4) becomes

$$\hat{\underline{x}} = (B^T B)^{-1} B^T \underline{y} \quad (7)$$

or

$$\hat{\underline{x}} = \left( \begin{bmatrix} 0 & 0.95 & 0.05 & 0 & 0 \\ 0 & 0 & 0.85 & 0.15 & 0 \\ 0 & 0 & 0.05 & 0.95 & 0 \\ 0 & 0 & 0 & 0.15 & 0.85 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.95 & 0 & 0 & 0 \\ 0.05 & 0.85 & 0.05 & 0 \\ 0 & 0.15 & 0.95 & 0.15 \\ 0 & 0 & 0 & 0.85 \end{bmatrix} \right)^{-1} \begin{bmatrix} 0 \\ 250 \\ 282 \\ 158 \\ 56 \end{bmatrix} = \begin{bmatrix} 263 \\ 310 \\ 107 \\ 66 \end{bmatrix} \begin{matrix} 6'' \\ 8'' \\ 10'' \\ 12'' \end{matrix} \quad (8)$$

where

$\hat{\underline{x}}$  contains predicted values of the past stand table. The magnitude of the difference between the observed value of  $\underline{x}$  (equation 5) and the predicted value (equation 8) depends on how well the sample-based transitional matrix ( $B$ ) estimates the true transitional matrix ( $A$ ).

To make sure that the result from equation (8) is correct, we need to project  $\hat{\underline{x}}$  to the present:

$$\underline{\hat{y}} = B\hat{\underline{x}} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.95 & 0 & 0 & 0 \\ 0.05 & 0.85 & 0.05 & 0 \\ 0 & 0.15 & 0.95 & 0.15 \\ 0 & 0 & 0 & 0.85 \end{bmatrix} \begin{bmatrix} 263 \\ 310 \\ 107 \\ 66 \end{bmatrix} \begin{matrix} 6'' \\ 8'' \\ 10'' \\ 12'' \end{matrix} = \begin{bmatrix} 0 \\ 250 \\ 282 \\ 158 \\ 56 \end{bmatrix} \begin{matrix} 6'' \\ 8'' \\ 10'' \\ 12'' \\ 14'' \end{matrix} \quad (9)$$

where

$\underline{\hat{y}}$  = the current stand table predicted from  $\hat{\underline{x}}$ . Both equations (2) and (9) yield identical values for the current stand table.

### Other Cases

Some values of the growth-index ratios ( $\underline{m}$ ) may require fine tunings to match observed and predicted current stand tables. We will next consider two of these scenarios.

Case 1:  $\underline{m} = [2.2 \ 2.15 \ 2.2 \ 2.1]$

Equation (10) shows the projection from past to current stand table:

$$A\underline{x} = \underline{y} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.8 & 0 & 0 & 0 \\ 0.2 & 0.85 & 0 & 0 \\ 0 & 0.15 & 0.8 & 0 \\ 0 & 0 & 0.2 & 0.9 \\ 0 & 0 & 0 & 0.1 \end{bmatrix} \begin{bmatrix} 313 \\ 229 \\ 134 \\ 70 \end{bmatrix} \begin{matrix} 6'' \\ 8'' \\ 10'' \\ 12'' \end{matrix} = \begin{bmatrix} 0 \\ 250 \\ 257 \\ 142 \\ 90 \\ 7 \end{bmatrix} \begin{matrix} 6'' \\ 8'' \\ 10'' \\ 12'' \\ 14'' \\ 16'' \end{matrix} \quad (10)$$

Suppose the following matrix  $B$  is the estimate of the transitional matrix ( $A$ ).

$$B = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.75 & 0 & 0 & 0 \\ 0.25 & 0.65 & 0 & 0 \\ 0 & 0.35 & 0.9 & 0 \\ 0 & 0 & 0.1 & 0.8 \\ 0 & 0 & 0 & 0.2 \end{bmatrix} \quad (11)$$

The past stand table ( $\hat{x}$ ) is predicted from

$$\hat{x} = (B^T B)^{-1} B^T \underline{y} = \begin{bmatrix} 333 & 6'' \\ 267 & 8'' \\ 54 & 10'' \\ 102 & 12'' \end{bmatrix} \quad (12)$$

The current stand table is then projected from  $\hat{x}$  and  $B$ .

$$B\hat{x} = \underline{\hat{y}} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.75 & 0 & 0 & 0 \\ 0.25 & 0.65 & 0 & 0 \\ 0 & 0.35 & 0.9 & 0 \\ 0 & 0 & 0.1 & 0.8 \\ 0 & 0 & 0 & 0.2 \end{bmatrix} \begin{bmatrix} 333 & 6'' \\ 267 & 8'' \\ 54 & 10'' \\ 102 & 12'' \end{bmatrix} = \begin{bmatrix} 0 & 6'' \\ 250 & 8'' \\ 257 & 10'' \\ 142 & 12'' \\ 87 & 14'' \\ 20 & 16'' \end{bmatrix} \quad (13)$$

Note that the result from (13) matches the observed current stand table from (10) except for the largest two diameter classes. The growth-index ratio for the largest diameter class needs to be changed to fix this problem, using the trial-and-error method. This leads to new matrices  $B$  and  $C$ , and new solution  $\hat{x}$ . Projection of  $\hat{x}$  is carried out again as follows:

$$B\hat{x} = \underline{\hat{y}} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.75 & 0 & 0 & 0 \\ 0.25 & 0.65 & 0 & 0 \\ 0 & 0.35 & 0.9 & 0 \\ 0 & 0 & 0.1 & 0.92 \\ 0 & 0 & 0 & 0.08 \end{bmatrix} \begin{bmatrix} 333 & 6'' \\ 267 & 8'' \\ 54 & 10'' \\ 92 & 12'' \end{bmatrix} = \begin{bmatrix} 0 & 6'' \\ 250 & 8'' \\ 257 & 10'' \\ 142 & 12'' \\ 90 & 14'' \\ 7 & 16'' \end{bmatrix} \quad (14)$$

Now the predicted current stand table matches the observed stand table (10) perfectly.

Case 2:  $\underline{m} = [0.9 \ 1.1 \ 1.15 \ 1.2]$

The current stand table ( $\underline{y}$ ) is projected from the past stand table ( $\underline{x}$ ) and the matrix of transitional proportions ( $A$ ) as follows.

$$A\underline{x} = \underline{y} = \begin{bmatrix} 0.1 & 0 & 0 & 0 \\ 0.9 & 0 & 0 & 0 \\ 0 & 0.9 & 0 & 0 \\ 0 & 0.1 & 0.85 & 0 \\ 0 & 0 & 0.15 & 0.8 \\ 0 & 0 & 0 & 0.2 \end{bmatrix} \begin{bmatrix} 313 & 6'' \\ 229 & 8'' \\ 134 & 10'' \\ 70 & 12'' \end{bmatrix} = \begin{bmatrix} 31 & 6'' \\ 282 & 8'' \\ 206 & 10'' \\ 137 & 12'' \\ 76 & 14'' \\ 14 & 16'' \end{bmatrix} \quad (15)$$

Let  $B = \begin{bmatrix} 0.05 & 0 & 0 & 0 \\ 0.95 & 0 & 0 & 0 \\ 0 & 0.85 & 0 & 0 \\ 0 & 0.15 & 0.8 & 0 \\ 0 & 0 & 0.2 & 0.75 \\ 0 & 0 & 0 & 0.25 \end{bmatrix}$  be an estimate of the transi-

tional matrix ( $A$ ). The past stand table is predicted from  $B$  and the current stand table ( $\underline{y}$ ):

$$\hat{x} = (B^T B)^{-1} B^T \underline{y} = \begin{bmatrix} 298 & 6'' \\ 242 & 8'' \\ 126 & 10'' \\ 67 & 12'' \end{bmatrix} \quad (16)$$

To double check this solution, the current stand table is then predicted from  $\hat{x}$  and  $B$ .

$$B\hat{x} = \underline{\hat{y}} = \begin{bmatrix} 0.05 & 0 & 0 & 0 \\ 0.95 & 0 & 0 & 0 \\ 0 & 0.85 & 0 & 0 \\ 0 & 0.15 & 0.8 & 0 \\ 0 & 0 & 0.2 & 0.75 \\ 0 & 0 & 0 & 0.25 \end{bmatrix} \begin{bmatrix} 298 & 6'' \\ 242 & 8'' \\ 126 & 10'' \\ 67 & 12'' \end{bmatrix} = \begin{bmatrix} 15 & 6'' \\ 283 & 8'' \\ 206 & 10'' \\ 137 & 12'' \\ 75 & 14'' \\ 17 & 16'' \end{bmatrix} \quad (17)$$

The result from (17) matches the observed current stand table from (15), except for the first two and last two values. The adjustment of the growth-index ratios is carried out in two steps. First, the growth-index ratio for the smallest diameter class is changed using the trial-and-error method. This leads to a new matrix  $B$  and a new solution  $\hat{x}$ . Projection of  $\hat{x}$  is carried out again as follows:

$$B\hat{x} = \underline{\hat{y}} = \begin{bmatrix} 0.1 & 0 & 0 & 0 \\ 0.9 & 0 & 0 & 0 \\ 0 & 0.85 & 0 & 0 \\ 0 & 0.15 & 0.8 & 0 \\ 0 & 0 & 0.2 & 0.75 \\ 0 & 0 & 0 & 0.25 \end{bmatrix} \begin{bmatrix} 313 & 6'' \\ 242 & 8'' \\ 126 & 10'' \\ 67 & 12'' \end{bmatrix} = \begin{bmatrix} 31 & 6'' \\ 282 & 8'' \\ 206 & 10'' \\ 137 & 12'' \\ 75 & 14'' \\ 17 & 16'' \end{bmatrix} \quad (18)$$

Next, the growth-index ratio for the largest diameter class is adjusted, resulting in a different matrix  $B$  and its corresponding solution  $\hat{x}$ .

$$B\hat{x} = \underline{\hat{y}} = \begin{bmatrix} 0.1 & 0 & 0 & 0 \\ 0.9 & 0 & 0 & 0 \\ 0 & 0.85 & 0 & 0 \\ 0 & 0.15 & 0.8 & 0 \\ 0 & 0 & 0.2 & 0.78 \\ 0 & 0 & 0 & 0.22 \end{bmatrix} \begin{bmatrix} 313 & 6'' \\ 242 & 8'' \\ 126 & 10'' \\ 65 & 12'' \end{bmatrix} = \begin{bmatrix} 31 & 6'' \\ 282 & 8'' \\ 206 & 10'' \\ 137 & 12'' \\ 76 & 14'' \\ 14 & 16'' \end{bmatrix} \quad (19)$$

After these two adjustments, the predicted current stand table finally matches the observed stand table (15).

## DISCUSSION

In this paper, a simple stand table projection method is shown to be equivalent to the result of multiplying a matrix of transitional proportions (which is based on growth-index ratios) and a vector of past stand table. This system allows the reverse calculation of the past stand table from the current stand table. The reverse stand table projection procedure also adheres to the same assumptions imposed upon the simple stand table projection method as follows:

1. The stand did not lose trees due to mortality. If considerable mortality is suspected, an estimate of mortality for each diameter class should be added to the past stand table predicted from the reverse projection procedure.
2. No ingrowth information is available. The amount of ingrowth, if available, should be deducted from the current stand table before proceeding with the reverse projection procedure.
3. Trees in each diameter class follow a uniform distribution.
4. All trees in each diameter class grew in diameter at the same rate.

5. Estimates of diameter growth rates are reasonably good. This assumption is especially important for the reverse stand table projection method, which is not a robust method. Deviation from the true diameter growth rates translates to an inaccurate matrix of transition proportions and might lead to negative numbers of trees in some diameter classes. Consider the example described in equations (6) and (8). The following estimated matrix of transitional proportions (B),

$$B = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.95 & 0 & 0 & 0 \\ 0.05 & 0.6 & 0.05 & 0 \\ 0 & 0.4 & 0.95 & 0.15 \\ 0 & 0 & 0 & 0.85 \end{bmatrix} \quad (20)$$

predicted a past stand table that contains a negative number of trees:

$$\hat{\underline{x}} = (B^T B)^{-1} B^T \underline{y} = \begin{bmatrix} 263 \\ 451 \\ -34 \\ 66 \end{bmatrix} \begin{matrix} 6'' \\ 8'' \\ 10'' \\ 12'' \end{matrix} \quad (21)$$

Note that the elements of B in (20) are identical to those in (6), except for the second column (containing the growth-index ratio for the 8 inch class). Changing the 8 inch growth-index ratio from 1.15 to 1.4 while keeping the other ratios the

same is enough to produce a negative number of trees in the 8 inch class. This example demonstrates that the result of the reverse stand table projection can be extremely sensitive to the estimates of the growth-index ratios.

In summary, the reverse stand table projection procedure can be an effective method to predict the past when not much information is available. Its main drawback is that it has low tolerance for poor estimates of past diameter growth rates, which can result in negative numbers of trees for some diameter classes.

## LITERATURE CITED

- Avery, T.E.; Burkhart, H.E. 2002. Forest measurements. 5<sup>th</sup> ed. New York, NY: McGraw-Hill. 456 p.
- Cao, Q.V.; Baldwin, V.C., Jr. 1999a. A new algorithm for stand table projection models. *Forest Science*. 45: 506-511.
- Cao, Q.V.; Baldwin, V.C., Jr. 1999b. Projecting a stand table through time. In: Haywood, J.D., ed. Proceedings of the tenth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-30. Asheville, NC: US Department of Agriculture, Forest Service, Southern Research Station: 515-518.
- Husch, B.; Beers, T.W.; Kershaw, J. 2003. Forest mensuration. 4<sup>th</sup> ed. Hoboken, NJ: John Wiley & Sons, Inc. 443 p.
- Nepal, S.K.; Somers, G.L. 1992. A generalized approach to stand table projection. *Forest Science*. 38: 120-133.
- Pienaar, L.V.; Harrison, W.M. 1988. A stand table projection approach to yield prediction in unthinned even-aged stands. *Forest Science*. 34: 804-808.

# MORTALITY OF TREES IN LOBLOLLY PINE PLANTATIONS

Boris Zeide and Yujia Zhang<sup>1</sup>

**Abstract**—The annual probability of mortality for planted loblolly pine (*Pinus taeda* L.) trees was estimated using a set of permanent plots covering the entire native range of the species. The recorded causes of death were infestation by the southern pine beetle (*Dendroctonus frontalis* Zimmermann) and other insects, lightning, and unknown reasons. It was found that mortality from these causes does not change with age of trees, which allowed us to calculate an overall mean annual mortality probability for each density-independent factor. Two sets of these estimates are provided: one for all plots and another for the plots that in the past were affected by a given factor. A model was constructed to analytically separate density-dependent from density-independent factors of mortality recorded as “other causes.” The average annual probabilities of mortality are 0.8 percent and 0.6 percent for density-independent and density-dependent causes, respectively. Our analysis also covers the events that wipe out entire plots such as flood, fire, and catastrophic insect infestation. This neglected kind of mortality, referred to as indiscriminate, eliminates four times as many trees as density-dependent mortality and three times as many as density-independent mortality.

## INTRODUCTION

Stand dynamics of even-aged stands consists of two basic processes, tree growth and mortality. These processes are related because the growth of some trees necessitates the death of others. This relationship between growth and mortality becomes more pronounced as stand density increases. In addition to this density-dependent mortality (also called regular or noncatastrophic), trees die from other causes unrelated to density, such as lightning. Too often, studies of population dynamics neglect the events that obliterate entire plots, resulting in indiscriminate mortality (fire, flood, tornado, and land development). Modeling stand dynamics requires detailed knowledge and estimates of all kinds of mortality. Because of the importance of loblolly pine (*Pinus taeda* L.) plantations to the national economy, this forest type is the object of the reported study.

## GOAL AND OBJECTIVES

The goal of the study was to estimate the annual probability of mortality for planted loblolly pine from all recorded physical, biological, social, and random factors. Our objectives were to analyze various causes of mortality, to develop a method for mortality calculation, to construct a model that separates density-dependent from density-independent mortality, and to provide estimates of mortality on the stand and the region-wide levels for the entire native range of loblolly pine from the Atlantic coast to eastern Texas.

## DATA

Long-term observations of loblolly pine plantations maintained by the Loblolly Pine Growth and Yield Research Cooperative at Virginia Polytechnic Institute and State University (Burkhart and others 1985) were used in this investigation. They constitute one of the largest data sets on pine growth. The plots were established from 1980 to 1982 on 186 locations which were selected in cutover, site-prepared plantations, originated from woods-run (unimproved) seedlings. There are three plots at

each location: control (unthinned), lightly thinned (about one-third of basal area removed at each thinning), and heavily thinned (approximately one-half of basal area removed). Since some plots did not survive to the last measurement, the total number of plot measurements is 2,502. The plots were measured five times at 3-year intervals. The total range of age is 29 years, from 9 to 38 years. Summary statistics for the initial measurement are given in table 1. The dataset contains information on tree vitality and causes of death: lightning, insect damage, and unknown causes (codes 1, 2, and 3, respectively). Other relevant information is provided by status code because, among other factors, it identifies plots attacked by the southern pine beetle (SPB) (*Dendroctonus frontalis* Zimmermann).

## MORTALITY ESTIMATES

This study characterizes mortality by annual probability, *M*. Because plots are rarely measured annually, it is not always possible to obtain *M* directly. Usually, *M* is calculated as:

**Table 1—Basic statistics of the loblolly pine dataset at the first measurement (559 plot measurements)**

Variable	Statistics		
	Minimum	Mean	Maximum
Age from seed, years	9	16	26
Number of trees per ha	339	1,459	2,746
Arithmetic mean height (m)	4.2	11.6	22.2
Diameter (cm)	6.5	14.8	25.6
Basal area (m <sup>2</sup> / ha)	2.1	18.3	60.0
Stand density index of pine trees	147.5	570.9	1,094.3
Stand density index of hardwoods	0.64	22.05	150.25

<sup>1</sup> Professor of Forestry, University of Arkansas, School of Forest Resources, Monticello, AR 71656-3468; and Research Coordinator, D.B. Warnell School of Forest Resources, Athens, GA 30602-2151, respectively.

$$M = \frac{N_0 - N_t}{N_0 t} \quad (1)$$

where

$N_t$  and  $N_0$  = numbers of trees/ha at the end and the beginning of the period, and

$t$  = the time between plot measurements.

Because number of trees does not change linearly with age, this formula underestimated annual mortality by 19 percent for a 3-year period and more for longer periods. To improve the estimates, we tried the expression of relative growth rate commonly used in growth studies (Harper 1977):

$$M = \frac{\ln(N_0) - \ln(N_t)}{t} \quad (2)$$

This method errs in the opposite direction by about half as much.

To find a better expression, we assumed that the annual probability  $M$  does not change during the period,  $t$ . Then the number of trees at the end of a period can be expressed in terms of initial number of trees,  $N_0$ , and  $t$  as follows:

$$N_t = N_0 (1 - M)^t \quad (3)$$

which leads to:

$$M = 1 - \left( \frac{N_t}{N_0} \right)^{\frac{1}{t}} \quad (4)$$

This equation predicts mortality better than the others and was accepted for subsequent calculations.

In the stands already infested by insects, mortality is often higher than that in the entire data set. Similarly, lightning strikes trees in some locations more often than in others. This shows that density-independent mortality is not totally random. To reflect this fact, we will provide two sets of mortality estimates, one for all plots and another for the plots affected in the past by a given mortality factor.

### INITIAL MORTALITY

For 222 plots out of the total 559 plots, the dataset contained the number of planting spots. By comparing this number with the number of trees at the first measurement, one could estimate the initial mortality of trees, defined as annual mortality for the period between planting and the first inventory. During this period (lasting on average 14.7 years) volunteer pines often appeared among planted trees. When the data were analyzed, those tagged at the first measurement could not be distinguished from planted trees, which may have biased our estimates of initial mortality. Most likely, the initial mortality was more intensive during the first 2 or 3 years after planting. Because annual information was not available, we computed the initial mortality using equation (4). The mean initial annual mortality is 0.0219. In other words, about 2 out of every 100 planted trees died each year prior to the first measurement.

### MORTALITY CAUSED BY THE SPB

The SPB was found on 22 (out of 186) plot locations. Eighty two (out of 2,502) plot measurements were affected by the beetle,

with some plots attacked repeatedly. Annual probability of mortality was calculated using equation (4) with a 3-year time interval between measurements. It was found that neither age (slope =  $-0.0017 \pm 0.0022$ ,  $R^2 = 0.0220$ ) nor stand density (slope =  $-0.0002 \pm 0.0027$ ,  $R^2 = 0.0065$ ) were statistically significant predictors for SPB attack, so we could use an overall mean probability to predict the annual mortality of pine trees on SPB-infested plots. This annual probability of mortality was obtained from the weighted mean of annual mortality probability. The total number of trees in each age class was used as weight. We also studied the effect of previous beetle attacks and calculated the mortality probability for plots where at least one tree died from the SPB (table 2). This probability of mortality was about 40 times higher than the average of all plots (0.0398 versus 0.0010).

### MORTALITY CAUSED BY OTHER INSECTS

Plots having a status code other than 1 (which indicates SPB infestation) were considered for estimation of the mortality caused by other insects. There were 580 dead trees with an insect damage code (cause of death = 2). When the annual mortality caused by this factor was regressed on age, the slope was  $-0.00005 \pm 0.0017$  ( $R^2 = 0.0000$ ), which indicates that the mortality is not related to age. Calculations showed that the probability of mortality on all plots was 0.0011, which was 10 times less than on plots containing at least 1 tree that died from the same cause in the past (0.0011 versus 0.0095). This ratio is four times smaller than the ratio for the SPB, indicating that the SPB is more contagious than other insects (table 2).

### MORTALITY FROM LIGHTNING

Records indicate that lightning killed 27 trees from 17 plot measurements, with age varying from 10 to 30 years. The weighted annual probability of trees killed by lightning is 0.0001. The linear regression of the probability of lightning mortality on age was not statistically significant. The slope was 0.0002 with standard error 0.0029 ( $R^2 = 0.0002$ ). The ratio of the mean diameter of the trees killed by lightning to the mean diameter of live trees is 1.12 with the standard

**Table 2—Annual probability of mortality on sample plots for density-dependent and density-independent causes. Affected plots are plots with at least one dead tree in the past from the listed reason**

Cause	Annual mortality probability		Ratio of probabilities
	Affected plots	All plots	
Lightning	0.0063	0.0001	56
Insects	0.0095	0.0011	9
SPB	0.0398	0.0010	40
Density-independent component of unknown causes	0.0062		
Total density-independent mortality	0.0618	0.0084	7
Density-dependent mortality	0.0060		

deviation of 0.24611. Although the ratio confirms the common knowledge that lightning kills larger trees, it does not differ from 1 significantly.

### MORTALITY FROM OTHER CAUSES: ANALYTICAL SEPARATION OF DENSITY-DEPENDENT FROM DENSITY-INDEPENDENT MORTALITY

There were 2,925 trees that died from the reasons recorded as “other causes.” It is known that competition among trees is a leading cause of death, at least in dense stands. If so, the probability of mortality should increase with stand density. As a measure of stand density, we used Reineke’s (1933) stand density index. To facilitate comparisons with other species, the index was normalized by dividing it by the maximum value for the studied species. Reineke reported that for loblolly pine such a value was 450 or in metric units 1,112. As a result, the normalized stand density index,  $I$ , is equal to:

$$I = \frac{N}{1112} \left( \frac{D}{25.4} \right)^r \quad (5)$$

where

$N$  = the number of trees per ha,

$D$  = the quadratic mean of diameter in cms, and

$r$  = a parameter.

The points representing plots with  $I < 0.5$  did not show any density-related increase as would be expected from mortality caused by competition. This finding indicated that the unknown causes included not only density-dependent but also density-independent mortality. To estimate the mortality caused by density-dependent factors, it is necessary to separate it from density-independent mortality. In reality, both groups of factors are blended, which makes physical separation impossible. In this study, the separate estimates were obtained by constructing a model that includes both kinds of mortality.

### Number of Trees and Their Average Size

The relationship between  $D$  and  $N$  is well-known in forestry as Reineke’s (1933) equation:

$$N = kD^{-r} \quad (6)$$

where

$k$  and  $r$  = parameters.

### Parameter k

In growth modeling we often predict number of trees,  $N_2$ , at some future moment when the current diameter,  $D_1$ , number of trees,  $N_1$ , and future diameter,  $D_2$ , are known. From

$$N_1 = kD_1^{-r} \quad (7)$$

one can express  $k$  as:

$$k = \frac{N_1}{D_1^{-r}} \quad (8)$$

Now it is possible to present  $N_2$  without using  $k$ :

$$N_2 = kD_2^{-r} = N_1 \left( \frac{D_2}{D_1} \right)^{-r} \quad (9)$$

### Parameter r

Reineke’s relationship holds true only for fully stocked stands. It can be applied to managed plantations with their changing canopy closure by making  $r$  variable. When trees do not compete with each other, their number changes little. Equation (9) is still applicable if  $r = 0$ . If the plantation remains unthinned and trees are allowed to compete, stand density builds up and  $r$  gradually tends to a certain stationary value. Using unreported intuitive methods, Reineke estimated  $r$  as 1.605. When MacKinney and others (1937) reanalyzed the data using standard statistical methods, they arrived at the power equal to 1.7070. Thus, as density increases, Reineke’s parameter changes from 0 to 1.7. To model density-dependent mortality, we need to express  $r$  as a function of density,  $I$ .

### Reineke’s Parameter as a Function of Density

This function should satisfy the following requirements: (1) When trees are located far away from each other, they do not compete and their increment and mortality do not depend on density. Therefore, when  $I$  is below some threshold value of  $I_0$ ,  $r$  should be zero:  $r(I_0) = 0$ . (2) When density is maximal and  $I = 1$ ,  $r$  should reach its maximum value, 1.7:  $r(I=1)=1.7$ . (3) When  $I = 1$ , the tangent of the relationship between  $r$  and  $I$  should equal zero:  $r'(I=1)=0$ , where  $r'$  is the first derivative. The following model satisfies these requirements:

$$r = 1.7 \left( 1 - e^{-b \frac{I-I_0}{1-I}} \right) \quad (10)$$

### Density-Dependent Mortality

If trees died only from density-dependent factors, the number of surviving trees,  $N_2$ , could be calculated by the following equation:

$$N_2 = N_1 \left( \frac{D_2}{D_1} \right)^{-1.7} \left( 1 - e^{-b \frac{I-I_0}{1-I}} \right) \quad (11)$$

where

$N_1$  and  $D_1$  = initial number of trees,

diameter  $D_2$  = the diameter of trees at the next remeasurement, and

$b$  = a parameter to be estimated from data.

### Combined Mortality

Equation (11) cannot be applied to our dataset because it records trees that died from a combination of density-dependent and density-independent factors. Assuming that density-independent mortality is proportional to the initial number of trees, we can include into the equation (11) a term  $c$  is the mortality probability that a tree dies from density-independent causes during the studied period:

$$N_2 = N_1 \left[ \left( \frac{D_2}{D_1} \right)^{-1.7} \left( 1 - e^{-b \frac{I-I_0}{1-I}} \right) - c \right] \quad (12)$$

The parameters  $b$  and  $c$  were estimated using the data on mortality from unknown causes except for the plots infested by the SPB ( $b = 0.1920 \pm 0.0299$  and  $c = 0.0187 \pm 0.0030$ ). To obtain the annual probability of mortality from density-independent factors, the estimate of  $c$  was divided by three (the time between remeasurements). The equation (12) predicts the number of trees with an  $R^2$  higher than 0.97.

The accuracy of this model can be compared with those using the same variables, such as the model by Harrison and Borders (1996). For the interval of 3 years from age 15 to 18 years, the difference between their prediction and the data was 32 trees/ha. For a 6-year interval, it was 45 trees/ha. The corresponding errors of our model were 19 and 14 trees/ha.

### INDISCRIMINATE MORTALITY

Some plots were lost during the study because of various disturbances (table 3). Unlike mortality on the tree and stand levels, the mortality caused by hurricanes, fire, or road construction that wipes out the whole plot is indiscriminate. The annual probability of this kind of mortality was obtained for each recorded cause by dividing the number of lost plots by the total number of plots and the time between remeasurements (3 years).

### DISCUSSION

In this study, the mortality of trees in loblolly pine plantations was assessed for each recorded cause of death. We also inferred the rate of initial mortality by comparing the number of trees at the first measurement with the number of planting spots. The actual mortality is likely to be higher than the estimate of 0.0219 because the number of trees at the first measurement includes large number of volunteers. All other estimates relate to the period after the first inventory. One of the major causes of mortality is insects. On the intact plots, each year they kill 2 out of every 1000 trees. The SPB is responsible for half of this mortality. Mortality from unknown causes was split analytically into two components, accounting for density-dependent and density-independent factors. Because the plantations are relatively young and not fully stocked, this component is less damaging than it would be in older, unmanaged stands. Still, the density-independent component of mortality from unknown causes is three times as great as the insect damage. The combined annual probability

of mortality from all density-independent causes is 0.8 percent. Plugging in average diameter, its increment, and stand density into equation (11), it is possible to assess the average annual probability of mortality from density-dependent causes for all plots, which is 0.6 percent, slightly less than the probability of mortality from density-independent causes.

Not all recorded causes provide a true picture of mortality because it is not easy to disentangle primary and proximate causes of death. Recorded mortality from lightning is small. One out of 10,000 trees dies annually from this cause. This number is probably underestimated because there are indications that fully 70 percent of trees killed by insects were predisposed by lightning strikes (Wahlenberg 1960).

This investigation showed that mortality from lightning and insects was not related to stand characteristics such as age and stand density, etc. As a result, it was possible to provide the overall annual mortality probabilities for these causes, independent of age. Mortality from lightning was affected by tree size but not significantly. Among patterns of mortality documented by this study was the effect of stand history. Usually, stands with previous records of mortality from a given cause suffer heavier losses than do other stands. For example, the SPB damage in previously affected stands was 40 times higher than that for the entire data set. To reflect this fact, we provided two sets of mortality estimates, one for all plots and another for plots affected in the past by a given mortality factor. The connection between past and future mortality from unknown causes (which include competition mortality) is reflected by equation (12).

So far, relationships between number of trees and their size were developed only for unmanaged fully stocked stands (Reineke 1933, Yoda and others 1963). This study attempted to relate these variables for managed stands that are far from full density. Our approach was to present the constant parameter of Reineke's equation as a variable that changed with density from 0 to the maximum value of 1.7 [equation (10)]. Trying to uncover the ecological interpretation of the model parameters, we identified parameter  $I_0$  as the density at which trees start competing with each other and suggested a technique for its estimation. This model was extended to cover density-independent mortality on the assumption that this kind of mortality is proportional to current number of trees.

These estimates refer to mortality within the observed plots. They are smaller than the wholesale mortality that forced abandoning entire plots. The indiscriminate mortality caused by fire, flood, and land conversion destroys about four times as many trees as density-dependent mortality and three times as many as density-independent mortality (tables 2 and 3). On average, for the entire region about 4 (3.8) out of 100 planted trees die every year from all causes. This information may be useful in projecting growth and yield of loblolly pine.

### ACKNOWLEDGMENTS

We are grateful to Harold E. Burkhart and Ralph L. Amateis of Virginia Polytechnic Institute and State University, who, on behalf of the Loblolly Pine and Yield Cooperative, shared their dataset with us and provided useful comments on this study. We also are indebted to John Stephens and Lynne Thompson for their thorough review of the paper and many helpful suggestions. Support from the Arkansas Agricultural Experiment Station is appreciated.

**Table 3—Annual probability of mortality in loblolly pine plantations from all causes**

Cause	Mortality level		
	Region (indiscriminate)	Plot	Total
Lightning		0.0001	0.0001
Flood	0.0003		0.0003
Fire	0.0004		0.0004
Ice	0.0004		0.0004
SPB	0.0076	0.0010	0.0086
Other Insects		0.0011	0.0011
Unknown	0.0148	0.0062	0.0210
Competition		0.0060	0.0060
Total	0.0235	0.0144	0.0379

## LITERATURE CITED

- Burkhart, H.E.; Cloeren, D.C.; Amateis, R.L. 1985. Yield relationships in unthinned loblolly pine plantations on cutover, site-prepared lands. *Southern Journal of Applied Forestry*. 9(2): 84-91.
- Harrison, W.M.; Borders, B.E. 1996. Yield prediction and growth projection for site-prepared loblolly pine plantations in the Carolinas, Georgia, Alabama, and Florida. The University of Georgia, Athens, GA: The University of Georgia, School of Forest Resources PMRC Research Paper 1996-1. 59 p.
- Harper, J.L. 1977. Population biology of plants. New York: Academic Press. 892 p.
- MacKinney, A.L.; Schumacher, F.X.; Chaiken, L.E. 1937. Construction of yield tables for nonnormal loblolly pine stands. *Journal of Agricultural Research*. 54(7): 531-545.
- Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. *Journal of Agricultural Research*. 46: 627-638.
- Wahlenberg, W.G. 1960. Loblolly pine. Raleigh, NC: Duke University, The School of Forestry. 603 p.
- Yoda, K.; Kira, T., Ogawa, H.; Hozumi, K. 1963. Self-thinning in overcrowded pure stands under cultivated and natural conditions. *Journal of Biology, Osaka City University*. 14: 107-129.

# DYNAMICS OF DENSE DIRECT-SEEDED STANDS OF SOUTHERN PINES

J.C.G. Goelz<sup>1</sup>

**Abstract**—Direct seeding of southern pines is an effective method of artificial regeneration, producing extremely dense stands when survival exceeds expectations. Long-term studies of dense direct-seeded stands provide ideal data for exploring development of stands as they approach the limit of maximum stand density. I present data from seven studies with ages of stands ranging from 11 to 42 years. Reineke's relationship serves as the paradigm of stand density. A weighted regression estimated the limiting density line for loblolly (*Pinus taeda* L.) and longleaf pines (*Pinus palustris* Mill.). The slope was common for both species, but the intercept varied, providing a maximum stand density index for loblolly pine that was roughly 9 percent greater than that for longleaf pine. I fit simple response surfaces for mortality, growth of basal area, volume, and weight to explore how these processes changed with stand density. Stand density did not affect mortality of longleaf pine, allowing stand stagnation as diameter growth decreased greatly. However, dynamics of loblolly pine included significant density-dependent mortality when stand density was > 50 percent of maximum. For basal area growth, both species had maximal growth at or below 50 percent of maximum stand density. For volume growth of loblolly pine, maximal growth occurred near 50 percent of maximum stand density. For volume growth of longleaf pine and weight growth of both species, maximal growth occurred at or near maximal stand density.

## INTRODUCTION

As plantations of trees develop over time, trees initially grow unimpeded by competition. As the trees become larger, crowns and roots of neighboring trees begin to interfere with each other. As the interference increases, growth in diameter of the individual trees will decrease relative to trees experiencing less competition. As growth reduces, so will vigor of the trees, making them more likely to die. This density-dependent mortality, termed natural thinning, will progress towards some limiting density relationship (Harper 1977).

If the natural thinning relationship appears on axes of trees per acre and quadratic mean diameter (typically on log-log scale), this limiting density relationship is the Reineke (1933) relationship. This relationship is  $N = bD^c$ , where  $N$  is number of trees per acre,  $D$  is quadratic mean diameter, and  $b$  and  $c$  are parameters. The  $c$  parameter was initially -1.605, but subsequent investigators have allowed  $c$  to vary. Cao and others (2000) suggest that the limiting density line does not have a constant  $c$  for direct-seeded slash pine stands, but that it is curvilinear in log-log scale. If the natural thinning relationship appears on axes of trees per unit area and mean plant weight, this is the -3/2 power law (Yoda and others 1963). It may be represented as  $V = bN^c$ , where  $V$  is average volume or weight, and  $c$  was initially believed to be equal to -3/2. Given a relationship of volume proportional to diameter at breast height (d.b.h.)<sup>2.4</sup>, the -3/2 thinning law is mathematically equivalent to Reineke's relationship (Bredenkamp and Burkhart 1990). Thus the choice between exploring the Reineke or -3/2 thinning relationship is rather arbitrary. Foresters have long used the Reineke relationship, which precedes identification of the -3/2 power law by plant population biologists. Frothingham (1914) seems to have used the Reineke relationship in constructing yield tables for white pine. I present stand dynamics on the axes of the Reineke relationship. Zeide (2004) provides a recent discussion of alternative perspectives on quantifying stand density.

Although direct-seeding is an effective method of regenerating southern pines, foresters seldom use this method currently. Planting seedlings, rather than seed, produces stands that are more uniform and less wasteful of improved seed. Direct-seeding remains a viable option only where maximizing timber production is irrelevant to management objectives, or where planting seedlings is impractical. Direct-seeding often produces stands with many more trees per acre than plantations of seedlings. High rates of seeding come from the presumption of high variability of direct seeding and as a hedge against low establishment rates, which may occur in suboptimal conditions. With data of direct seeding with high establishment rates, I hope to explore the dynamics of pine stands as they approach the limiting density line.

## MATERIAL AND METHODS

### Studies

This analysis used data from seven studies of precommercial thinning of direct seeded stands (table 1). Both the seeding procedure (broadcast or strip) and thinning treatment (selective or strip, or a combination) varied among the studies. The age of precommercial thinning varied from 5 to 20 years; only study 312 was thinned later than age 7 years. Concerned with long-term stand dynamics of dense pine stands, I ignored the specific management practices that produced these dense stands. Six of the seven studies are located in central or west-central Louisiana; one is from southeast Mississippi. The species are appropriate for the sites that were seeded.

### Fitting the Limiting Density Line

The objective is to fit a straight line on axes of the natural log of trees per acre and the natural log of quadratic mean diameter that describes the limiting density relationship.

$$\ln(N) = b_0 + b_1 \cdot \ln(D_q) \quad (1)$$

Equation (1) would pass through the middle of the data, rather than represent a limiting relationship, if it were fit to the data

<sup>1</sup> Research Forester, USDA Forest Service, Southern Research Station, 2500 Shreveport Highway, Pineville, LA 71360.

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**Table 1—Datasets included in this analysis**

Study	Pine species	Plots	Plot size	Range of treatments <sup>a</sup>	Age <sup>b</sup>
		no.	acres		
307	Loblolly	33	0.10	750 – 4,350/acre, unthinned	16 – 34
315	Loblolly	18	0.119	908 – 5,445/acre	14 – 22
318	Loblolly	27	0.10	750 – 4,350/acre, unthinned	14 – 29
325	Loblolly	28	0.053	908 – 5,445/acre	11 – 21
312	Longleaf	21	0.4	40 – 140 ft <sup>2</sup> /acre, unthinned	25 – 40
320	Longleaf	24	0.10	500 – 3,000/acre	32 – 42
331	Longleaf	15	0.10	500 – 3,000/acre	18 – 36

<sup>a</sup> Treatments are defined as residual stand at time of study establishment (age 3 to 20 years).

<sup>b</sup> Age represents age at time of measurement.

by least squares. Thus, rather than least squares, I fit the line by weighted least squares by minimizing the following loss function:

$$loss = \sum (r^2)w \quad (2)$$

where  $r$  is the residual and  $w$  is the weight. The distance of the observation from the maximum stand density index (proportional to  $N(D_q)^{b_1}$ ) determines the weight.

$$w = \left( \frac{(N(D_q)^{b_1} - \min(N(D_q)^{b_1}))}{(\max(N(D_q)^{b_1}) - \min(N(D_q)^{b_1}))} \right)^{32} \quad (3)$$

This weighting function is equal to one for the observation of maximum stand density index and to zero for the observation of minimum stand density index. I arbitrarily set the exponent of 32 so that the line was very near the limit of the data, although some observations were above the line. As the data are measured with error, the fitted line should not represent a true limit to the data. While the error associated with measuring d.b.h. may be small, there is also the generally unrecognized variability in measuring trees per acre. At first blush, one might only expect error in trees per acre if a tree was included in a plot when it should have been excluded or a tree excluded when it should have been included. However, functionally “trees per acre” is not pertinent, but “area per tree” is. For a given plot placement, the plot may exclude some trees that use resources on the plot, and some trees on the plot may use resources off the plot. This is practically unavoidable. Bi (2001) also presents a method to estimate the self-thinning line that allows data points to occur above the line.

Note that the  $b_1$  parameter in equation (3) may not vary as the nonlinear regression procedure estimated equation (1), thus it is designated as  $b_1^*$ . From past experience (Leduc and Goelz 2004), allowing variation of the  $b_1$  parameter in equation (3) yields undesirable consequences. Basically, the weighting function will drive the estimate of  $b_1$ , rather than the actual relationship I am trying to estimate, equation (1). Thus, there were two iteration procedures. I fit equation (1) using a preliminary estimate of  $b_1$  in equation (3). Then I put the new estimate of  $b_1$  into equation (3) and iterated until the parameter value of  $b_1$  didn't change to the fourth significant digit.

Rather than fit equation (1) independently to the two species, I fit the lines in one procedure by using a dummy variable [actually, I fit equation (1) independently to get starting values for the parameters]. Expanding equation (1) yields:

$$\ln(N) = b_{01} + b_{02}(I) + (b_{11} + b_{12}(I))\ln(D_q) \quad (4)$$

where  $I$  is an indicator variable that is zero if the species is longleaf pine and one if the species is loblolly pine. I deleted parameters  $b_{02}$  and  $b_{12}$  if they were not significantly different from zero ( $\alpha = 0.05$ ).

### Fitting Response Trends for Growth and Mortality

To explore dynamics as stands approached the limiting density line, I produced response surfaces for mortality, basal area growth, total cubic foot volume growth, and total green weight growth on the axes of trees per acre and quadratic mean diameter. I calculated volume and green weights of individual trees with the equations of Baldwin and Saucier (1983) for longleaf pine and Baldwin and Feduccia (1987) for loblolly pine. I based the periodic (current) annual growth on a linear assumption (periodic growth divided by years) between measurements taken at approximately 5-year increments. I based the periodic annual mortality on an assumption of constant mortality, thus equal to 1 minus survival raised to the (1/year) power. The response surface was a simple second-order polynomial of trees per acre and quadratic mean diameter and their interactions.

$$Y = b_0 + b_1 \ln(N) + b_2 (\ln(N))^2 + b_3 \ln(D_q) + b_4 (\ln(D_q))^2 + b_5 \ln(N) \ln(D_q) + b_6 (\ln(N))^2 \ln(D_q) + b_7 \ln(N) (\ln(D_q))^2 + b_8 (\ln(N))^2 (\ln(D_q))^2 \quad (5)$$

where  $Y$  represents current annual mortality, basal area growth, volume growth, or weight growth. This equation was not meant to represent growth in any functional way but merely to fit a simple response surface to the data to facilitate discussion of dynamics as stands approach the limiting density line. Thus, I did not include age and site quality, two variables known to affect stand dynamics, in the equation. Not all of the terms of equation (5) are significant. After I fit all possible models, the final model had the highest  $r^2$  among those for which all parameters were significant. I estimated the response surfaces independently for longleaf and loblolly pine. By differentiating equation (5) with respect to  $\ln(N)$  or

$\ln(D_q)$  and setting equal to zero, I obtained the extrema (minima or maxima); as they are partial derivatives, they could be plotted as a line. I included extrema when present within the range of the graph of the response surface.

I also plotted directional fields of actual data. Plotting the entire trend for all stands produced graphs that were difficult to interpret because of the many overlapping lines. Thus, I made directional fields by creating line segments where one end was the initial observation and the other end was the sum of the initial observation plus 1 year of change (annualized from growth intervals that were typically 5 years).

## RESULTS AND DISCUSSION

In the results and discussion, I use the term “density” to be stand density index, or percent of maximum stand density. Although the figures will not have stand density as an axis, stand density may be a proportion of maximum stand density, which would represent lines that are parallel to the maximum density line. I provide only the maximum and 50 percent of maximum lines. Fit statistics for the response surfaces appear in table 2.

### Limiting Density Relationships

The slope of the limiting density relationship is common between species, but the intercept varies (thus, parameter  $b_{12}$  is set to zero). The values (and asymptotic standard errors) of the parameters of equation (4) are  $b_{01}$ : 10.025 (0.013),  $b_{02}$ : 0.0877 (0.0074),  $b_{11}$ : -1.775 (0.006). As  $b_{02}$  is positive, this indicates that loblolly pine may maintain a greater density than longleaf pine. This finding corroborates Reineke’s (1933) initial observation that the maximum stand density index of loblolly pine, 450, is greater than maximum stand density index of

longleaf pine, 400; stand density index is relative to a quadratic mean diameter of 10 inches, and represents the trees per acre at that diameter. However, the parameter estimates correspond to a maximum stand density index of 379 for longleaf and 414 for loblolly pine. The values are lower than Reineke, but the proportions of longleaf to loblolly are similar. Note that I calculate the stand density index as  $N(D_q/10)^{1.775}$  for both species. The  $b_{11}$  parameter is significantly different from the -1.605 assumption of Reineke; it is a common finding for the slope from real data to vary up or down from Reineke’s assumption (Cao and others 2000). For loblolly pine, MacKinney and Chaiken (1935) found a slope of -1.707, Harms (1981) found a slope of -1.696, and Williams (1994, 1996) found a slope of -1.505. In figure 1, the limiting density lines for longleaf and loblolly pines are plotted, along with lines representing 50 percent of maximum and basal area of 50, 100, 150, and 200 square feet per acre. If  $b_{11}$  was equal to -2, the limiting density lines would parallel the lines of constant basal area. As the magnitude is  $< 2$ , the limiting density line reflects about 150 square feet per acre of basal area at a quadratic mean diameter of 2 inches, and about 200 square feet per acre at quadratic mean diameter of 9 inches. This result is typical for measures of stand density: At a constant stand density, basal area increases with increases in quadratic mean diameter.

### Stand Dynamics

**Loblolly pine mortality**—The response surface for annual mortality appears in figure 2. The 50 percent density line represents a fairly good estimate of where density-dependent mortality begins to increase, although the increase is continuous as density nears the limiting density line, rather than representing an abrupt increase near 50 percent of maximum

**Table 2—Parameter estimates (and standard errors), and  $R^2$  and root mean squared error for response surface functions**

Variable	Longleaf				Loblolly			
	Mortality	Basal area growth	Volume growth	Weight growth	Mortality	Basal area growth	Volume growth	Weight growth
Intercept		-162.95 (57.00)	76.322 (14.530)	1.019 (0.216)	5.508 (1.210)	-150.74 (47.33)	-1,083.0 (413.4)	-3.495 (1.289)
$\ln(\text{tpa})$		39.930 (13.615)				34.807 (11.451)	141.78 (49.41)	0.575 (0.149)
$\ln(D_q)$		40.117 (14.889)			210.69 (30.36)	49.567 (10.611)		1.422 (0.222)
$\ln(\text{tpa})^2$	0.137 (0.023)	-2.345 (0.818)				-1.815 (0.700)		
$\ln(D_q)^2$	1.481 (0.220)				-35.777 (6.072)	-9.016 (1.976)	-140.52 (52.10)	
$\ln(\text{tpa})\ln(D_q)$		-4.475 (1.673)			-59.220 (7.841)		219.22 (79.00)	
$\ln(\text{tpa})^2\ln(D_q)$	-0.102 (0.022)				3.929 (0.479)	-0.715 (0.134)	-23.006 (8.777)	
$\ln(\text{tpa})\ln(D_q)^2$		-0.706 (0.241)	-21.356 (2.060)	-0.317 (0.031)	6.132 (0.968)			
$\ln(\text{tpa})^2\ln(D_q)^2$			3.896 (0.360)	0.059 (0.005)				
$R^2$	0.67	0.42	0.39	0.40	0.85	0.26	0.05	0.10
RMSE	2.616	1.846	57.143	0.848	2.145	4.543	109.71	1.347

RMSE = root mean squared error.

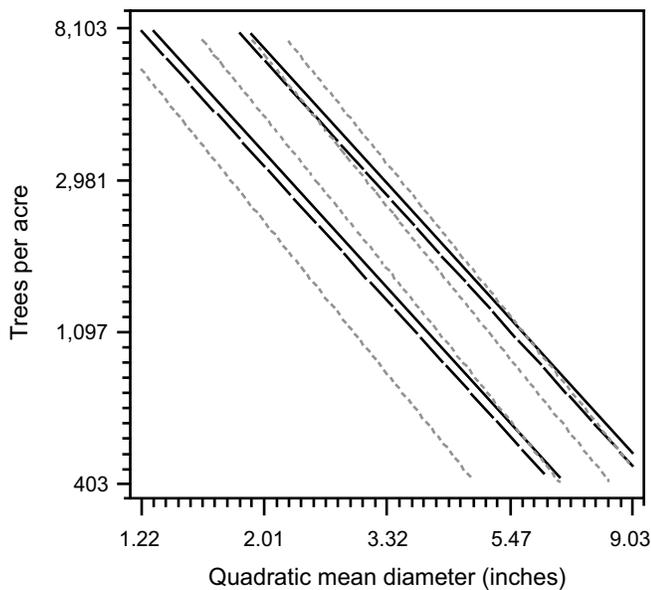


Figure 1—The limiting density function for loblolly pine (dark solid line farthest to right) and longleaf pine (dark dashed line farthest to the right). The lines represent 50 percent of maximum (dark lines to left of the limiting density line) and lines of constant basal area of 50, 100, 150, and 200 square feet per acre (gray dotted lines, with basal area increasing from left to right).

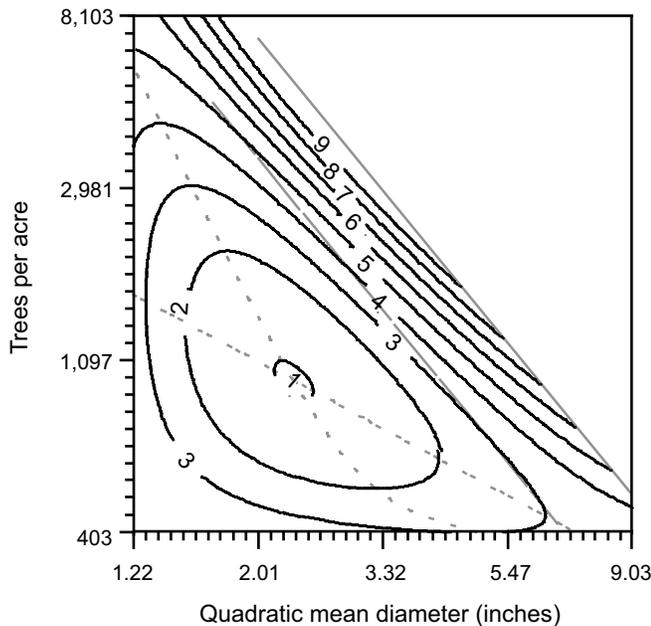


Figure 2—The response surface for annual mortality rate (in percent) for loblolly pine direct-seeded stands. The solid gray line represents the maximum density function, and the dashed gray line represents 50 percent of the maximum density. The single-dotted line represents minima obtained by taking partial derivatives with respect to diameter. The triplet-dotted line represents minima obtained by taking partial derivatives with respect to trees per acre.

density. At a given level of stand density index (proportional, i.e. parallel, to the maximum density line), mortality is higher where trees are smaller. The extrema, which here are minima, suggest mortality is least at low, but not lowest, stand density.

**Loblolly pine growth**—The response surface for loblolly pine basal area growth appears in figure 3. At a given level of stand density index, growth is greater for stands of smaller quadratic mean diameter. Growth is greatest at stand density indices that are considerably less than maximum, generally < 25 percent of maximum, although the maxima lines are not exactly parallel to the limiting density relationship and thus are not a constant proportion of maximum density. Generally, somewhat greater stand densities are appropriate for stands of smaller quadratic mean diameter.

Figure 4 plots the response surface for annual total cubic foot volume growth. The maxima, while curving, are generally between 50 and 100 percent of maximum stand density. As density increases from the lower left corner of the graph towards the upper right of the graph, volume growth increases, but the distance between contours increases, suggesting the response surface is getting progressively more flat. The 50 percent of maximum density represents a level that would nearly maximize net volume growth.

Figure 5 plots the response surface for annual net growth in tons per acre. The greater the density, the greater the growth, and at the same density, the greater the quadratic mean diameter, the greater the growth.

**Loblolly pine directional field**—Figure 6 depicts annual dynamics in trees per acre and quadratic mean diameter.

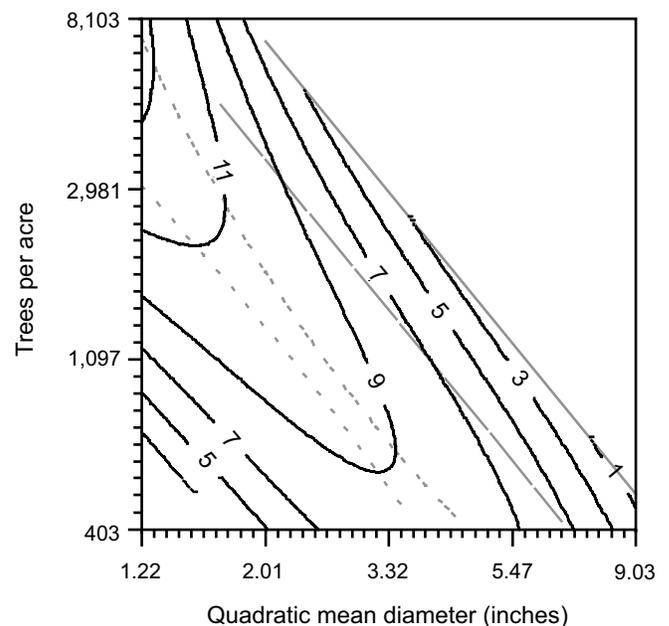


Figure 3—The response surface of annual basal area growth (square feet per acre per year) for loblolly pine direct-seeded stands. The solid gray line represents the maximum density function, and the dashed gray line represents 50 percent of the maximum density. The single-dotted line represents maxima obtained by taking partial derivatives with respect to diameter. The triplet-dotted line represents maxima obtained by taking partial derivatives with respect to trees per acre.

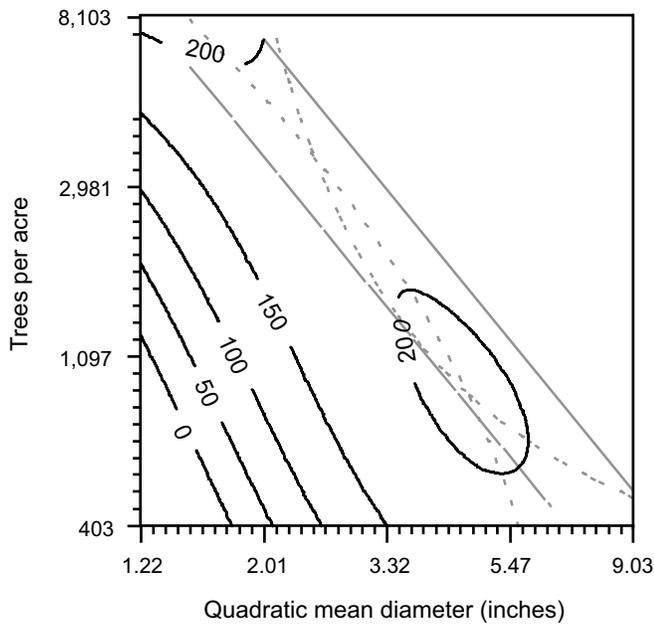


Figure 4—The response surface of annual total cubic foot volume growth, outside bark (cubic feet per acre per year) for loblolly pine direct-seeded stands. The solid gray line represents the maximum density function, and the dashed gray line represents 50 percent of the maximum density. The single-dotted line represents maxima obtained by taking partial derivatives with respect to diameter. The triplet-dotted line represents maxima obtained by taking partial derivatives with respect to trees per acre.

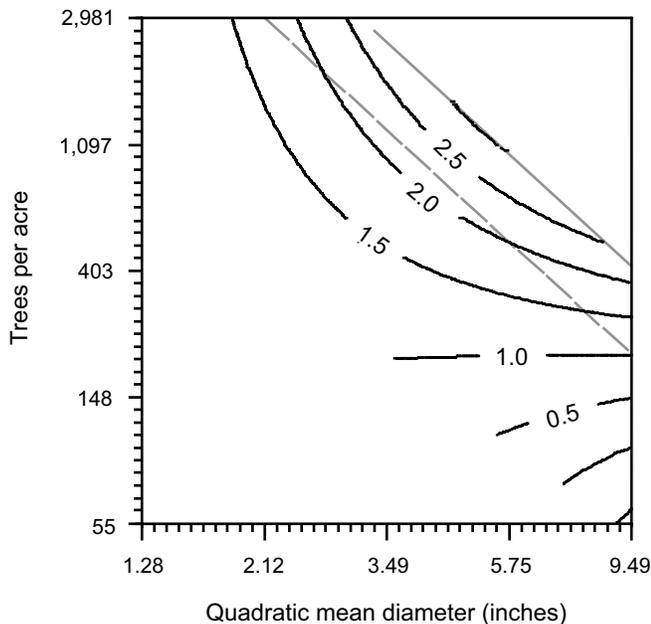


Figure 5—The response surface of annual total bole dry weight growth outside bark (cubic feet per acre per year) for loblolly pine direct-seeded stands. The solid gray line represents the maximum density function, and the dashed gray line represents 50 percent of the maximum density.

Horizontal line segments suggest plots where there was no mortality. While there is some mortality before plots cross the line of 50 percent of maximum, there are few or no plots beyond that line that avoid mortality. Therefore, for loblolly pine, the 50 percent of maximum density line is a reasonable threshold for the initiation of density-dependent mortality. Line segments are shorter as the maximum density line is approached; increases in stand density decrease growth of individual trees.

**Longleaf pine mortality**—Contrary to reason, mortality is not well-related to stand density for longleaf pine (fig. 7). The contours of mortality range from 3 to 6 percent per year, but root mean squared error for the response surface function is 2.6. I will explore mortality more fully below in the section on the directional field.

**Longleaf pine growth**—The maxima for net longleaf pine basal area growth per year are very near the 50 percent of maximum density line (fig. 8). At a given level of stand density, growth is greater when quadratic mean diameter is smaller. The contours of negative basal area growth are slightly beyond the range of the data. The greatest net volume growth occurs near the maximum density line (fig. 9). For much of the range of data, at the same stand density, volume growth is greater at smaller quadratic mean diameters. The contours of weight growth (fig. 10) are very similar in shape to the contours of volume growth. Three tons per acre per year are predicted when trees per acre are around 1,500 and  $D_q$  is around 4.5 inches.

**Loblolly pine directional field**—Contrary to loblolly pine where mortality is very responsive to stand density, mortality does not determine longleaf pine dynamics with response to density (fig. 11). Rather, density greatly decreases individual tree growth rather than increasing mortality. Note that many

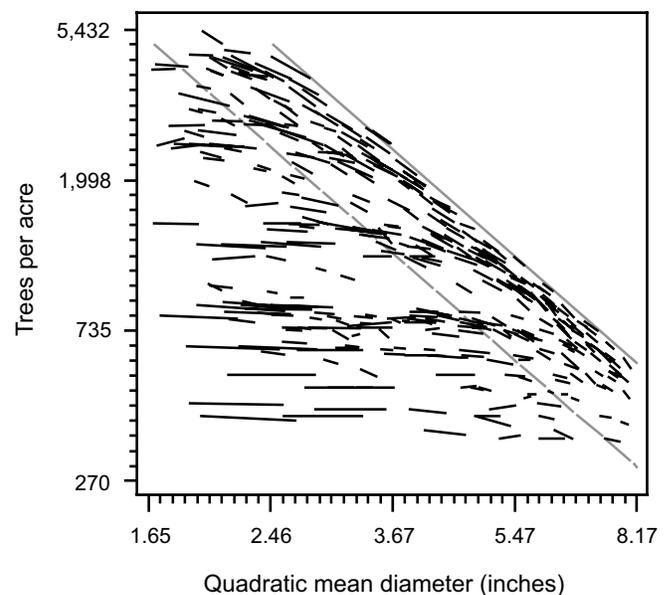


Figure 6—The directional field for stand dynamics of loblolly pine direct-seeded stands. The line segments represent 1 year of change in trees per acre and quadratic mean diameter. The solid gray line represents the maximum density function, and the dashed gray line represents 50 percent of the maximum density.

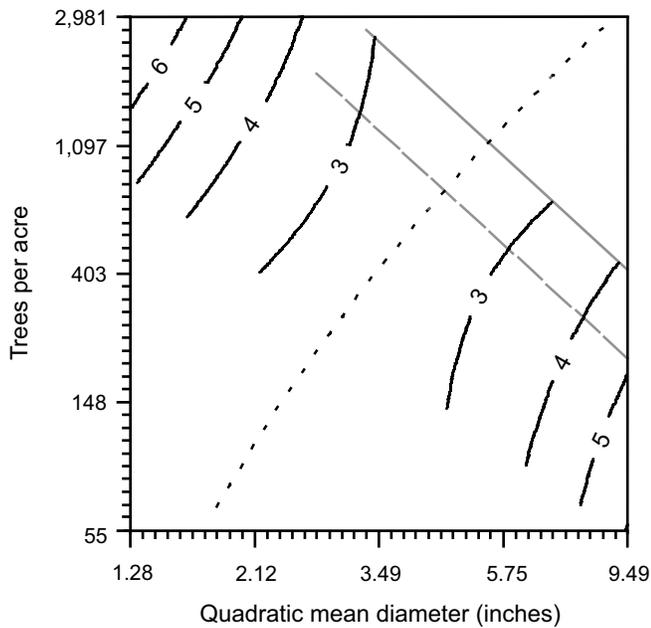


Figure 7—The response surface for annual mortality rate (in percent) for longleaf pine direct-seeded stands. The solid gray line represents the maximum density function, and the dashed gray line represents 50 percent of the maximum density. The dotted line represents minima obtained by taking partial derivatives with respect to diameter.

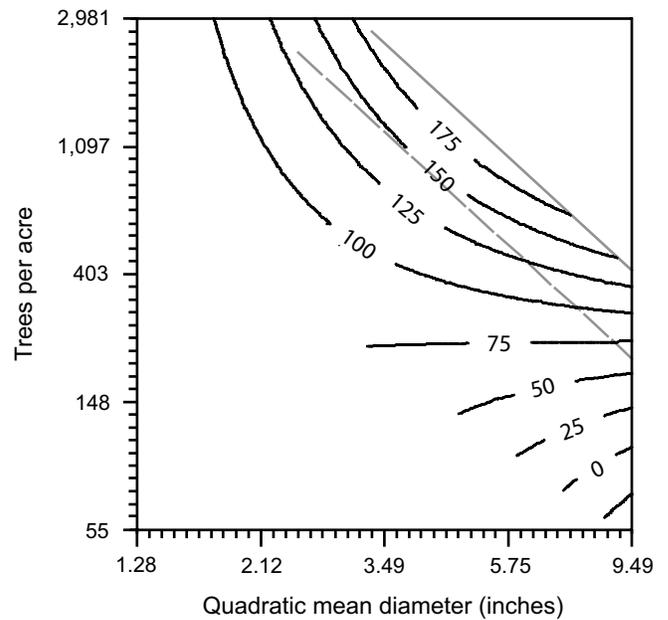


Figure 9—The response surface of annual total cubic foot volume growth, outside bark (cubic feet per acre per year) for longleaf pine direct-seeded stands. The solid gray line represents the maximum density function, and the dashed gray line represents 50 percent of the maximum density.

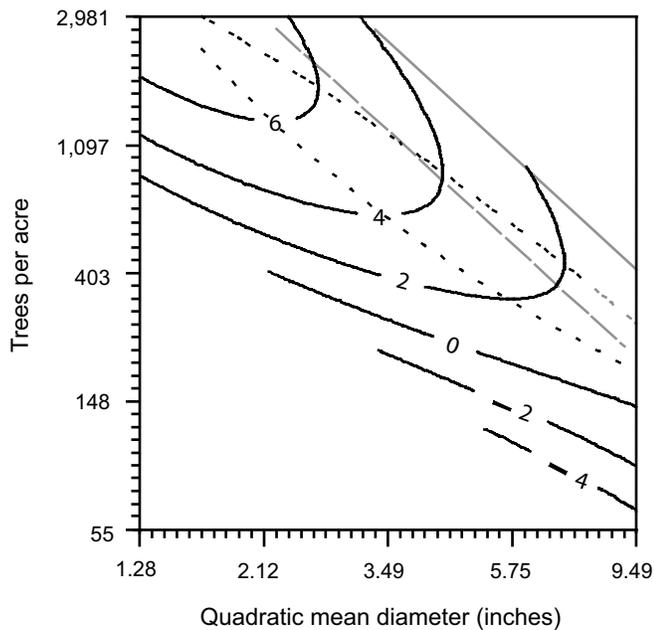


Figure 8—The response surface of annual basal area growth (square feet per acre per year) for longleaf pine direct-seeded stands. The solid gray line represents the maximum density function, and the dashed gray line represents 50 percent of the maximum density. The single-dotted line represents maxima obtained by taking partial derivatives with respect to diameter. The triplet-dotted line represents maxima obtained by taking partial derivatives with respect to trees per acre.

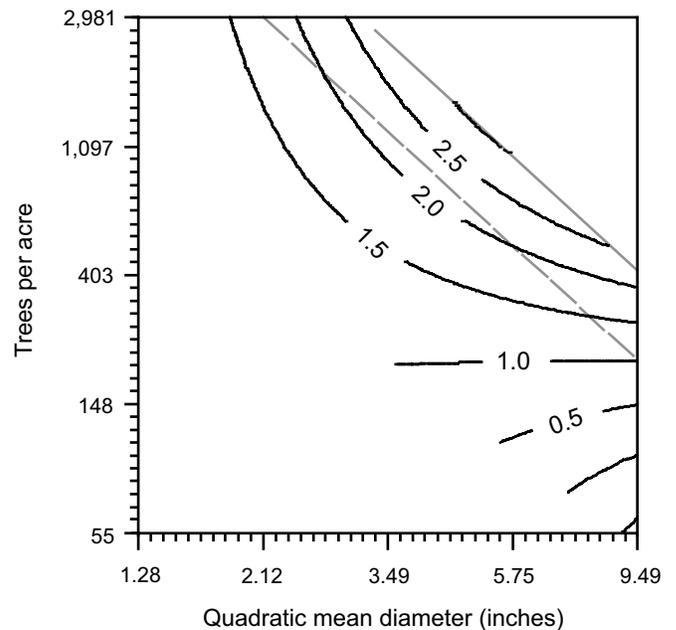


Figure 10—The response surface of annual total bole dry weight growth outside bark (tons per acre per year) for longleaf pine direct-seeded stands. The solid gray line represents the maximum density function, and the dashed gray line represents 50 percent of the maximum density.

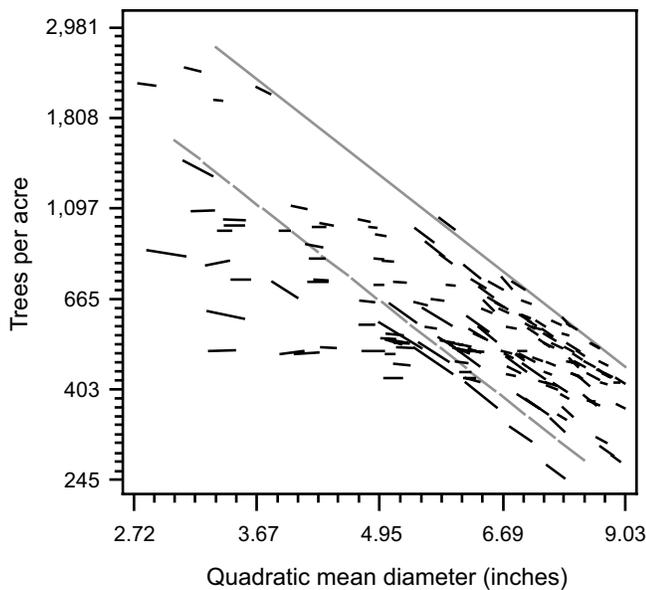


Figure 11—The directional field for stand dynamics of longleaf pine direct-seeded stands. The line segments represent 1 year of change in trees per acre and quadratic mean diameter. The solid gray line represents the maximum density function, and the dashed gray line represents 50 percent of the maximum density.

plots have little or no mortality even though they are greater than the 50 percent of maximum density line. Thus, for longleaf pine, the 50 percent of maximum density line is not a satisfactory threshold for the initiation of density-dependent mortality. In fact, mortality is almost non-density-dependent. Goelz and Leduc (2002) found that intermediate crown class longleaf pine could persist for many years in an inferior crown class, which is atypical for shade-intolerant species. This finding does suggest that longleaf pine stands could be maintained at relatively high densities without high losses to mortality. However, our data do not address whether these near-stagnating conditions permanently reduce vigor and thus potential to respond to subsequent thinning.

## LITERATURE CITED

- Baldwin, V.C., Jr.; Feduccia, D.P. 1987. Loblolly pine growth and yield prediction for managed west gulf plantations. Res. Pap. SO-236. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 27 p.
- Baldwin, V.C., Jr.; Saucier, J.R. 1983. Aboveground weight and volume of unthinned planted longleaf pine on West Gulf forest sites. Res. Pap. SO-191. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 25 p.
- Bi, H. 2001. The self-thinning surface. *Forest Science*. 47: 361-370.
- Bredenkamp, B.V.; Burkhart, H.E. 1990. An examination of spacing indices for *Eucalyptus grandis*. *Canadian Journal of Forest Research*. 20: 1909-1916.
- Cao, Q.V.; Dean, T.J.; Baldwin, V.C., Jr. 2000. Modeling the size-density relationship in direct-seeded slash pine stands. *Forest Science*. 46: 317-321.
- Frothingham, E.H. 1914. White pine under forest management. Bull. 13. Washington, DC: U.S. Department of Agriculture. 70 p.
- Goelz, J.C.G.; Leduc, D.J. 2002. A model describing growth and development of longleaf pine plantations: consequences of observed stand structures on structure of the model. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 439-442.
- Harms, W.R. 1981. A competition function for tree and stand growth models. In: Barnett, J.P., ed. Proceedings of the first biennial southern silvicultural research conference. Gen. Tech. Rep. SO-34. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 179-183.
- Harper, J.L. 1977. Population biology of plants. New York: Academic Press. 892 p.
- Leduc, D.J.; Goelz, J.C.G.. 2004. Development of mature natural even-aged stands of loblolly pine in the piedmont. In: Connor, K.F., ed. 2004. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 221-228.
- MacKinney, A.L.; Chaiken, L.E. 1935. A method of determining density of loblolly pine stands. Tech. Note 15. Asheville, NC: U.S. Department of Agriculture, Forest Service, Appalachian Forest Experiment Station. 3 p.
- Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. *Journal of Agricultural Research*. 46: 627-638.
- Williams, R.A. 1994. Stand density index for loblolly pine plantations in north Louisiana. *Southern Journal of Applied Forestry*. 18: 40-45.
- Williams, R.A. 1996. Stand density index for loblolly pine plantations in north Louisiana. *Southern Journal of Applied Forestry*. 20: 110-113.
- Yoda, K.; Kira, T.; Ogawa, H.; Hozumi, K. 1963. Self-thinning in over-crowded pure stands under cultivated and natural conditions. Osaka City University: *Journal of Biology*. 14: 107-129.
- Zeide, B. 2004. How to measure stand density. *Trees*. 19: 1-14.

# A WHOLE STAND GROWTH AND YIELD SYSTEM FOR YOUNG LONGLEAF PINE PLANTATIONS IN SOUTHWEST GEORGIA

John R. Brooks and Steven B. Jack<sup>1</sup>

**Abstract**—A whole stand growth and yield system for planted longleaf pine (*Pinus palustris* Mill.) was developed from permanent plot data collected annually over an 8 year period. The dataset consists of 12 intensively-managed longleaf pine plantations that are located in Lee, Worth, Mitchell, and Baker counties in southwest Georgia. Stand survival, dominant height, basal area, and cubic foot volume yield models were developed and incorporated in a computer growth and yield simulator. Model prediction error remained low across a variety of planting densities.

## INTRODUCTION

A whole stand growth and yield system was developed for young (< age 20) longleaf pine (*Pinus palustris* Mill.) plantations based on a permanent plot system from 15 plantations located in the Flint River Basin of southwest Georgia. A system of equations was developed for stand survival, dominant height, basal area per acre, and cubic foot volume outside bark (ob) per acre. Initial testing using a west gulf system developed by Lohrey and Bailey (1976) provided less than acceptable results, especially for the dominant height prediction model.

## STUDY DESCRIPTION

The longleaf pine data is part of a growth and yield study from 15 stands located in Lee, Worth, Mitchell, and Baker counties in southwest Georgia. Sample plots are approximately 0.1 (mean 0.10585) acre in size with stands ranging from 2 to 19 years old. Stand density ranges from 273 to 940 trees per acre and from 5 to 136 square feet of basal area per acre. Rectangular fixed area plots were established at different dates and have been remeasured annually; thus the number of measurements available per plot ranges from 2 to 10. A total of 105 plot measurement and remeasurement observations are available providing 49 unique growth intervals.

At each measurement date, diameter at breast height (d.b.h.) was measured with a diameter tape and recorded for every tree to the nearest 0.1 inch. Total tree height was measured with a height pole or an Impulse laser (depending upon tree size) and recorded to the nearest 0.1 foot. Trees < 15 feet were measured with a height pole while taller trees were measured with an Impulse 200 laser. Initially, crown class was recorded for just the older stands (> 12 years) except for the most recent measurement period, where crown class was assigned to all trees, regardless of age. The traditional definition of crown class was slightly modified in order to assign crown class to the younger aged stands. The younger plantations generally have wider initial planting spacing, and thus all trees receive full sunlight. The codominant crown class was defined as those trees that make up the main crown canopy, while intermediate and suppressed classes were assigned to those trees visually shorter (and usually less vigorous) than the trees that constitute the average crown height. Cubic foot

volumes are based on a taper function developed by Brooks and others (2002) based on trees sampled from the same plantations.

## SURVIVAL PROJECTION

A survival projection model commonly employed for loblolly (*Pinus taeda* L.) and slash pine (*Pinus elliottii* Engelm. var. *elliottii*) plantations (Pienaar and others 1988) was used to model stand level survival. Since mortality in these young stands was negligible, this model was fit independently from the other stand level models, and initial planting density was included as an initial condition. The model is of the form:

$$N_2 = N_1 * Exp \left\{ \alpha_1 \left[ \left( \frac{A_2}{10} \right)^{\alpha_2} - \left( \frac{A_1}{10} \right)^{\alpha_2} \right] \right\} \quad (1)$$

where

$N_2$  = projected survival in trees per acre at age  $A_2$ ,

$N_1$  = current trees per acre at age  $A_1$ , and

$\alpha_1, \alpha_2$  = parameters to be estimated from the data.

## DOMINANT HEIGHT PROJECTION

The algebraic difference equation form of a modified Chapman-Richards height/age projection function was selected as the model form:

$$DHT_2 = DHT_1 \left[ \frac{1 - Exp(\beta_1 * A_2)}{1 - Exp(\beta_1 * A_1)} \right]^{\beta_2} \quad (2)$$

where

$DHT_2$  = projected dominant height at age  $A_2$ ,

$DHT_1$  = current dominant height at age  $A_1$ , and

$\beta_1, \beta_2$  = parameters to be estimated from the data.

This equation form has been used successfully in both loblolly (Pienaar and Shiver 1980) and slash (Pienaar and Shiver 1984) pine plantations. All possible non-overlapping growth intervals were used to fit this nonlinear, two parameter model. This model was fitted as part of a system of equations which also included a basal area projection model, a volume prediction model, and a volume projection model.

<sup>1</sup> Associate Professor, West Virginia University, Division of Forestry, Morgantown, WV 26505; and Conservation Ecologist, Joseph W. Jones Ecological Research Center, Newton, GA 31770, respectively.

## BASAL AREA PROJECTION

The following algebraic difference model was selected from several model forms tested. Once non-significant parameters were removed, the final model was of the form:

$$BA_2 = \text{Exp} \left\{ \text{Ln}(BA_1) + \delta_1 \left( \text{Ln}(DHT_2) - \text{Ln}(DHT_1) \right) + \delta_2 \left( \text{Ln}(N_2) - \text{Ln}(N_1) \right) \right\} \quad (3)$$

where

$BA_2$  = projected basal area at age  $A_2$ ,

$BA_1$  = current basal area at age  $A_1$ ,

$\delta_1, \delta_2$  = parameters to be estimated from the data, and other variables as previously defined.

## VOLUME PREDICTION AND PROJECTION

In order to make the system more flexible, both a volume prediction and projection model were fitted to the data. The final form of the volume prediction model was:

$$V_i = \text{Exp} \left\{ \lambda_1 + \lambda_2 * \text{Ln}(DHT_1) + \lambda_3 * \text{Ln}(N_1) + \lambda_4 * \text{Ln}(BA_1) \right\} \quad (4)$$

where

$V_i$  = current cubic foot volume (ob) at age  $A_1$ ,

$\lambda_i$  = parameters to be estimated from the data,

$i = 1..4$ , and other variables as previously defined.

The projection model is an algebraic difference form of equation (4):

$$V_2 = \text{Exp} \left\{ \text{Ln}(V_1) + \theta_1 * \left( \text{Ln}(DHT_2) - \text{Ln}(DHT_1) \right) + \theta_2 * \left( \text{Ln}(BA_2) - \text{Ln}(BA_1) \right) \right\} \quad (5)$$

where

$V_2$  = projected cubic foot volume (ob) at age  $A_2$ ,

$\theta_i$  = parameters to be estimated from the data,

$i = 1,2$ , and other variables as previously defined.

All equations except the survival prediction model were fitted as a system of seemingly unrelated regressions (SUR) using SAS SYSNLIN (SAS 1993).

## RESULTS AND CONCLUSIONS

Parameter estimates for each model are displayed in table 1.

In addition, the fit statistics of average bias  $\left( \frac{\sum_{i=1}^n (\hat{Y}_i - Y_i)}{n} \right)$  and

root mean squared error  $\left( \sqrt{\frac{\sum_{i=1}^n (\hat{Y}_i - Y_i)^2}{n}} \right)$  were computed for each model form and are displayed in table 2. Residual analysis for each model did not indicate any unusual trends in the data even though the stands cover a wide range of planting densities and site types. The technique employed provides an accurate whole stand growth and yield system for the longleaf pine plantations that comprise this dataset. Due to the limited size of the dataset, no independent verification of this prediction system was tested. In addition, the effects of potential correlation from the use of plot remeasurement

**Table 1—Parameter estimates for the planted longleaf pine growth and yield system**

Parameter	Estimate	Approximate Pr >  t
$\alpha_1$	-0.206745	< 0.0001
$\alpha_2$	0.360652	< 0.0001
$\beta_1$	-0.07576	< 0.0001
$\beta_2$	2.099041	< 0.0001
$\delta_1$	1.817699	< 0.0001
$\delta_2$	7.398342	0.0227
$\lambda_1$	-0.70743	< 0.0001
$\lambda_2$	1.004848	< 0.0001
$\lambda_3$	0.025178	0.0239
$\lambda_4$	0.97592	< 0.0001
$\theta_1$	1.458852	0.0010
$\theta_2$	0.642513	0.0276

**Table 2—Fit statistics for the system of growth and yield models by model type**

Model	n	Average bias	RMSE
$N_2$	49	1.706	10.076
$DHT_2$	49	-0.002	0.622
$BA_2$	49	0.317	3.483
$V_1$	49	-2.970	18.235
$V_2$	49	8.080	77.374

data have not been investigated. This dataset does include a variety of densities and also includes cutover as well as oldfield sites. Extrapolation to other datasets should be conducted with caution due to the limited age distribution. In addition, caution must be employed when projecting stands beyond the upper age limits of the existing data; the older stands are just reaching the point of self thinning, so the existing survival model may not accurately account for this mortality. However, it does provide a system that should be applicable to plantations in this region whose ages are consistent with those currently in the Conservation Reserve Program. A computer simulation system incorporating these models can be obtained from the primary author.

## LITERATURE CITED

- Brooks, J.R.; Martin, S.; Jordan, J.; Sewell, C. 2002. Interim taper and cubic-foot volume equations for young longleaf pine plantations in southwest Georgia. In: Outcalt, K.W., ed. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 467-470.
- Lohrey, R.E.; Bailey, R.L. 1976. Yield tables and stand structure for unthinned longleaf pine plantations in Louisiana and Texas. Res. Pap. SO-133. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 53 p.
- Pienaar, L.V.; Shiver, B.D. 1980. Dominant height growth and site index curves for loblolly pine plantations in the Carolina flatwoods. Southern Journal of Applied Forestry. 4(1): 54-59.
- Pienaar, L.V.; Shiver, B.D. 1984. The effect of planting density on dominant height in unthinned slash pine plantations. Forest Science. 30(4): 1059-1066.
- Pienaar, L.V.; Harrison, W.M.; Burgan, T.; Rhoney, J.W. 1988. Yield prediction for site-prepared slash pine plantations in the Coastal Plain. Plantation Management Research Cooperative Technical Report No. 1988-1. Athens, GA: University of Georgia, Warnell School of Forest Research. 81 p.
- SAS Institute Inc. 1993. SAS/ETS user's guide. Version 8.2. 2<sup>nd</sup> ed. Cary, NC: SAS Institute Inc. 956 p.

# DEVELOPMENT OF GROWTH AND YIELD MODELS FOR SOUTHERN HARDWOODS: SITE INDEX DETERMINATIONS

John Paul McTague, Daniel J. Robison, David O'Loughlin,  
Joseph Roise, and Robert Kellison<sup>1</sup>

**Abstract**—Growth and yield data from across 13 southern States, collected from 1967 to 2004 from fully-stocked even-aged southern hardwood forests on a variety of site types, was used to calculate site index curves. These derived curves provide an efficient means to evaluate the productivity-age relation which varies across many sites. These curves were derived for mixed-species and represent a substantial improvement over previously available curves of this nature. These site index curves will be used as a “productivity driver” in the development of growth and yield models for these forest types.

## INTRODUCTION

Growth and yield information are reasonably well-documented for species that occupy pure natural stands and plantations. Such is the case with the southern pines (*Pinus* spp.), especially loblolly (*P. taeda* L.) and slash (*P. elliottii* Engelm.) pines for which multiple growth and yield tables have been developed (Burkhart and Strub 1974, Clutter 1963, Clutter and Jones 1980, Hafley and Buford 1985). Species that occur in mixed stands are much more difficult to model unless they have similar growth rates and quality attributes. The southern hardwoods are difficult to quantify for growth and yield parameters because of the diversity of species within and among site types. Of the 214 million acres of forest land in the South, hardwoods occupy about 120 million (FIA 2002). Rauscher and others (2000) performed an accuracy test on 10 publicly available hardwood growth and yield models and found some models performed well while others were lacking. In this paper, we report the development of site index curves for a variety of stand and species types typical of even-aged southern hardwoods. These curves, representing the influence of site type = productivity on tree growth rates, will be used as drivers in the development of growth and yield models.

## PROCEDURE

In 1967, the Hardwood Research Cooperative at North Carolina State University initiated a project to develop growth and yield tables for southern hardwoods. The first effort was to recognize the forest site types that were of sufficient size to be identified as separate operating units. Nine such units were identified, six in the Coastal Plain (red river bottoms, black river bottoms, branch bottoms, muck swamps, peat swamps, wet flats) and three in the Piedmont/mountains (bottomlands; coves, gulfs and lower slopes; upland slopes and ridges).

Plots, totaling 641, were established by members of the Hardwood Research Cooperative from Delaware to Florida and Texas. The stands selected for plot establishment were relatively even-aged, fully stocked, and otherwise unmanaged. Thus results from this study cannot be extrapolated with accuracy to stands that have been abused, thinned, or subjected to various intermediate stand treatments. Selecting a uniform

distribution of age classes was a challenge, because prolonged selective cutting from above in many southern hardwood forests has created stands with two or more age classes. Such stands were avoided in plot establishment to the extent possible. Plots were established in stands ranging from 20 to 60 ( $\pm$  10 years) years old.

Circular 0.2-acre plots were used, in which all trees > 5.5 inches d.b.h. were measured by species and age for total height, merchantable height, d.b.h., and stand density. Merchantable height to the nearest foot was measured to a 4-inch top (outside bark). A subplot of 0.01-acre was installed within the 0.2-acre plot for the measurement of number of stems by species, by 1-inch diameter class, from 1.6 to 5.5 inches d.b.h. Seedlings and sprouts smaller than 1.6 inches d.b.h. were recorded by species without regard to diameter or height class. Of the 641 plots installed, 187 were maintained for repeated measurements on a 5-year cycle, and 146 were observed more than once (13,008 trees were used in the data analysis).

## RESULTS AND DISCUSSION

Some southern hardwood site types are much more productive than others, and in addition, within a single site type, productivity will vary. In the Southern United States forests, the most commonly used method to quantify stand productivity is site index (the expected tree height at a given base age). Site index curves are almost always species specific. In Carmean and others' (1989) inventory of site index curves for the Eastern United States, 127 individual curves were presented representing a wide range of species and conditions. Most were for a single species. The best example of a mixed species curve is for upland oaks, where Olsen (1959) combined data for white, northern red, scarlet, black, and chestnut oaks (*Quercus* spp.). As noted by Avery and Burkhart (2002), the concept of single species site index is not generally well-suited for mixed-species stands. Hardwood stands are commonly mixed species.

Southern hardwood stands have a wide range of species with a mix often confounded by past management practices.

<sup>1</sup> Timberland Investment Resources, LLC, Atlanta, GA 30326 and Adjunct Professor, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695; and Associate Professor, Research Assistant, Professor, and Professor Emeritus, respectively, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695.

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Quantifying site productivity is difficult, in part because site quality changes between species for the same parcel of land. To standardize the measurement of site quality, height/age curves for mixed species stands needed to be developed. This is an extension of the concept of site quality being the integration of genetic quality, fertility, water, and climate over time.

In the development of a height over age relation, we went through many iterations. We ultimately selected polymorphic site index curves for our purpose and used the equation form and two-step procedure discussed by Bailey and Clutter (1974). The equation has the form:

$$\ln H = a_i + b(1/A)^k \quad (1)$$

where

$a_i$  = the site specific intercept

$b$  = the common slope

$k$  = the linearization parameter.

Following the methodology outlined by Bailey and Clutter (1974), we first developed an estimate for  $k$ , where

$$\hat{k} = 0.38509 \quad (2)$$

Once  $k$  was predetermined, the equation was linear, and a linear model could be used to estimate parameters  $a$  and  $b$ . This is where we deviated in a subtle way from Bailey and Clutter (1974). We continued to model  $(1/A)^k$  as the covariate; however, instead of treating the plots as fixed effects of the intercept, we felt that it was more logical to treat the plots as a random effect and that the repeated height observations within each plot were correlated. The remeasurements, which were 5 years apart, led inevitably to a positive autocorrelation, implying that an above-average value on a plot was likely to be followed by another above-average value. Failing to recognize the within-plot correlation is not especially serious, since it is likely that the estimated parameters are unbiased. In the presence of autocorrelation, the precision of the estimators is usually overstated, resulting in  $p$ -values that are too small (Schabenberger and Pierce 2001). Recognizing that many forestry studies have either missing measurements or a remeasurement schedule that varies from study to study, it was decided to model covariance structure of the error using exponential spatial covariance structure. We employed SAS PROC MIXED to estimate the coefficients. The resulting height age model was:

$$\ln H = 5.5253 - 4.2858 \left( \frac{1}{A^{0.38509}} \right) \quad (3)$$

where

5.5253 = the average intercept value. A family of site index curves was derived by isolating the  $b$  term and imposing the condition that at base age 25, height =  $S$ ; then

$$-4.2858 = (\ln S - 5.5253)25^{0.38509} \quad (4)$$

Substituting this last equation (4) into the previous one (3) and solving for  $H$  we get:

$$H = 251 \left( \frac{S}{251} \right) \left( \frac{25}{A} \right)^{0.38509} \quad (5)$$

where

$S$  = site index (base age 25)

$H$  = predominant mean height (40 tallest trees per acre)

$A$  = total stand age.

The fit index (F.I.) is:

$$(1-2.707805/32.19649) = 0.9159 \quad (6)$$

where F.I. is defined as  $1-SSE/SS_y$ . ANOVA was used to estimate  $SS_y$  and the SAS means procedure was used to estimate the SSE. The residual is computed after including both random and fixed terms in equation (3). REML rather than ordinary least squares was used to estimate the parameters. The site index curves expressed in equation (5) are shown in figure 1.

These site index curves represent a substantial advance in our ability to model productivity across a range of site types for even-aged southern hardwoods. The data from the plots were then used to calculate and model southern even-aged hardwood merchantable stand survival, basal area projection, total number of merchantable trees including ingrowth, ingrowth basal area, stand-level and individual tree-level equations, individual tree mortality and growth, individual tree height prediction and diameter projection, submerchantable tree estimations, and volume estimation (inside and outside bark for total volume, merchantable volume, and volume ratio).

## ACKNOWLEDGMENTS

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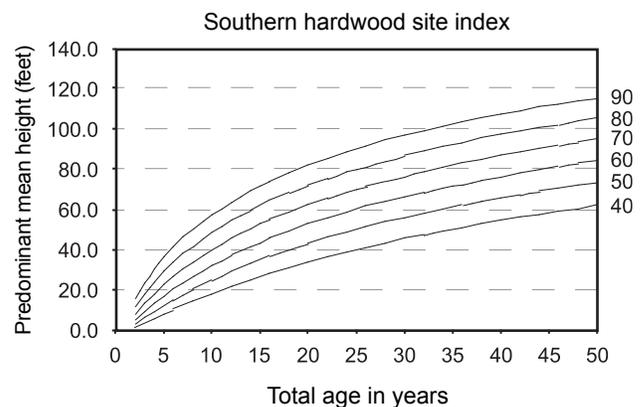


Figure 1—Site index curves for mixed species southern hardwood stands. These are from the polymorphic Bailey-Clutter approach modeled with a mixed model analysis of covariance with plot location as a random effect. Site index base age is 25 years.

## LITERATURE CITED

- Avery, T.E.; Burkhart, H.E. 2002. Forest measurements. Fifth edition. New York, New York: McGraw Hill. 455 p.
- Bailey, R.L.; Clutter, J.L. 1974. Base-age invariant polymorphic site curves. *Forest Science*. 20: 155-159.
- Burkhart, H.E.; Strub, M.R. 1974. A model for simulation of planted loblolly pine stands. In: Fries, J., ed. Growth models for tree and stand simulation. Research Notes No. 30. Stockholm, Sweden: Royal College Forestry: 128-135.
- Carmean, W.H.; Hahn, J.T.; Jacobs, R.D. 1989. Site index curves for forest tree species of the Eastern United States. Gen. Tech. Rep. NC-128. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 148 p.
- Clutter, J.L. 1963. Compatible growth and yield models for loblolly pine. *Forest Science*. 9: 354-371.
- Clutter, J.L.; Jones, E.P. 1980. Prediction of growth after thinning in old-field slash pine plantation. Res. Pap. SE-217. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 14 p.
- Forest Inventory and Analysis – Southern Region (FIA). 2002. Draft RPA 2002. Forest resource of the United States. [http://ncrs2.fs.fed.us/4801/fiadb/rpa\\_tabler/Draft\\_RPA\\_2002\\_Forest\\_Resource\\_Tables.pdf](http://ncrs2.fs.fed.us/4801/fiadb/rpa_tabler/Draft_RPA_2002_Forest_Resource_Tables.pdf).
- Hafley, W.L.; Buford, M.A. 1985. A bivariate model for growth and yield prediction. *Forest Science*. 31: 237-247.
- Olsen, D.F. 1959. Site index curves for upland oak in the Southeast. Res. Note SE-125. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 2 p.
- Rauscher, H.M.; Young, M.J.; Webb, C.D.; Robison, D.J. 2000. Testing the accuracy of growth and yield models for Southern hardwood forests. *Southern Journal of Applied Forestry*. 24: 176-185.
- Schabenberger, O.; Pierce, F.J. 2001. Contemporary statistical models for the plant and soil sciences. Boca Raton, FL: CRC Press. 738 p.

# EVOLUTION OF SILVICULTURAL THINNING: FROM REJECTION TO TRANSCENDENCE

Boris Zeide<sup>1</sup>

**Abstract**—Our views on a main tool of forestry, silvicultural thinning, have changed greatly since the beginning of forestry over 200 years ago. At first, thinning was rejected as something unnatural and destructive. It was believed that the densest stands were the most productive and any thinning only detracted from maximum growth produced by nature. This philosophy was still dominant during the second stage when the “fathers” of forestry developed the practice of light thinning from below. It took another 100 years to acknowledge the benefit of a less “natural” medium to heavy thinning. During the last 70 years, the consensus has been that, within a wide range of densities, stand growth remains more or less constant. Even better results can be achieved when density increases with age. Heavy thinning at the beginning speeds up growth, whereas higher stocking at the end secures a larger final harvest. The last stage takes the trend of progressively lighter thinning to its logical conclusion: to control density by planting only the trees we intend to harvest at the end of rotation. Wood quality and stem form can be improved by pruning. Specific management recommendations are provided.

## INTRODUCTION

Our attitude toward silvicultural thinning has evolved from total prohibition to the realization that thinning is not the best method to control stand density and maximize yield. Given that our views on thinning intensity have returned to the point where we started, this trend can be characterized as a revolution (the action of going round) rather than evolution. Several other concomitant trends are truly evolutionary. They include the increase in initial spacing of planted trees and a diminished enthusiasm for worshipping nature. Major stages of these trends are described below.

## HISTORY OF THINNING

### Initial Proscription

In the 18<sup>th</sup> century when forestry was systematized, forests in densely populated countries of Europe were badly depleted by irregular and usually illegal cutting of timber by local peasants. This kind of “thinning” instilled the belief that any thinning only detracts from the maximum growth produced by nature. At that time, thinning was considered as something unnatural and destructive, useful only to get a quick return at the expense of the final harvest. This belief was further supported by not only the popular veneration of nature but also by reasoning, both physical and ecological. That thinning could increase growth seemed to violate a basic law of nature: Nothing comes out of nothing. Equally convincing was an ecological consideration: A complete canopy intercepts more light and consequently should be more productive than a broken canopy. Forestry had not yet realized that thinning accelerates growth, and when foresters were in charge of forests, they opposed thinning (Fernow 1913).

Another manifestation of the preoccupation with full stocking was planting density. Traditionally, foresters tried to copy nature and planted as many seedlings as found in natural regeneration. As reported in Savill and others (1997, p. 160-161), in some parts of Germany, even the relatively intolerant Scotch pine is still planted at 10,000 to 18,000 trees/ha, which is “a considerable reduction from earlier practice.” This tradition

overlooks the critical difference between natural and planted regeneration—us. Only few trees survive until maturity under natural conditions and almost all when we control intra- and interspecific competition.

### Light Thinning

After securing forest protection, foresters recognized the economic advantage of harvesting suppressed trees after the remaining trees were cleared of lower and middle branches. This timid beginning of silvicultural thinning (called German or light thinning from below) is attributed to the “fathers” of forestry, Georg Ludwig Hartig and Heinrich von Cotta (Fernow 1913). Particularly influential was the publication of Hartig’s “Instructions on the Evaluation of Forests” in 1795. Its third “General Rule” of forestry required keeping such a density that prevents vegetation on the forest floor (Fernow 1913, p.103). The instructions recommended periodic removal of suppressed, damaged, and undesirable trees when they could be sold profitably. At the same time, Hartig (1795, p. 17, translated by Hans Pretzsch) saw the harm done by high density and regretted “that there are unfortunately many foresters who do not thin forests but permit all stems to grow up together and refuse to deal with the excesses of abundance.” Yet, he still sternly warned against ever breaking the canopy. To maintain the full closure, he would retain up to half of the crooked trees. These views had “the greatest influence upon the treatment of German forests between 1795 and 1914 (and even later)” (Kostler 1956, p.238).

### Thinning to Increase Growth

In addition to his many distinguished hats, the great Danish statesman Christian Ditlev Frederik Viscount Reventlow was also a forestry prophet. On the basis of observations of tree growth in his vast estates, Reventlow realized that thinning actually stimulated stand growth. As a result, the total stand volume increases and does not diminish, as was presumed from a facile analogy with physical laws of conservation. Reventlow believed that frequent thinnings substantially reducing canopy closure would increase not only merchantable volume but total production and volume per unit area as

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<sup>1</sup> Professor of Forestry, School of Forest Resources, University of Arkansas at Monticello, Monticello, AR 71656-3468.

well. To Reventlow's skeptical contemporaries, his view was equivalent to the possibility of having your cake and eating it, too. Outside Denmark, a brief summary of his results that appeared in 1811 (Mar:Moller 1954), and his book published in 1879 failed to change forestry practice.

It took 100 years after Reventlow's announcement of 1811 to acknowledge the benefit of medium to heavy thinning by forestry professionals. The decisive factor was the analysis of permanent plot data that replaced chance observations and heated arguments. Many plots, established in Germany in the second half of the 19<sup>th</sup> century, produced first results at the beginning of the next century. Summarizing the results of 30 years of observations on 40 permanent sample plots established in Prussian beech stands, Schwappach (1911) showed that heavy thinning substantially increased the total volume growth. Scientists in other countries, including the United States, quickly arrived at similar results (Li 1923).

### Thinning to Redistribute Growth

The enthusiasm brought by the possibility of increasing stand growth was short lived. In 1932, Wiedemann, Schwappach's successor in charge of the Prussian Forest Experiment Station, using longer 50-year-old observations of the same beech stands, demonstrated that, within a wide range of density, total wood production is almost independent from thinning intensity. An indistinct peak of total volume production occurring at a moderate density was documented by many researchers in Europe and the United States. The prevalent consensus at present is that thinning can redistribute volume growth from smaller to larger stems but cannot increase its amount: "As long as the site is fully occupied (trees making their full use of available resources), the species will produce the same amount of wood per year at various densities. Whether there are many small trees or fewer large trees, a similar wood volume is produced" (Spurr and Barnes 1980, p. 376). Graphically, this conviction is depicted by Langsaeter's curve (shown in Daniel and others 1979, p. 318).

In this country, the optimal range of density is defined quantitatively, usually in terms of basal area per unit area. To maximize stand volume in even-aged loblolly pine (*Pinus taeda* L.) stands on good sites, many authors (Chapman 1953, Schultz 1997, Wahlenberg 1960) recommend keeping basal area between 28 m<sup>2</sup>/ha (thinning density) and 18 m<sup>2</sup>/ha (residual density). Lately, stand density index (Reineke 1933) has become popular for specifying the optimal range of density. Dean and Chang (2002) recommend growing loblolly pine between indices of 610 and 390. Doruska and Nolen's (1999) estimates of the range are 560 and 390. Similar values (540 and 390) are used by Williams (1994).

### Thinning to Variable Density

These recommendations would be sufficient for maximizing wood production if we have to maintain the same average stand density over the rotation. But nobody has proved that keeping density at 15 years the same as at 35 years would maximize final and total harvest. It may be possible to increase forest production by varying current density during the lifetime of a stand. Although maintaining a fixed level of average (and residual) density is still a common practice, some forest scientists perceive the advantage of density that increases with age. Already Wiedemann (1937) and later Assmann and Franz (1965) advocated the so called "staggered thinning".

Its advantages are twofold: fast growth at the beginning when density is low and high final yield and income secured by full stocking at the end.

Similar observations were made by Burton (1980, p.22) in the United States. He found that the best sawtimber yield of loblolly pine was produced by "initial heavy thinning from below, on good sides, to a basal area of 70 square feet per acre (16 m<sup>2</sup>/ha) at age 20 and then increasing the residual stand density by 5-square-foot (1.15 m<sup>2</sup>/ha) steps." In practice we do not keep average density constant all the time: To accumulate more volume for final harvest, usually we do not thin stands in the last 5 to 10 years. Instead of keeping a fixed level, during this final period we let density increase.

### PROPOSED SYSTEM

The proposed system develops further the benefit of progressively higher density and brings the idea of variable density to its final form. Although the system has been developed and tested for loblolly pine, it is applicable to even-aged stands of any species.

### A Rule to Maximize Final Yield

For a given site, stand volume in general and final harvest in particular increase with stand density and average tree size. Maximum density maximizes volume growth at a given moment, but it decreases average tree size and, as a result, may not be optimal in the long run. On the other hand, the maximization of the second component of the harvest, average tree size, requires maintaining the lowest density. To minimize the negative side of density (small size) and maximize its positive side (maximum volume of trees with a given size), we need to find an optimal trajectory of density rather than a single optimal value or a range. The trajectory should start with a low density at the beginning of tree life (to increase tree size) and end with a density high enough to assure maximum final harvest or income. This rule for maximizing final yield differs from the views held in the past: Optimal density is not in the middle and not at the highest density; it is at the low extreme at the beginning and at the high density at the end.

### Minimax Strategy

The rule is clear about the initial and harvest densities but not about the intermediate values of the optimal density trajectory. Ideally, density should be minimal until harvest and then jump to the maximum. Since density does not increase instantly, it seems that we have to find some equation describing a gradually increasing trajectory of basal area or stand density index. A simpler description of the optimal trajectory can be cast in terms of the number of trees per unit area—Keep it constant. When the number is constant, stand density increases with age due to diameter growth. The number should be the minimum that assures the density sufficient to maximize yield (or income) by harvest time. At the beginning, the number secures the minimum density and, as a result, the fast diameter growth.

Such a prescription is called the minimum number-maximum yield (minimax) strategy. Albeit unknown in forestry, it is not new. For millennia, farmers have grown only the plants (sometimes after the initial thinning of seedlings) they intend to harvest. In addition to the chief advantage, maximum final volume, this strategy has several other advantages such as saving on planting and thinning. This strategy dealing with

number of trees and their yield is not to be confused with the minimax in game theory, which operates with different concepts.

### **Disadvantages of Minimax**

The minimax strategy may maximize final yield in theory but in practice it would not work as is for the following reasons:

1. Interspecific competition—at the beginning, minimax requires less than 10 percent of land for trees, which provides large savings on tree planting and tending. Yet, this feature is a mixed blessing if the remaining land is left unattended. Competing vegetation, especially hardwoods, would kill most of the pines and reduce the growth of the remaining survivors.
2. Establishment mortality—even well spaced trees suffer mortality, especially during the establishment period. Losing 20 to 30 percent of trees does not have much effect on regular plantations but would hurt those started with a minimum number of trees.
3. The lack of selection—in regular plantations the excessive number of trees allows the forester to select the better ones. Planting the minimal number removes this important method of stand improvement.
4. Poor quality of wood—the initial low stand density would diminish wood quality so that trees could be sold only for pulpwood.

To realize the potential of the minimax strategy and turn it into a practical management system, it is proposed to combine forestry with agriculture and use several silvicultural techniques, including cluster planting and pruning.

### **Diversifying Land Use: Agroforestry**

Instead of struggling with the competing vegetation, we can put to agricultural use the portion of land unutilized by pines until they close their crowns. Thus, minimax leads naturally to diversified land use—agroforestry. It is a natural extension of forestry; optimal forestry is agroforestry. The space between pine rows can be used to grow forage or any crop (wheat, oats, soybeans) that does not compete with trees for light. When trees reach the cow-resistant height (3 to 4 m), grazing can be permitted. Combining the two most common kinds of land management, forestry and agriculture, is attractive for a variety of ecological, economic, and personal reasons. Root systems of established trees are deeper than those of agricultural species. This fact minimizes competition for soil nutrients and moisture, and allows for fuller land utilization. The following benefits of agroforestry are compatible; indeed, they complement each other: (1) for trees—minimal cost of establishment; control of undesirable vegetation; natural and artificial fertilization, which come as byproducts of agricultural use; stand density that maximizes growth of trees (low at the beginning and high at the end); accessibility for pruning and harvesting; reduced damage from ice, root rot, and wildfire; (2) for agricultural crops and cattle—land for cultivation or grazing; shade for animals; wind shelter for cattle and crops. The microclimate of agroforests is favorable to both plants and animals. It is characterized by higher soil moisture, humidity, and night-time carbon dioxide levels and lower evaporation that result in reduced respiration rates; (3) for the land—when tree rows are planted along the contour, erosion is minimized. Cattle manure increases soil fertility and activates many bene-

cial processes that are suppressed in dense forest monocultures. By definition, agroforests have more plant species than either of the components. Reflecting this fact, they are inhabited by a greater number of animals; and (4) for landowners—increased utilization of the land potential and the mutualistic nature of the agricultural and forest uses mean higher income as compared with growing trees and agricultural crops separately. Risk is spread over a number of crops, and cash flow is more stable. While the returns from the forestry component will materialize 20 to 25 years after the planting, the agricultural components will provide most of their returns during the initial period. Agroforestry also fits the human life cycle. As individuals become older, they prefer less strenuous activities such as timber management. If a farmer switches to agroforestry in his middle years, then this transition will occur naturally.

### **Initial Spacing for Density Control**

Minimax avoids thinning altogether (except, the initial cluster thinning) and controls density by planting only the trees to be harvested at the end of rotation. The main advantage of this approach is the maximum income from final harvest. In even-aged stands, this harvest always brings the larger part of the total income. With the declining market for small timber, the part of final harvest approaches the whole 100 percent.

**Cluster planting**—Some of the minimax disadvantages can be corrected by planting trees in clusters rather than singly. Each cluster consists of 4 seedlings planted at the corners of a square with sides of 30 cm. All but one tree per cluster is to be thinned by age 5. Along with other features of the proposed system, cluster planting was tested on an agroforestry study established by our school in Hope, AR, during 1997-1998 (Zeide 1999, 2003). Clusters provide the possibility of selecting better trees, eliminate (or at least drastically reduce) the disruption of stand structure caused by mortality and assure the needed number of crop trees.

### **Pruning**

Traditionally, foresters improved wood quality by keeping high stand density. Unfortunately, such density kills many trees and slows the growth of the rest. Pruning is a better way to improve stem form and wood quality than choking trees with density. Pruning improves wood quality physically by cutting off branches and physiologically by removing the apical meristem (which stimulates the production of juvenile wood) with the limbs and forcing trees to grow taller, which moves the crown apical meristems further from the lower bole. Pruning also makes the pruned portion less tapered, though it increases the size of knots above the pruned area. Two prunings are recommended. The first clears 50 percent of the bole when trees reach the height of about 5.5 m. The second pruning, done when trees are 8.6 m high, clears 60 percent of the bole (one sawlog of 5.2 m).

### **Growth Projection**

In order to predict stand dynamics, a set of models has been developed to describe growth processes (Zeide 1993, 2002, 2004a, 2004b, 2005). The core of these models is a proposition that, for any even-aged stand, three variables (average tree size,  $y$ , age,  $t$ , and current density,  $s$ ) are necessary and sufficient to predict the increment of the size,  $y'$ . These variables are convenient proxies of all growth factors. Size and age stand for two groups of density-independent factors,

those that boost growth and those that impede it. Stand density index represents all density-dependent forces. This proposition is expressed as an equation consisting of three modules driven by the predicting variables:

$$y'(y,s,t) = ky^p e^{-t(g+s/m)} \quad (1)$$

where

$k$  = a measure of site quality for a given species

$p$  = the rate of unrestrained growth

$g$  = the rate of various factors slowing growth, primarily aging

$m$  = the maximum stand density index

Each parameter and the form of the modules are ecologically meaningful. Parameter  $p$  is equal to one third of fractal dimension (sponge dimension) of the average tree and could be measured directly in the field. Parameter  $g$  is a function of  $p$  and the age of the inflection point,  $t_g$ , of a given variable:  $g = -t_g / \ln(1-p)$ . It is related to the natural longevity of a species, that is, the maximum of age. It appears that  $g$  and  $m$  serve to normalize the corresponding variables. At least for diameter, the age of inflection,  $t_g$ , can be measured on a tree cross-section (it is the number of rings from the pith to the largest ring). Another fractal dimension, called the sieve dimension, which is obtained from measuring a two-dimensional projection of tree crown, is the power to which diameter is raised in the stand density index that is used to predict growth (as opposed to mortality). Both dimensions describe the spatial structure of trees, or, more specifically, pattern of foliage distribution, which could be determined instantly. Besides theoretical interest, the link between the spatial and temporal (growth) characteristics (parameter  $p$ ) can expedite time-consuming studies of stand dynamics.

## Data

Model parameters were computed using the data from several sets of permanent plots, including the Monticello thinning and pruning study, which is the longest active and, as far as density is concerned, the most diverse thinning and pruning study of loblolly pine. The 45 plots, currently 48 years old, were measured 11 times and thinned 7 times to the target basal areas of 20.7, 16.1, 11.5, and an unusually low 6.9 m<sup>2</sup>/ha. The variation in stand density was further enhanced by 3 severe ice storms that occurred at ages 16, 21, and 36. The long-term observations of loblolly pine plantations maintained by the Loblolly Pine Growth and Yield Research Cooperative at Virginia Polytechnic Institute and State University were also used in this investigation, specifically for mortality estimations. This set is described in Burkhart and others (1985). The initial

values for modeling were taken from the agroforestry study in Hope. The applicability of the developed models was also tested using data for teak (*Tectonia grandis* L.f.) from Kerala, India, and for Norway spruce [*Picea abies* (L.) Karst.] and European beech (*Fagus sylvatica* L.) from the oldest Bavarian plots that have been remeasured for over 100 years.

## Economic Analysis

Economic analysis of the proposed system is based on the following assumptions: An agroforest is established in an existing pasture, which belongs to the landowner; the initial annual net returns from the portion of land used by agriculture are \$124/ha (Husak and Grado 2002), the portion of land for agricultural use decreases as trees become larger, the interest rate is 6 percent, the stumpage price is \$36 per ton for sawlogs and \$8 for pulpwood, post-establishment mortality and other hazards reduce income by 10 percent, and several others. This information is used to compute the equal annual income, which combines all costs and returns into a single annual sum. It is equivalent to all cash flows spread uniformly over the rotation period. The results of economic analysis show that on poor sites with site indices of less than 17, agroforestry is unprofitable (table 1). Modifications of interest rates and values of pruned sawlogs increase income but do not change the optimal rotation age and number of trees/ha. Income is very sensitive to site quality and on good sites, site index > 20, it doubles sustainable returns as compared with regular forestry or agriculture practiced separately.

The described system makes it possible not only to increase financial returns but to maximize them as a result of the following activities: optimization of stand density throughout the rotation, optimization of rotation period, diversification of land use by growing compatible species, improving quality of merchantable wood by cluster planting and pruning, reduction of expenses on planting and thinning, minimization of root rot, insect infestation, and other risks associated with high density, which would be maintained only during a relatively short period before harvest, and growing sturdy well-spaced trees with symmetrical crowns which would reduce ice damage and other hazards.

## Thinning Returns

Since thinning has been an integral part of forest management, some foresters consider the loss of income from thinning as a serious shortcoming of minimax. This impression seems reasonable. However, economically it makes little sense because benefits of a faster growth rate and agricultural income outweigh the financial gain from thinning. To settle

**Table 1—Characteristics of agroforests at the age of maximum returns (equal annual income), by site index (base age is 25 years). N is number of trees/ha at that age, D is average tree diameter in cms, weights are in ton/ha, and income is in \$/ha**

Site index	Age	N	D	Weight				Returns			Equal annual income		
				Top	Pulp	Sawlog	Total	Pulp	Sawlog	Total	Field	Stand	Total
15	33	173	29.5	0.5	15	91	107	119	3,610	3,731	87	19	106
17	29	247	30.5	0.8	17	154	172	135	6,121	6,254	78	55	132
18	27	346	30.5	1.1	23	235	259	184	9,318	9,503	66	104	170
20	25	420	30.5	1.3	29	295	325	233	11,671	11,903	60	158	218
21	23	445	30.7	1.4	28	331	361	228	13,106	13,334	58	214	272

this question, the model incorporating the equations and assumptions described above was run for site index 20.4 (base age is 25 years), which is the actual average index of the Monticello plots. Without thinning, maximum annual income/ha of \$237 can be obtained by planting 400 trees and harvesting them at age 24.

If at the age of 15 half of these trees are thinned and sold as pulpwood while the remaining 200 trees are grown for sawlogs, maximum income at age 25 drops to \$170. This number, however, underestimates the income, because when half of the trees are thinned, the optimal planting number is 700 and not 400 trees/ha. Running the model for this number, half of which is thinned for pulpwood and the rest kept until 26 years, raises the income to the maximum of \$177, which is 25 percent smaller than the minimax returns of \$237. These calculations show empirically that thinning does not pay, and that the best strategy is to grow, after the initial thinning of clusters, only the trees intended for final harvest.

## DISCUSSION

After centuries of striving to maximize forest productivity, we have arrived at the original recommendation regarding thinning: Do not thin forest stands. This does not mean that we are just walking in circles; many other things have changed. Some of these changes are summarized in table 2.

### Respect of Nature Rather than Worship

Progress in thinning and planting has been achieved since we stopped imitating the growth of undisturbed stands. In forestry, the reverence of nature has been misplaced and counterproductive, because it neglected our knowledge and ability to improve growth on a sustainable basis. Our planes fly like birds and even better, but they do not flap their wings. Similarly, our way to grow trees need not copy what is going on in the wild. Because we care for trees, they grow and survive much better than those tended by nature, which cares for many other creatures that kill the trees we plant. The rejection of the “aping” of nature does not mean that our work destroys the natural potential and diversity (Zeide 2001). Agroforests are definitely more diverse and productive than natural monocultures of pine or soybeans.

**Table 2—Evolution of silvicultural thinning. The arrow indicates a gradual transition from high to low numbers of trees planted per hectare**

Period	Conceptual development	Technical implementations	
		Thinning intensity	Planted number
Prior 1795	Thinning decreases growth and volume	No thinning	> 20,000
1795-1911		Light	
1911-1932	Thinning increases growth and volume	Medium-heavy	
1932-present	Thinning redistributes growth	Medium-heavy	
1937-present		Decreasing	
2005-	Initial spacing as density control	No thinning	250-450

## What Is Ahead?

Could the exposed trends shed some light on the future development of forestry? One thing we can learn is that not all trends are continuous. Some drastic changes could occur. The second lesson is that our method is to actively modify growth processes and conditions, rather than to copy those of undisturbed forests. Third is that, while many things have changed, some remain constant. One of these is the tug of war between quantity and quality of wood. The history of forestry can be presented as various tradeoffs between these opposing characteristics.

This dilemma between quantity and quality of wood may be resolved soon. We used to think that the abundance of light was good for quantity but bad for quality of wood. If so, the conflict is unavoidable. Actually, the situation is more promising. Over 50 years ago, it was discovered that, as far as trees are concerned, what we call light consists of two distinct components—energy to grow and the signal to modify the shape. The signal, which is the ratio of the radiation intensity in the red part of the spectrum (wavelengths between 650 and 680 nm) to that in the far-red (between 710 and 740 nm), shortens trees and plants in general (Smith 2000) and makes them branchy. Natural shading connects these components so that deficiency of energy comes together with improved tree form. But genetic engineering is capable of decoupling this connection. Disabling the receptors of the signal (phytochromes) removes the inhibition of stem elongation, decreases allocation of photosynthates to seed production, and enhances apical dominance (Smith 2000). In other words, we can get trees growing faster than open-grown trees but as slender as forest trees. Although a dream today, this possibility could transform the forestry of tomorrow as nothing before.

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## LITERATURE CITED

- Assmann, E.; Franz, F. 1965. Vorläufige Fichten-Ertragstafel für Bayern. *Forstwissenschaftliches Centralblatt*. 84. Jg., H. 1:13-43.
- Burkhart, H.E.; Cloeren, D.C.; Amateis, R.L. 1985. Yield relationships in unthinned loblolly pine plantations on cutover, site-prepared lands. *Southern Journal of Applied Forestry*. 9(2): 84-91.
- Burton, J.D. 1980. Growth and yield in managed natural stands of loblolly and shortleaf pine in the West Gulf Coastal Plain. Res. Paper SO-159. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 23 p.
- Chapman, H.H. 1953. Effects of thinning on yields of forest-grown longleaf and loblolly pines at Urania, LA. *Journal of Forestry*. 51(1):16-26.
- Daniel, T.W.; Helms, J.A.; Baker, F.S. 1979. Principles of silviculture. 2<sup>nd</sup> ed. New York: McGraw-Hill Book Co. 500 p.
- Dean T.J.; Chang, S.J. 2002. Using simple marginal analysis and density management diagrams for prescribing density management. *Southern Journal of Applied Forestry*. 26(2): 85-92.

- Doruska, P.F.; Nolen, W.R. 1999. Use of stand density index to schedule thinnings in loblolly pine plantations: a spreadsheet approach. *Southern Journal of Applied Forestry*. 23(1): 21-29.
- Fernow, B.E. 1913. A brief history of forestry. 3<sup>rd</sup> revised ed. Toronto: University Press. 506 p.
- Hartig, G.L. 1795. Anweisung zu Taxation der Forsten oder zur Bestimmung des Holzertrags der Wälder, In Kommission bei Buchhändler Heyer, Gießen. 200 p.
- Husak, A.L.; Grado, S.C. 2002. Monetary benefits in a southern silvopastoral system. *Southern Journal of Applied Forestry*. 26(3): 159-164.
- Kostler, J. 1956. *Silviculture*. Edinburgh: Oliver and Boyd. 416 p.
- Li, T.T. 1923. Do thinnings actually increase growth per acre as compared to unthinned stands? *Journal of Forestry*. 21: 125-128.
- Mar:Moller, C. 1954. The influence of thinning on volume increment. I. Results of investigations. In: Mar:Moller, C.; Abell, J.; Jagd, T.; Juncker, F., eds. *Thinning problems and practices in Denmark*. Technical Publication 76. Syracuse, Ny: State University of New York, College of Forestry at Syracuse: 5-32.
- Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. *Journal of Agricultural Research*. 46(7): 627-638.
- Savill, P.; Evans, J.; Auclair, D.; Falck, J. 1997. *Plantation silviculture in Europe*. Oxford: Oxford University Press. 297 p.
- Schultz, R.P. 1997. *Loblolly pine*. Agric. Handb. 713. Washington, D.C.: U.S. Department of Agriculture, Forest Service.
- Schwappach, A.F. 1911. *Die Rotbuche*. J. Neumann, Neudamm. 231 p.
- Smith H. 2000. Phytochromes and light signal perception by plants— an emerging synthesis. *Nature*. 407: 585-591.
- Spurr, S.H.; Barnes, B.V. 1980. *Forest ecology*. 3<sup>rd</sup> ed. New York: Wiley. 687 p.
- Wahlenberg, W.G. 1960. *Loblolly pine*. Raleigh, NC: Duke University, The School of Forestry. 603 p.
- Wiedemann, E. 1932. *Die Rotbuche 1931*. Mitteilungen aus Forstwirtschaft und Forstwissenschaft. Hanover: Verlag M. u. H. Schaper. 191 p.
- Wiedemann, E. 1937: *Die Fichte 1936*, Hanover: Verlag M. & H. Schaper. 248 p.
- Williams, R.A. 1994. Stand density management diagram for loblolly pine plantations in north Louisiana. *Southern Journal of Applied Forestry*. 18 (1): 40-45.
- Zeide, B. 1993. Analysis of growth equations. *Forest Science*. 39: 591-616.
- Zeide, B. 1999. Long-term study of agroforestry systems based on structured tree clusters. In: Kleinn, C; Kohl, M., eds. *Long term observations and experiments in forestry*. Proceedings of IUFRO S4.11 international symposium. Costa Rica: CATIE: 176-186.
- Zeide, B. 2001. Resolving contradictions in forestry: back to science. *Forestry Chronicle*. 77(6): 973-981.
- Zeide, B. 2002. Density and the growth of even-aged stands. *Forest Science*. 48:743-754.
- Zeide, B. 2003. Evolution of agroforestry: From uniformity to diversity. In: Clason, t.r., ed. *Land-use management for the future*. Proceedings of the 6<sup>th</sup> North American agroforestry conference. Columbia, MO: Association for Temperate Agroforestry: 227-234.
- Zeide, B. 2004a. Optimal stand density: a solution. *Canadian Journal of Forest Research*. 34: 846-854.
- Zeide, B. 2004b. Intrinsic units in growth modeling. *Ecological Modeling*. 175: 249-259.
- Zeide, B. 2005. How to measure stand density. *Tree - Structure and Function* 19(1):1-14.

# ADJUSTING SLASH PINE GROWTH AND YIELD FOR SILVICULTURAL TREATMENTS

Stephen R. Logan and Barry D. Shiver<sup>1</sup>

**Abstract**—With intensive silvicultural treatments such as fertilization and competition control now commonplace in today's slash pine (*Pinus elliottii* Engelm.) plantations, a method to adjust current growth and yield models is required to accurately account for yield increases due to these practices. Some commonly used ad-hoc methods, such as raising site index, have been found to inadequately account for yield responses seen in designed studies. Based on data from a Plantation Management Research Cooperative (PMRC) slash pine site preparation study, a PMRC slash pine improved planting stock – vegetation control study, and a PMRC slash pine mid-rotation release study, two model forms have been fit to account for fertilization, competition control, bedding, and mid-rotation release. These models are used to adjust current dominant height and basal area equations for the various treatments. The model forms, different treatment response patterns, and magnitude of each treatment response are presented.

## INTRODUCTION

Silvicultural treatment options have grown tremendously over the last 25 years. After the loss of 2-4,5 -T in the late 1970s, several new herbicides were labeled for forestry use. The result was chemistry that was previously unavailable is now usable for control competing vegetation at site preparation, for woody release, and for herbaceous weed control. Research over the same time period documented that large yield increases were possible when vegetation control was used on research plots. Forest nutrition work on slash pine at the University of Florida and on loblolly pine at North Carolina State University also documented the high probability of yield gains in plantations from nutritional supplements. Again, most of the empirical information came from research plots, not from operational stands. Regardless, operational fertilization grew to more than 1,000,000 acres in the Southeast by the year 2000.

A problem with both vegetation control and forest fertilization is that the available yield models have not typically handled the amount and timing of the silvicultural response so that financial analyses of the investment could be reliably conducted. Whether it is nutritional amendments or the control of competing vegetation, the change in stand growth must be analyzed to determine if the treatment is financially positive. This paper presents an accurate method to account for these silvicultural treatments that is not overly complex so all forest managers can make sound decisions when faced with these situations.

## SILVICULTURAL ADJUSTMENT METHODS

Various methods of accounting for the effects of silvicultural treatments on pine growth and yield have been explored over the years. One of the most rudimentary of these methods is the adjustment of site index. Although generally inaccurate, this method is commonly used today in at least two variations by forest managers. The first variation simply involves increasing site index by the amount equal to the expected dominant height gains from the silvicultural treatment. An example would be increasing base age 25 site index from 62 feet to 66 feet because the forest manager estimates that a fertilization

treatment will result in an increase in dominant height at age 25 of 4 feet. Although this seems like a logical method of accounting for a treatment, this assumes that a treatment will cause an anamorphic change to the dominant height growth curve. Based on the current study, this is an inaccurate assumption. This method of adjustment also ignores the fact that many treatments increase diameter growth, and therefore yield, more than the increase in site index estimates.

The second variation of this method has been used in an attempt to more accurately model the effects of the silvicultural treatments on volume growth, not just height growth. In this method, users adjust site index to whatever value is needed to increase volume by some expected amount for a chosen time period. An example of this method would be adjusting site index to cause an increase in volume of 9.6 tons after 8 years. The 9.6 tons is based on the assumption that a treatment will cause an average increase of 1.2 tons per year over an 8 year period. Although this method does make an attempt to more directly quantify the effects of silvicultural treatments on volume, it still makes the assumption that all treatments will cause an anamorphic change in tree growth. This method generally results in large over-predictions in weight or volume at rotation age when used to model site preparation treatments.

Newer methods of accounting for silvicultural treatments involve using flexible mathematical equations as additive response terms to the current pine growth and yield models. Two such equations are presented in this paper.

## DATA

Three PMRC studies were used to examine the effects of vegetation control and fertilization treatments on the growth and yield of slash pine plantations. All study installations were located in the flatwoods region of the lower Coastal Plain throughout southern Georgia and northern Florida.

### Slash Pine Site Preparation Study

The slash pine site preparation study was established in 1979 at 20 locations. The 20 locations were originally stratified

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<sup>1</sup> Research Coordinator and Professor, respectively, University of Georgia, Daniel B. Warnell School of Forest Resources, Athens, GA 30602.

equally over 4 soil groups: poorly drained nonspodosol, somewhat poorly to moderately well drained nonspodosol, poorly to moderately well-drained spodosol with an underlying argillic horizon, and poorly- to moderately well-drained spodosol without an underlying argillic horizon. Half acre treatment plots, with a maximum site index variance of 5 feet, were installed at each site. Average site index across installations ranged from 54 to 80 feet. The following 11 treatments were applied at each location:

1. Control (harvest and plant, no site preparation) CNTL
2. Chop (single pass with a rolling drum chopper) UCHP
3. Chop, fertilize FCHP
4. Chop, burn (chop followed by a broadcast burn) UCHB
5. Chop, burn, fertilize FCHB
6. Chop, burn, bed (treatment 4 followed by a double-pass bed) UCBB
7. Chop, burn, bed, fertilize FCBB
8. Chop, burn, herbicide (treatment 4 followed by complete vegetation control) UCBH
9. Chop, burn, herbicide, fertilize FCBH
10. Chop, burn, bed, herbicide (treatment 6 followed by complete vegetation control) UBHB
11. Chop, burn, bed, herbicide, fertilize FBHB.

Fertilizer was applied to the selected treatment plots after the 1<sup>st</sup>, 12<sup>th</sup>, and 17<sup>th</sup> growing seasons. Height and diameter measurements were made at ages 2, 5, 8, 11, 14, 17, 20, and 23. Due to the design of the study, it is possible to isolate the effect of treatments. For example, the difference in yield between treatment 8 (UCBH) and treatment 4 (UCHB) is due to the addition of vegetation control.

### Slash Pine Improved Planting Stock - Vegetation Control Study

The slash pine improved planting stock – vegetation control study was established in the planting seasons of 1986 and 1987 at a total of 19 locations. Six top-ranked genetically improved seed families were selected by PMRC cooperators for inclusion in the study. Unimproved seed was obtained from the same region encompassed by the study. Bulk lot improved seed stock was obtained by mixing equal amounts of the six selected seed families. The following six treatments were included at each installation:

1. Unimproved stock, no vegetation control (UNC)
2. Unimproved stock, complete vegetation control (UCC)
3. Bulk lot improved stock, no vegetation control (BNC)
4. Bulk lot improved stock, complete vegetation control (BCC)
5. Single family improved stock, no vegetation control (SNC)
6. Single family improved stock, complete vegetation control (SCC).

One single family was randomly assigned to each installation, so on average each single family was planted at three installations. The two levels of vegetation control were either no control or complete control of all competing vegetation. Complete vegetation control was obtained by killing woody vegetation with prescribed herbicides prior to planting, by

spraying sulfometuron methyl in early spring in each of the first three growing seasons, and by directed application of glyphosate and triclopyr as needed during the growing season. Height and diameter measurements were made at ages 3, 6, 9, 12, and 15. Again, the design of the study allows for estimation of the effects of vegetation control. The difference between UNC and UCC, the difference between BNC and BCC, and the difference between SNC and SCC all estimate the influence of vegetation control. The design also allows for a test of the interaction of vegetation control and level of genetic improvement. That interaction was not significant so the vegetation control effect was estimated using all three comparisons.

### Slash Pine Midrotation Release Study

The slash pine midrotation release study was established in 1976 at 36 locations. Paired permanent plots were installed in existing 9- to 15-year-old slash pine plantations with considerable competing vegetation and at least 400 evenly spaced trees per acre. Plots were carefully located to match closely on numbers of trees per acre, site index, and basal area per acre before treatment. No vegetation control was performed on the control portion of the paired plots. All competing vegetation was cut at ground level and left on site on the treatment portion of the paired plots. Severed stems were retreated with herbicide soon after resprouting and periodic competition control was performed as needed. On this study, the vegetation control response was estimated as the difference between the yields on the paired plots.

### TREATMENT RESPONSE PATTERNS

Four general response patterns (fig. 1) to silvicultural treatments have been identified, types A, B, C and D (Hughes and others 1979, Morris and Lowery 1988, NCSFNC 1995). Type A responses occur when growth gains on treated stands continue to increase throughout the rotation. This type of response is commonly associated with anamorphic increases in height growth. Type B responses occur when growth gains achieved early during the response period are maintained but do not increase after an initial response period. Type C responses occur when the early growth gains are subsequently lost and eventually converge with the untreated stand.

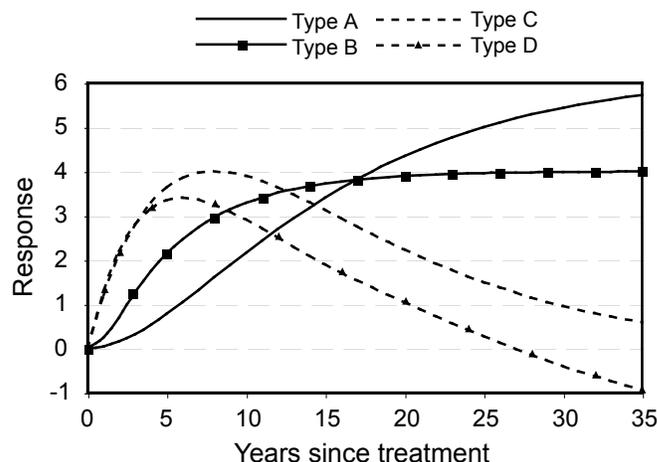


Figure 1—Four general silvicultural response patterns.

Type D responses are similar to type C response except that the treated stand actually falls below the level of the untreated stand.

## MODEL DEVELOPMENT

Based on the treatments examined in this study, two response patterns (Type B and C) were observed and modeled.

### Type C Response

Pienaar and Rheney (1995) described a flexible equation form to model a type C response:

$$R = b_1 (Y_{st}) e^{-b_2(Y_{st})} \quad (1)$$

where

R = treatment response,

$b_1, b_2$  = parameters that define the response curve, and

$Y_{st}$  = year since treatment.

The maximum response occurs ( $1/b_2$ ) years after the treatment, and the magnitude of the maximum response is defined by  $(b_1/b_2)e^{-1}$ . Based on this, the parameters can be defined empirically as:

$$b_2 = 1/(Y_{st})_{\max}$$

$$b_1 = R_{\max} \cdot b_2 \cdot e^{(1)}$$

where

$(Y_{st})_{\max}$  = years until maximum treatment response

$R_{\max}$  = maximum treatment response.

### Type B Response

The type B response can be modeled by the following equation (Personal communication. 2004. Leon Pienaar, Professor (retired), 525 Pine Forest, Athens, GA 31029):

$$R = R_{\max} (1 - e^{-b \cdot Y_{st}}) \quad (2)$$

where

all variables are as defined previously. The user will provide treatment age, the maximum expected treatment response, and the years until 90 percent of the maximum treatment response occurs so that:

$$b = \frac{-\ln(1 - .9)}{Y_{st(.9\max)}}$$

where

$Y_{st(.9\max)}$  = years until 90 percent of the maximum treatment response occurs.

## MODEL USE

The previous models are used as an additive term to current "base" models. General use includes calculating dominant height with the current model and using the appropriate response model to calculate the treatment response at a given age. This dominant height response is added to the calculated dominant height, which is put into the "base" basal area model. Depending on the treatment, an additional basal area response may be warranted. If needed, the appropriate basal area response model is used to calculate an additional basal area treatment response that is added to the calculated basal area. The adjusted dominant height and basal area are

then used in the whole stand volume or weight equation to calculate an estimate of volume or weight after treatment.

Based on data from the previously mentioned designed studies, it was determined that low sites generally respond more to silvicultural treatments than high sites. To account for this, maximum responses for site index (base age 25) 50 and 80 are presented. Simple linear interpolation can be used to calculate a maximum treatment response for a given site. Also, since spodosol soils were observed to respond more to silvicultural treatments than nonspodosol soils, separate responses are presented.

When modeling multiple treatments at the same time or repeated treatments over time, it is not uncommon to see less than additive responses from the multiple treatments. An example is when modeling a silvicultural treatment that includes a combination of fertilization and vegetation control. On spodosol soils, the benefits of each treatment are not additive and can be accounted for by using only the dominant height gains associated with fertilization and vegetation control. On nonspodosol soils, the effect of both treatments are additive. In cases where multiple fertilizations are being modeled, the full benefit of the repeated fertilizations is not realized. To account for this, we used 75 percent of the maximum response from the first fertilization for subsequent fertilization treatments.

## Response Values

Response type, maximum response, and years until maximum response (or years until 90 percent of maximum response for type B responses) are presented in table 1 for 4 treatments as estimated from 3 studies.

## Model Usage Example

Assume we have a slash pine stand with a base age 25 site index of 62 on nonspodosol soils. We plan on fertilizing the stand at ages 5 and 15 and want to know the response we can expect from the repeated fertilization treatments. Based on the data in the response table, we will use a type B dominant height response and a type C basal area response. The maximum dominant height response from the first fertilization can be calculated as 1.1 feet by use of linear interpolation. The table indicates this will occur 8 years after treatment. The maximum dominant height response from the second fertilization will be 75 percent of the maximum response from the first fertilization, or 0.83 feet. The maximum basal area response is calculated in the same manner. We expect a maximum basal area response of 2.2 square feet from the first fertilization and a maximum basal area response of 1.65 square feet, or 75 percent of the response from the first fertilization, from the second fertilization. These basal area responses are in addition to the basal area response obtained from the height response. This will occur 10 years after the fertilization treatments. Based on this information we can calculate the fertilization treatment response at any age, as below for ages 8 and 20.

The dominant height response at age 8 is calculated as:

$$b = \frac{-\ln(1 - .9)}{Y_{st(.9\max)}} = \frac{-\ln(.1)}{8} = 0.2878$$

$$R = R_{\max} (1 - e^{-b \cdot Y_{st}}) = 1.1(1 - e^{-.2878 \cdot 8}) = 0.64 \text{ ft.}$$

**Table 1—Dominant height (feet) and basal area (square feet per acre) response types and values for slash pine**

Treatment	Nonspodosol			Spodosol		
	Response type	SI=50 response	SI=80 response	SI=50 response	SI=80 response	Years to max response
<b>Dominant height</b>						
Bedding	C	3.0	1.0	4.5	2.5	8.0
Veg. control	B	6.0	3.0	8.0	4.0	12.0
Fertilization	B	1.5	0.5	3.0	2.0	8.0
Release	B	2.0	1.0	2.0	1.0	10.0
<b>Basal area</b>						
Bedding	C	4.0	3.0	4.0	3.0	5.0
Veg. control	B	0.0	0.0	6.0	6.0	12.0
Fertilization	C	3.0	1.0	3.0	1.0	10.0
Release	B	6.0	6.0	6.0	6.0	10.0

To calculate the dominant height response at age 20 the response from both the first and second fertilizations must be calculated as follows:

$$R_{fert1} = R_{max} (1 - e^{-b \cdot Y_{st}}) = 1.1(1 - e^{-2878 \cdot 15}) = 1.09 \text{ ft.}$$

$$R_{fert2} = R_{max} (1 - e^{-b \cdot Y_{st}}) = 0.83(1 - e^{-2878 \cdot 5}) = 0.63 \text{ ft.}$$

The total dominant height response at age 20 from the fertilization treatments is 1.72 feet. Dominant height response over time can be seen in figure 2.

The basal area response at age 8 is calculated as:

$$b_2 = 1 / (Y_{st})_{max} = 1 / 10 = 0.1$$

$$b_1 = R_{max} \cdot b_2 \cdot e^{(1)} = 2.2 \cdot 0.1 \cdot e^{(1)} = 0.598$$

$$R = b_1 (Y_{st}) e^{-b_2(Y_{st})} = 0.598(3) e^{-0.1(3)} = 1.329 \text{ ft.}^2$$

To calculate the basal area response at age 20, the  $b_1$  coefficient must be recalculated because it is a function of the maximum response of the second fertilization. The  $b_2$  coefficient remains the same.

$$b_1 = R_{max} \cdot b_2 \cdot e^{(1)} = 1.65 \cdot 0.1 \cdot e^{(1)} = 0.4485$$

$$R_{fert1} = b_1 (Y_{st}) e^{-b_2(Y_{st})} = 0.598(15) e^{-0.1(15)} = 2.00 \text{ ft.}^2$$

$$R_{fert2} = b_1 (Y_{st}) e^{-b_2(Y_{st})} = 0.4485(5) e^{-0.1(5)} = 1.36 \text{ ft.}^2$$

The total basal area response at age 20 from the fertilization treatments is 3.36 square feet. Basal area response over time can be seen in figure 3. Note that the majority of the basal area response results from the increase in dominant height from the repeated fertilizations. The resulting increase in green weight can be seen in figure 4. The green weight growth curves of the treated and untreated stands can be seen in figure 5.

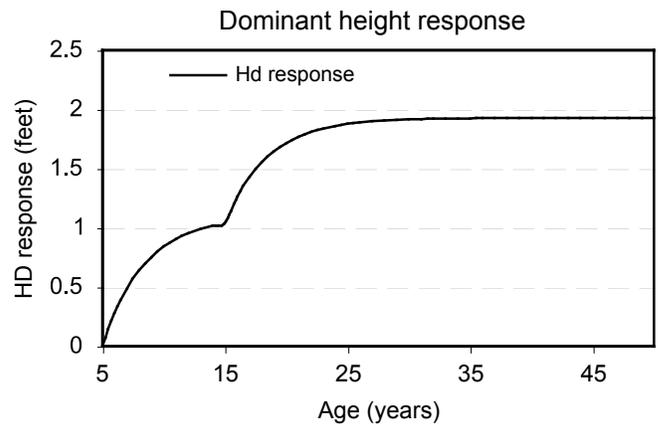


Figure 2—Expected dominant height (feet) response over time for two fertilization treatments on a slash pine stand.

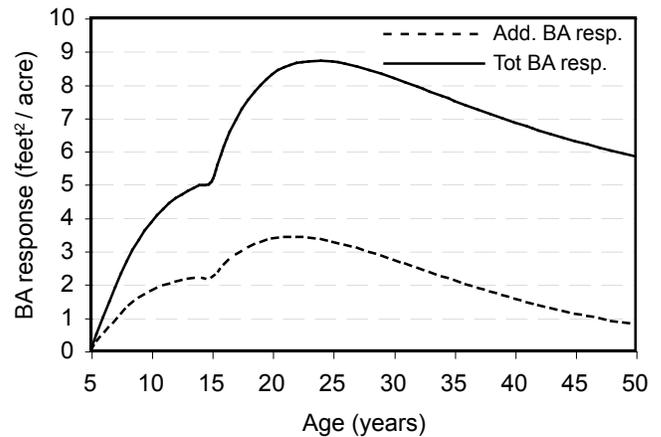


Figure 3—Expected basal area response (square feet per acre) in addition to basal area response from dominant height increase and total basal area response over time for two fertilization treatments on a slash pine stand.

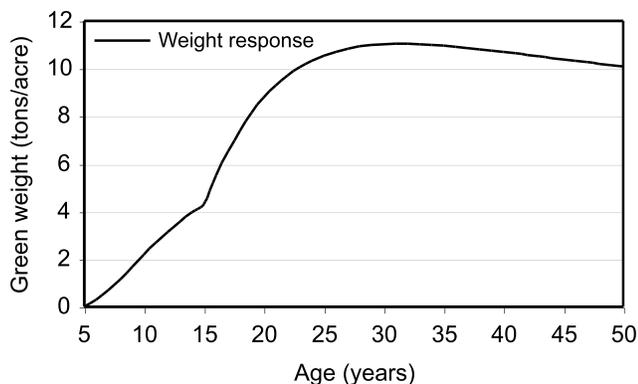


Figure 4—Expected green weight (OB) response (tons per acre) over time for two fertilization treatments on a slash pine stand.

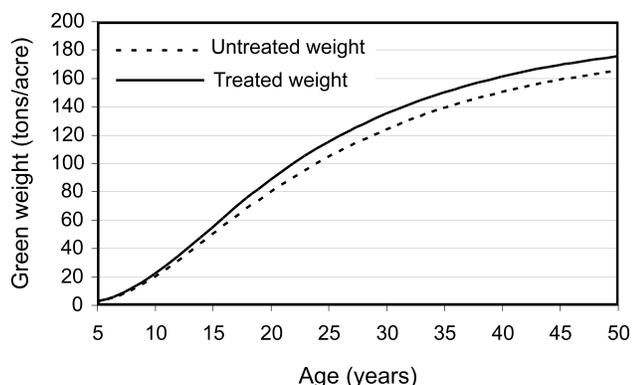


Figure 5—Green weight (OB) growth (tons per acre) over time for a twice fertilized and an unfertilized slash pine stand.

## CONCLUSIONS

The presented models give forest managers a flexible tool for modeling silvicultural treatments on planted slash pine stands. These response values are based on results from designed studies and are good average values for most stands. If a forest manager feels that these responses are not accurate for a particular stand, different response values can be used to reparameterize these equations. Caution should be used when adjusting response values and final volume or weight responses should be scrutinized to ensure reasonable growth responses.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Hughes, J.H.; Campbell, R.G.; Duzan, H.W.; Dudley, C.S. 1979. Site index adjustments for intensive forest management treatments at North Carolina. Forestry Research Technical Report. New Bern, NC: Weyerhaeuser Co. 12 p.
- Morris, L.A.; Lowery, R.F. 1998. Influence of site preparation on soil conditions affecting stand establishment and tree growth. *Southern Journal of Applied Forestry*. 12: 170-178.
- NCSFNC. 1995. Effects of harvest utilization, site preparation and vegetation control on growth of loblolly pine on a Piedmont site. North Carolina State Forest Nutrition Cooperative. Research Note Number 11. Raleigh, NC: North Carolina State University, Department of Forestry. 28 p.
- Pienaar, L.V.; Rhoney, J.W. 1995. Modeling stand level growth and yield response to silvicultural treatments. *Southern Journal of Applied Forestry*. 41: 629-638.

# THE STATISTICAL REASON WHY SOME RESEARCHERS SAY SOME SILVICULTURAL TREATMENTS “WASH-OUT” OVER TIME

David B. South and Curtis L. VanderSchaaf<sup>1</sup>

**Abstract**—The initial effects of a silvicultural treatment on height or volume growth sometimes decline over time, and the early gains eventually disappear with very long rotations. However, in some reports initial gains are maintained until harvest but due to statistical analyses, a researcher might conclude the treatment effect has “washed-out” by ages 10 to 18 years (even when the gain is 6 green tons per acre or more). This claim is sometimes made even when the volume gains have increased over time. Researchers who end up making Type II statistical errors do so because of the inherent variability which increases with stand age (i.e., statistical power declines over time). To avoid making Type II errors, some researchers have decided to model their data instead of applying statistics to a data set that has low power.

## INTRODUCTION

“In the past, the emphasis of statistics in forestry, and other applied fields, has been on an assessment of statistical significance, or the probability that the null hypothesis will be rejected when it is true (i.e., the probability of committing a ‘Type I error’). However, there is growing awareness (e.g., see Peterman 1990a, 1990b; Toft and Shea 1983) that researchers should also be concerned with the possibility that statistical methods may fail to reject a false null hypothesis (i.e., a ‘Type II error’ might be committed). The statistical theory and methods by which this important issue can be examined are referred to as ‘power analysis’ (Nemec 1991)”. Power is the probability of getting a statistically significant response when a real treatment difference exists. In some cases, a lack of power explains why some researchers say a treatment will “wash-out” over time.

Sometimes landowners are told that certain silvicultural treatments are not worth pursuing since they will “wash-out” over time. We have discovered there are two definitions for the phrase wash-out (fig. 1). Definition No. 1 states that a wash-out occurs when: the absolute treatment response declines over time and, prior to harvest, the treated stand ends up with the same overall stand characteristics as the untreated stand. As a result, there are no absolute differences in stand volume between the untreated and treated plots. The second definition states that a wash-out occurs when there is an absolute gain, but the difference between treatment means is not statistically significant. As a result, some researchers say a treatment has washed-out even when field foresters realize there is a substantial economic difference in volume (e.g., 5 green tons per acre or more). When the gain is indeed a result of the treatment, then a Type II error occurs if the researcher claims the treatment effect has disappeared or has washed-out.

Several researchers have said treatment differences “disappeared” as the stand aged even though the absolute differences were substantial. For example, in 10 loblolly pine studies, the absolute volume gain from applying herbicides increased over a 3-year interval from 45 to 84 cubic feet per acre. Even so, the researchers concluded that “early growth responses declined between ages 5 and 8 years...” In another

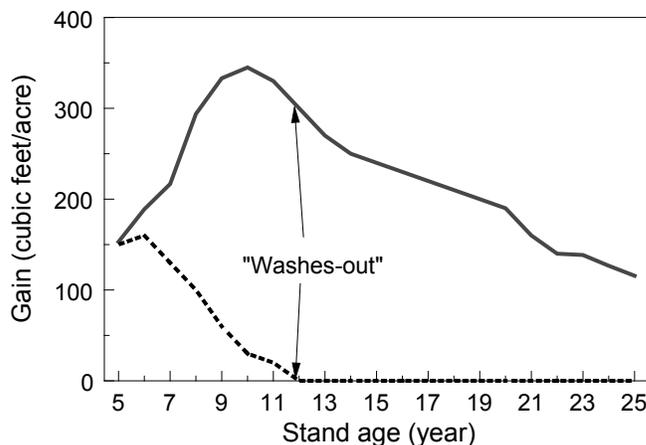


Figure 1—The effect of stand age on volume gain due to two silvicultural treatments. In one case (dashed line), a field forester says the treatment “washes-out” at age 12 years when there is no absolute difference in stand volume between treatments. In the second case (solid line), a field forester says there is a gain in volume, but the researcher says the treatment “washes-out” when the difference in volumes is no longer statistically significant ( $\alpha = 0.05$ ). In this case, the difference between treatments at 15 years is equal to 240 cubic feet per acre.

article, the statement was made that treatment “differences had disappeared upon re-examination at age 31.” However, the power of the statistical test at age 31 years was so low that it could not detect a 21 percent increase in merchantable volume as significant ( $\alpha = 0.05$ ). This difference was equal to an increase of 270 cubic feet per acre (or approximately a 5-year advance in stand development). If this experimental design could not detect a 5-year gain as statistically significant, we wonder at what stand age would a researcher be unable to declare a 1- or 3-year gain as statistically significant?

To address this question, we conducted a-priori power tests in preparation for a “year of planting” study. The objective was to determine at what stand ages a Type II error would occur. We could identify a “true” Type II error since the null hypothesis (i.e., there is no effect of planting date on stand growth) in our case was always wrong.

<sup>1</sup> Professor, School of Forestry and Wildlife Sciences and Alabama Agricultural Experiment Station, Auburn University, Auburn, AL 36849-5418; and Graduate Student, Virginia Polytechnic Institute and State University, Department of Forestry, Blacksburg, VA 24061, respectively.

## METHODS

Data were obtained from a spacing study established by the Virginia Polytechnic Institute and State University Loblolly Pine Growth and Yield Research Cooperative. The site was located on an Upper Atlantic Coastal Plain site near Roanoke Rapids, NC (Zhang and others 1996). Treatment plots were replicated three times. A spacing of 8 feet by 12 feet was selected for the untreated control. For the ages used in this paper, data from this site has had little or no impacts from windthrow, hurricanes, ice storms, beetles, etc. Thus, all variation for a particular dependent variable among replications was due to growth variation among planted trees, measurement error, and environmental variation. The variance values exhibited by these plots are reasonable approximations of the error that would be expected in non-damaged loblolly pine plantations in this region.

Four stand-level variables were examined: quadratic mean diameter (QMD), average height, basal area per acre, and total cubic foot volume per acre. Individual tree diameter at breast height (d.b.h.) was measured on all trees within a replication for stand ages of 5 to 21; total tree height (Ht) was measured annually from ages 2 to 10 and then every other year from 10 to 20 years. Individual tree total stem cubic-foot volume (stump to tip, outside-bark) was estimated using an equation developed by Tasissa and others (1997):

$$\text{cubic feet} = 0.21949 + 0.00238 \text{dbh}^2 \text{Ht} \quad (1)$$

where

cubic feet = total cubic foot volume (outside-bark) per tree.

Since d.b.h. and height are independent variables in equation (1), volume was estimated from actual data only for the ages that are common between the two predictors (e.g., ages 2 to 10, 12, 14, 16, 18, 20).

Stand-level values were obtained for each of the three replications by appropriate expansion factors. For ages 11, 13, 15, 17, and 19, stand-level average height and total cubic foot volume were interpolated. For plantation ages of 21 to 28, Chapman-Richards equations (Richards 1959) were developed separately for each of the three replications to estimate stand-level average height and total cubic foot volume (adjusted R<sup>2</sup>s ranged from 0.9920 to 0.9985). For QMD and basal area per acre, Chapman-Richards equations were developed by replication to estimate yield for ages 22 to 28 (adjusted R<sup>2</sup>s ranged from 0.9903 to 0.9977). Estimates were checked to insure that they reasonably extrapolated beyond the range of the actual data.

For each age, we calculated the mean and standard deviation of the three replications for each of the four stand-level variables. Three potential age-shifts were then calculated; a 1-year age shift in stand development, a 2-year age shift, and a 3-year age shift. In our study, a 1-year age shift (i.e., treated mean) was equivalent to planting seedlings 1 year earlier than seedlings in the control plots (i.e., untreated mean).

Two-sided, two-sample independent t-tests were conducted (given age constraints of the dataset for a particular variable as described above) to test for significant differences due to the age-shifts. Two  $\alpha$  levels were used:  $\alpha = 0.05$  and  $\alpha = 0.10$ . The power of all tests conducted was then found using a formula provided by Kirk (1995):

$$d(n-1) \text{square root}(2n) \quad (2)$$

$$2(n-1) + 1.21(z_a - 1.06) \quad (3)$$

$$[\text{equation (2)/equation (3)}] - z_a \quad (4)$$

where

$d$  = [treated mean – untreated mean]/standard deviation,

$n$  = number of replications per treatment,

$z_a$  = z-score for a particular two-sided  $\alpha$  level (either 1.96 for  $\alpha = 0.05$  or 1.645 for  $\alpha = 0.10$ ), and 1.06 and 1.21 are constants regardless of  $n$  or the desired  $\alpha$  level

## RESULTS AND DISCUSSION

The effect of “planting year” on height growth of loblolly pine is illustrated in figure 2. Planting year is equivalent to what some researchers call an “age-shift” (VanderSchaaf and South 2004). A 2-year age-shift in stand development can be thought of as planting a site 2 years earlier than the control. Although we know these hypothetical stands were planted in different years, after year 17 there were no statistically significant differences ( $\alpha = 0.05$ ) in height (fig. 2), volume (fig. 3), or basal area (fig. 4). In contrast, differences in quadratic mean d.b.h. could still be detected at age 22 years (fig. 5). However, after age 26 years, there no longer was a significant difference (even when there was a 3-year age difference). Overall, Type II errors started to occur from ages 9 to 14 years. By age 20 years, Type II errors were observed for three out of four stand variables (table 1).

### Power Analysis

Forest researchers are familiar with  $\alpha$  levels (for Type I errors), but few understand the importance of  $\beta$  levels for Type II errors (Di Stefano 2001, Foster 2001). Although reviewers of forestry manuscripts sometimes object if an author uses an  $\alpha$  level of 0.15 (which increases statistical power), most reviewers do not ask that  $\beta$  levels be listed (Bennett and Adams 2004). As a result, readers of forestry journals are rarely told the power of the tests even when no statistical differences are detected. Some suggest experiments should be designed to

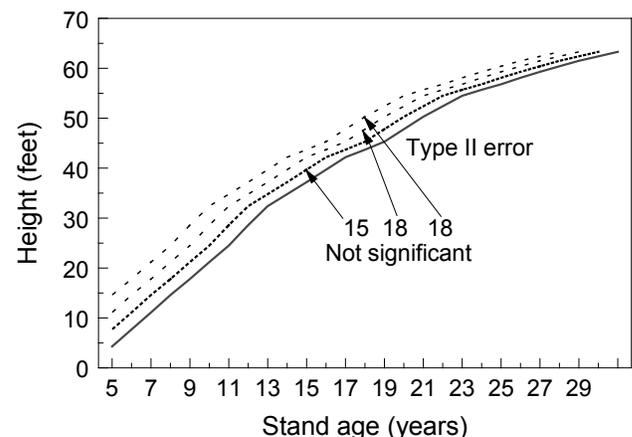


Figure 2—The effect of planting year on height growth of four identical stands. Dashed lines represent stands that were planted 1, 2, and 3 years before the control stand (solid line). The null hypothesis is: there is no difference in stand development due to stand age. Type II errors begin at ages 15, 18, and 18 years (for stands that are 1-, 2-, and 3-years older respectively).

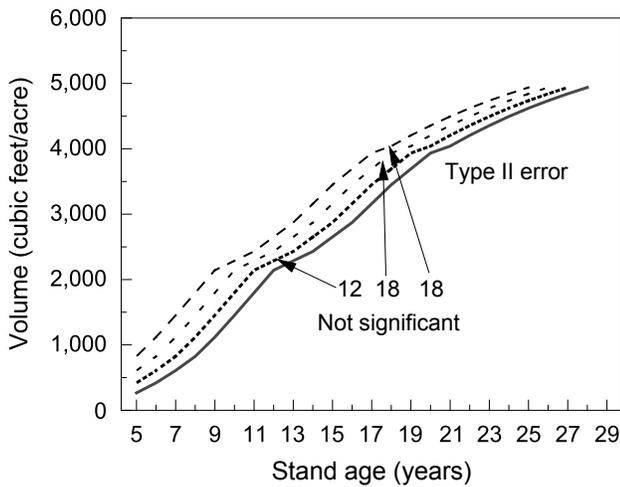


Figure 3—The effect of planting year on volume growth per acre of four identical stands. Dashed lines represent stands that were planted 1, 2, and 3 years before the control stand (solid line). The null hypothesis is: there is no difference in stand development due to stand age. Type II errors begin at ages 12, 18, and 18 years for stands that are 1-, 2-, and 3-years older, respectively.

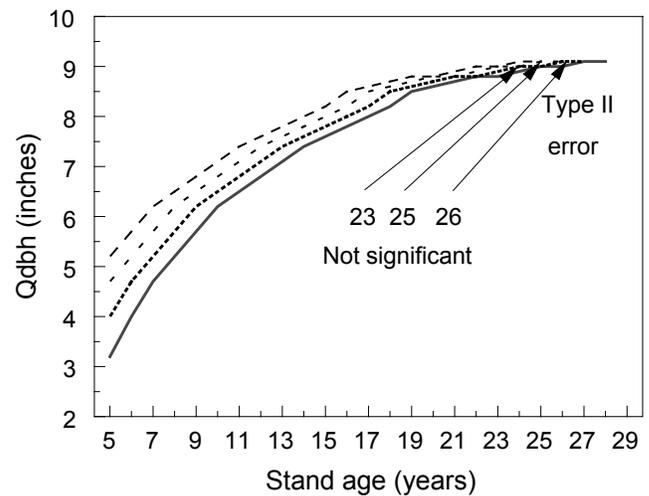


Figure 5—The effect of planting year on quadratic mean d.b.h. (Qdbh) of four identical stands. Dashed lines represent stands that were planted 1, 2, and 3 years before the control stand (solid line). The null hypothesis is: there is no difference in stand development due to stand age. Type II errors begin at ages 23, 25, and 26 years for stands that are 1-, 2-, and 3-years older, respectively.

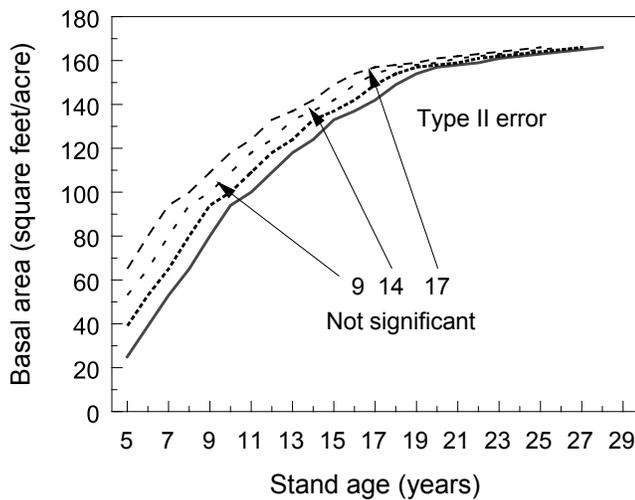


Figure 4—The effect of planting year on basal area per acre of four identical stands. Dashed lines represent stands that were planted 1, 2, and 3 years before the control stand (solid line). The null hypothesis is: there is no difference in stand development due to stand age. Type II errors begin at ages 9, 14, and 17 years for stands that are 1-, 2-, and 3-years older, respectively.

produce a power of 0.8 (i.e.,  $\beta$  value of 0.2). This might be rather expensive for most long-term silvicultural trials. A target  $\beta$  value of 0.5 would likely be more practical (Zedaker and others 1993).

There are two basic types of power tests: a-priori and post-priori (Nemec 1991). An a-priori power test helps during the experimental design process and is calculated using the desired sample effect size (i.e., effect size is fixed) and an estimate of the error variance (either an educated guess or error variance from a similar study in the past). A post-priori power test is conducted after the experiment has been measured and is calculated using the observed difference between treatment means (i.e., observed rather than desired sample effect size). Some see little value in post-priori power tests because power level is inversely related to the observed p-value (Haywood and others 1998, VanderSchaaf and others 2003). We therefore propose a “hybrid” power test where the error variance is derived after the study has been analyzed, but the sample effect size is predetermined (i.e., fixed). We suggest calculating power using a “fixed” sample effect size equal to 10 percent of the control mean (but this percentage difference might not be economically or biologically appropriate for all stand variables).

**Table 1—Effect of a 2-year difference in planting date on four stand variables. Probabilities associated with a t-test of treatment means ( $\alpha = 0.05$ ; two tailed test; three samples per mean; completely randomized design)**

Variable	Age 18	Age 20	P > t value	Power (1-b)	LSD	$\alpha$ level required to detect a 10% increase (3 samples) b = 0.2	Samples needed to detect a 10% increase b = 0.2	Standard deviation
volume	3,449.00	3,935.00	0.1561	0.282	773.000	0.6930	16.1	338.000
height	50.30	54.50	0.1308	0.468	6.100	0.1220	4.2	2.150
basal area	149	158	0.3179	0.173	21.900	0.2640	6.3	8.530
Qdbh	8.08	8.46	0.0015	1.000	0.251	0.0001	NA	0.062

If a particular test is not statistically significant, is it because there is no effect or because the study does not have enough replications to produce a small enough error term? A hybrid power analysis can be useful in answering this question. A hybrid power test can be calculated using web-based calculators (Thomas and Krebs 1997) or from our Excel program ([www.sfw.s.auburn.edu/south/power.xls](http://www.sfw.s.auburn.edu/south/power.xls)). Use of these programs can help researchers gain experience understanding how the  $\alpha$  level, number of replications, and use of a one-sided t-test might affect the power level.

In our example, statistical power remained high for at least 8 years. The power (i.e., ability to detect a 1-year difference in stand development) dropped below 0.5 around ages 13 to 16 for basal area and volume, respectively (fig. 6). For height, power did not drop below 0.5 until age 16 years. Quadratic d.b.h. was the least variable, and power remained high for about 20 years.

Similar power levels ( $\alpha = 0.05$ ) were reported for longleaf pine (*Pinus palustris* Mill.) for these growth variables. At age 34 years, Haywood and others (1998) reported the greatest power for tree height (0.443) and the lowest power for volume per acre (0.119). Statistical power for basal area and d.b.h. were intermediate, 0.244 to 0.284. Therefore, the ranking of growth variables in terms of relative power will vary with species, genotype (Burr and Tinus 1996), study (VanderSchaaf and others 2003), and response variable (South and others 2003).

We recommend that, prior to installing a test, researchers decide what difference between means they wish to detect as statistically significant and use computer programs to aid in designing experiments (e.g., Zedaker and others 1993). Too often a study is installed without any idea of how powerful the test will be. For example, in many experiments ( $\alpha = 0.05$ ), researchers can not detect a 12 percent decline in forest floor carbon (Yanai and others 2003), a 10 percent difference in control of woody competition (Zedaker and others 1993), a 9 percent increase in basal area (Miller and others 2001), or a 10 percent increase in seedling production (VanderSchaaf and others 2003).

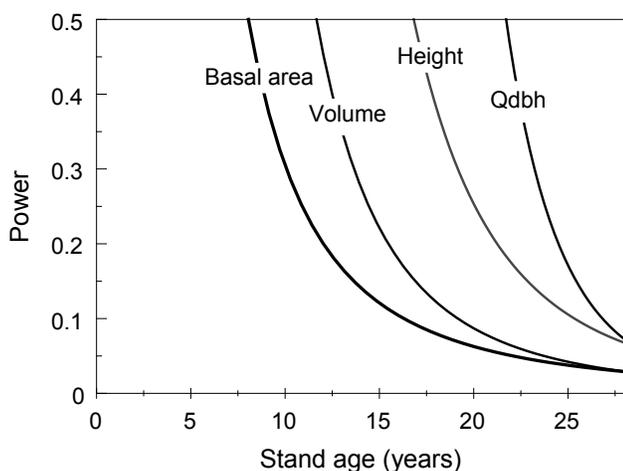


Figure 6—The effect of stand age on the statistical power for detecting a 1-year advance in stand development. A statistical power of 0.3 indicates there is a 70 percent chance of making a Type II error ( $\alpha = 0.05$ ).

For experiments containing silvicultural treatments, we recommend researchers publish the power level ( $1 - \beta$ ) that would detect a 10 percent difference from the control treatment (e.g., 5 percent  $\alpha$  level and two-sided test). We suggest using 10 percent as a standard since a post-priori power test is of little value (unless the researchers have failed to report p-values). In post-priori power analyses, where the outcome determines the observed difference between treatment means, power level is inversely related to observed p-value (Haywood and others 1998, VanderSchaaf and others 2003).

Another suggestion would be for researchers to present LSD values. An LSD value would allow the reader to determine how much of an increase in growth would be required before the experimental design could detect a significant difference. Although some reviewers have frowned on reporting unprotected LSD values, this does not mean that an LSD has no value in providing the reader some idea of the statistical power of the test. We recommend LSD values be routinely listed, especially when there are no statistically significant treatment differences.

Another suggestion would be for researchers to switch to modeling the data. Statistical analyses can be conducted when the power of the test is high (during the early stages of stand development), while models can be made when the power is low (during the latter stages of stand development).

## CONCLUSIONS

Researchers should expect statistical power to decline with stand age as the coefficient of variation increases over time. Eventually, a treatment that produces a “true” 1-year age-shift will eventually lose statistical significance (typically after age 10 years). However, just because an experiment has low power does not automatically mean the treatment effect has disappeared or has washed out. Forest researchers should remember that they can never “prove” a null hypothesis and therefore it would be unscientific to accept a null hypothesis (scientists can only fail to reject the null hypothesis).

## LITERATURE CITED

- Bennett, L.T.; Adams, M.A. 2004. Assessment of ecological effects due to forest harvesting: approaches and statistical issues. *Journal of Applied Ecology*. 41: 585-598.
- Burr, K.E.; Tinus, R.W. 1996. Use of clones increases the power of physiological experiments on coastal Douglas-fir. *Physiologia Plantarum*. 96: 458-466.
- Di Stefano, J. 2001. Power analysis and sustainable forest management. *Forest Ecology and Management*. 154: 141-153.
- Foster, J.R. 2001. Statistical power in forest monitoring. *Forest Ecology and Management*. 151: 211-222.
- Haywood, J.D.; Tiarks, A.E.; Elliott-Smith, M.L.; Pearson, H.A. 1998. Response of direct seeded *Pinus palustris* and herbaceous vegetation to fertilization burning, and pine straw harvesting. *Biomass and Bioenergy*. 14: 157-167.
- Kirk, R.E. 1995. *Experimental design: procedures for the behavioral sciences*. New York, NY: Brooks/Cole Publishing Company. 921 p.
- Miller, R.E.; Smith, J.; Anderson, H. 2001. Detecting response of Douglas-fir plantations to urea fertilizer at three locations in the Oregon coast range. Res. Pap. PNW-RP-533. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 20 p.
- Nemec, A.F.L. 1991. *Power analysis handbook for the design and analysis of forestry trials*. Biometrics Information Handbook 2. Victoria, BC: British Columbia Ministry of Forests. 26 p.

- Peterman, R.M. 1990a. Statistical power analysis can improve fisheries research and management. *Canadian Journal of Fisheries and Aquatic Sciences*. 47: 1-15.
- Peterman, R.M. 1990b. The importance of reporting statistical power: the forest decline and acidic deposition example. *Ecology*. 71: 2024-2027.
- Richards, F.J. 1959. A flexible growth equation for empirical use. *Journal of Experimental Botany*. 10: 290-300.
- South, D.B.; VanderSchaaf, C.L.; Smith, C.T. 2003. Number of trees per experimental unit is important when comparing transplant stress index values. *New Zealand Journal of Forestry Science*. 33: 126-132.
- Tasissa, G.; Burkhart, H.E.; Amateis, R.L. 1997. Volume and taper equations for thinned and unthinned loblolly pine trees in cutover, site-prepared plantations. *Southern Journal of Applied Forestry*. 21: 146-152.
- Thomas, L.; Krebs, C.J. 1997. A review of statistical power analysis software. *Bulletin of the Ecological Society of America*. 78: 126-139.
- Toft, C.A.; Shea, P.J. 1983. Detecting community-wide patterns: estimating power strengthens statistical inference. *American Naturalist*. 122: 618-625.
- VanderSchaaf, C.L.; South, D.B.; Doruska, P.F. 2003. The power of statistical tests of herbicide trials in forest nurseries. *Proceedings of the Southern Weed Science Society*. 56: 202-211.
- VanderSchaaf, C.L.; South, D.B. 2004. Early growth response of slash pine to double-bedding on a flatwoods site in Georgia. In: Connor, K.F., ed. *Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 363-367.
- Yanai, R.D.; Stehman, S.V.; Arthur, M.A. [and others]. 2003. Detecting change in forest floor carbon. *Soil Science Society of America Journal*. 67: 1583-1593.
- Zedaker, S.M.; Gregoire, T.G.; Miller, J.H. 1993. Sample-size needs for forestry herbicide trials. *Canadian Journal of Forest Research*. 23: 2153-2158.
- Zhang, S., Burkhart, H.E.; Amateis, R.L. 1996. Modeling individual tree growth for juvenile loblolly pine plantations. *Forest Ecology and Management*. 89: 157-172.

# NEW METHODS FOR ESTIMATING PARAMETERS OF WEIBULL FUNCTIONS TO CHARACTERIZE FUTURE DIAMETER DISTRIBUTIONS IN FOREST STANDS

Quang V. Cao and Shanna M. McCarty<sup>1</sup>

**Abstract**—Diameter distributions in a forest stand have been successfully characterized by use of the Weibull function. Of special interest are cases where parameters of a Weibull distribution that models a future stand are predicted, either directly or indirectly, from current stand density and dominant height. This study evaluated four methods of predicting the Weibull parameters, using data from loblolly pine (*Pinus taeda* L.) plantations. One method, the CDF Regression, consistently produced better goodness-of-fit statistics than those from the other methods.

## INTRODUCTION

The Weibull function was introduced by Bailey and Dell (1973) to model diameter distributions in forest stands. The advantages of the Weibull include its flexibility to fit shapes commonly found in both uneven-aged and even-aged stands and the ease of computing probabilities (or proportions of trees in diameter classes) without the need for numerical integration. Cao (2004) developed a new approach, termed CDF Regression, that outperformed the existing methods in estimating Weibull parameters of a stand from known density and dominant height. The objective of this study was to evaluate four methods to predict the parameters of Weibull functions that modeled diameter distributions of a future stand, whose attributes need to be predicted from current stand attributes.

## DATA

Data were from the Southwide Seed Source Study, which involved 15 loblolly pine (*Pinus taeda* L.) seed sources planted at 13 locations across 10 Southern States (Wells and Wakeley 1966). Seedlings were planted at a 6 foot x 6 foot spacing. Each 0.04-acre plot consisted of 49 trees measured 4 times at ages 10, 15 or 16, 20 or 22, and 25 or 27. A subset (100 plots) of the original data was randomly selected as the fit data set, to be used for fitting the models. Furthermore, only one growing period was randomly chosen from each plot. The fit data set therefore contained 100 growth periods. Another 100 plots were randomly selected from the remaining original data to form a validation data set. All 3 growing periods from these plots were used to evaluate the methods, resulting in a total of 300 observations in the evaluation data set. Table 1 shows summary statistics for stand attributes at the end of each growth period for the fit and validation datasets.

## METHODS

The Weibull probability density function (pdf), used in this study to characterize diameter distribution, has the following form:

$$f(x) = \left(\frac{c}{b}\right) \left(\frac{x-a}{b}\right)^{c-1} \exp\left[-\left(\frac{x-a}{b}\right)^c\right] \quad (1)$$

**Table 1—Means (and standard deviations) of stand attributes at the end of each growth period for the fit and validation data**

Age	n	Dominant height	Trees per acre	Basal area sq.ft./acre
----- Fit data -----				
15	30	42 (4)	778 (212)	146 (37)
16	4	55 (3)	537 (127)	138 (18)
20	33	58 (7)	484 (117)	148 (31)
25	20	61 (6)	436 (171)	139 (47)
27	13	63 (10)	327 (90)	129 (38)
----- Validation data -----				
15	86	43 (6)	702 (187)	134 (27)
16	14	53 (4)	515 (79)	130 (14)
20	95	56 (7)	526 (131)	153 (34)
22	5	46 (7)	385 (48)	83 (36)
25	72	65 (8)	489 (133)	176 (41)
27	28	67 (10)	322 (81)	141 (30)

where  $a$ ,  $b$ , and  $c$  are the location, scale, and shape parameters, respectively, and  $x$  is tree diameter at breast height (d.b.h.).

The annual growth model was employed in this study to project stand attributes, because it was found by Ochi and Cao (2003) to provide better stand predictions than compatible growth models. The stand attributes at time ( $t+1$ ) were projected from time  $t$  as follows:

$$\hat{N}_{t+1} = \hat{N}_t^{A_t / A_{t+1}} [b_1 + b_2 / A_t + b_3 \hat{N}_t]^{(1-A_t / A_{t+1})} \quad (2)$$

$$\hat{B}_{t+1} = \hat{B}_t^{A_t / A_{t+1}} [b_1 + b_2 / \hat{H}_t + b_3 / \ln(\hat{B}_t)]^{(1-A_t / A_{t+1})} \quad (3)$$

$$\hat{D} \min_{t+1} = \hat{D} \min_t^{A_t / A_{t+1}} [b_1 + b_2 / A_t]^{(1-A_t / A_{t+1})} \quad (4)$$

$$SD_{t+1} = SD_t^{A_t / A_{t+1}} [b_1 + b_2 / \ln(\hat{N}_t)]^{(1-A_t / A_{t+1})} \quad (5)$$

<sup>1</sup> Professor and Gilbert Fellow, respectively, Louisiana State University AgCenter, School of Renewable Natural Resources, Baton Rouge, LA 70803.

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where  $A$  = stand age in years,  $\hat{H}$  = the predicted dominant height (average height of the dominants and codominants),  $\hat{N}$  = predicted number of trees per acre,  $\hat{B}$  = the predicted stand basal area in square feet per acre,  $\hat{D}_{min}$  = the minimum diameter in inches,  $SD$  = the predicted standard deviation of diameter, and the subscripts place the attributes at time  $t$  or  $(t+1)$ . In addition, the  $b_i$ 's are regression coefficients.

The future 93<sup>rd</sup> diameter percentile ( $\hat{D}_{93_2}$ ) at the end of the growth period (age  $A_2$ ) was predicted from the future quadratic mean diameter ( $\hat{D}_{Q_2}$ ) and relative spacing ( $RS_2$ ):

$$\hat{D}_{93_2} = \hat{D}_{Q_2} [1 + \exp(b_1 + b_2 RS_2)] \quad (6)$$

where  $\hat{D}_{Q_2} = \sqrt{\hat{B}_2 / 0.005454}$ ,  $RS_2 = \sqrt{43560 / \hat{N}_2} / \hat{H}_2$ , and  $\hat{H}_2$ ,  $\hat{N}_2$ , and  $\hat{B}_2$  are dominant height, number of trees, and basal area per acre at age  $A_2$ , respectively.

Borders (1989) method was used to simultaneously estimate regression parameters of equations to predict  $N_2$ ,  $B_2$ ,  $D_{min_2}$ ,  $SD_2$ , and  $D_{93_2}$ .

The following methods to obtain the Weibull parameters were evaluated.

### Method 1—Moment Estimation

The Weibull location parameter ( $a$ ) must be smaller than the predicted minimum diameter in the stand ( $\hat{D}_{min_2}$ ). We set  $a = 0.5\hat{D}_{min_2}$  since Frazier (1981) found that this gave best results in terms of goodness-of-fit. The other Weibull parameters,  $b$  and  $c$ , were recovered from the first two moments of the diameter distribution (Cao and others 1982):

$$b = (\hat{D}_2 - a) / \Gamma_1 \quad (7)$$

$$\hat{D}_{Q_2}^2 + a^2 - 2a\hat{D}_2 - b^2 \Gamma_2 = 0 \quad (8)$$

where  $\hat{D}_2 = \sqrt{\hat{D}_{Q_2}^2 - SD_2^2}$  and  $\Gamma_1 = \Gamma(1 + 1/c)$ .

### Method 2—Hybrid

The Weibull location parameter was also computed from  $a = 0.5\hat{D}_{min_2}$ . In the hybrid method, developed by Baldwin and Feduccia (1987), the  $b$  and  $c$  parameters were recovered from a moment (the quadratic mean diameter or  $\hat{D}_{Q_2}$ ) and a percentile (the 93<sup>rd</sup> diameter percentile or  $\hat{D}_{93_2}$ ):

$$b = (\hat{D}_{93_2} - a) / 2.659261/c \quad (9)$$

$$0 = a^2 - \hat{D}_{Q_2}^2 + 2a(\hat{D}_{93_2} - a)\Gamma_1 / 2.65926^{1/c} + a(\hat{D}_{93_2} - a)2\Gamma_2 / 2.65926^{2/c} \quad (10)$$

where  $2.65926 = -\ln(1 - 0.93)$ .

### Method 3—CDF Regression

Similar to the previous two methods, the Weibull location parameter was set at  $a = 0.5\hat{D}_{min_2}$ . The scale and shape parameters were computed from:

$$b = \frac{-a\Gamma_1 + \sqrt{a^2(\Gamma_1^2 - \Gamma_2) + D_{Q_2}^2\Gamma_2}}{\Gamma_2} \quad (11)$$

$$c = \exp(b_1 + b_2 RS_2 + b_3 \hat{H}_2) \quad (12)$$

As in the procedure developed by Cao (2004), this method iteratively searched for the coefficients  $b_i$ 's in equation (12) to minimize the following function:

$$\sum_{i=1}^p \sum_{j=1}^{n_i} (F_{ij} - \hat{F}_{ij})^2 / n_i \quad (13)$$

where  $F_{ij}$  = observed cumulative probability of tree  $j$  in the  $i^{\text{th}}$  plot,  $\hat{F}_{ij} = 1 - \exp\{-[(x_{ij} - a)/b]^c\}$  = value of the cumulative distribution function (cdf) of the Weibull distribution evaluated at  $x_{ij}$ ,  $x_{ij}$  = d.b.h. of tree  $j$  in the  $i^{\text{th}}$  plot,  $n_i$  = number of trees in the  $i^{\text{th}}$  plot, and  $p$  = number of plots. This approach, similar to the procedure developed by Cao (2004), fit a regression equation for  $c$ , but the objective was to minimize the sum of squares of error with respect to the cdf (hence the name CDF Regression), rather than to  $c$ .

### Method 4—Cumulative TPA Regression

This method is similar to method 3 (CDF Regression), except that equation (12) was replaced with:

$$c = \exp(b_1 + b_2 RS_2 + b_3 / \hat{H}_2 + b_4 \ln(\hat{N}_2)) \quad (14)$$

The coefficients  $b_i$ 's in equation (14) were iteratively searched to minimize the following function:

$$\sum_{i=1}^p \sum_{j=1}^{n_i} (T_{ij} - \hat{T}_{ij})^2 / n_i \quad (15)$$

where  $T_{ij}$  and  $\hat{T}_{ij}$  are observed and predicted cumulative number of trees per acre up to diameter  $x_{ij}$ .

Again, this approach was similar to fitting a regression equation for  $c$ , but the goal was to minimize the sum of squares of error with respect to the cumulative trees per acre (hence the name Cumulative TPA Regression), rather than to  $c$ .

## EVALUATION

The following goodness-of-fit statistics were computed separately for each method and for each plot of the fit data and each plot-age combination of the validation data.

1. The chi-square statistic, and
2. Reynolds and others (1988) error indices for the  $i^{\text{th}}$  plot-age combination, based on number of trees per acre in each diameter class ( $EI_N$ ) and basal area per acre in each diameter class ( $EI_B$ ):

$$EI_{N,i} = \sum |m_{ik} - \hat{m}_{ik}| \quad (16)$$

$$EI_{B,i} = \sum |b_{ik} - \hat{b}_{ik}| \quad (17)$$

where  $m_{ik}$  and  $\hat{m}_{ik}$  = the observed and predicted number of trees per acre in diameter class  $k$  for the  $i^{\text{th}}$  plot-age combination, and  $b_{ik}$  and  $\hat{b}_{ik}$  = the observed and predicted basal area per acre in diameter class  $k$  for the  $i^{\text{th}}$  plot-age combination. The sum includes all diameter classes in the  $i^{\text{th}}$  plot-age combination.

**Table 2—Means<sup>a</sup> (and standard deviations) of goodness-of-fit statistics for the fit and validation data, by method**

Method	Chi-square statistic		Error index based on TPA		Error index based on BA	
	Fit data	Validation data	Fit data	Validation data	Fit data	Validation data
Moment Estimation	15(29)	30(88)	<u>247<sup>b</sup></u> (108)	267 (117)	68 (26)	75 (28)
Hybrid	8 (6)	11(25)	281 (132)	288 (111)	72 (28)	76 (29)
CDF Regression	<u>6</u> (5)	<u>7</u> (6)	250 (114)	<u>264</u> (113)	<u>66</u> (25)	<u>71</u> (28)
CTPA Regression	7 (5)	9(18)	265 (134)	276 (151)	69 (28)	73 (28)

<sup>a</sup> The smaller the statistic value, the better the fit.

<sup>b</sup> For each statistic, an underlined italic number indicates the best among four methods.

## RESULTS AND DISCUSSION

Table 2 displays the summaries of the chi-square statistic and the error indices for both datasets. The CDF Regression method produced the lowest goodness-of-fit statistics for both fit and validation data in all but one case. The lone exception is its second rank in terms of  $EI_N$  for the fit dataset. On the other hand, the rankings of the rest of the methods were not clearcut, with each method received ranks varied from 2 to 4.

The same predicted variables ( $\hat{N}_2$ ,  $\hat{D}_{min_2}$ , and  $\hat{D}q_2$ ) were employed in all methods. This means that all methods used the same location parameter and were constrained to produce the same total basal area per acre. The CDF Regression method performed well because the entire distribution (rather than just the average diameter or the 93<sup>rd</sup> diameter percentile) contributed to the fitting criterion.

Because total number of trees had to be predicted, error in the total number would in turn cause error in predicting number of trees in each diameter class. The Cumulative TPA Regression method was designed to optimize the Weibull parameter prediction by working directly with number of trees rather than proportions as did the CDF Regression. It was somewhat surprising to find that the CDF Regression was still the better method.

Cao (2004) concluded that the CDF Regression was best for predicting Weibull parameters to characterize current stands with known stand attributes. In this study, the CDF Regression was also found to be the most appropriate method for a future stand where its attributes had to be predicted from current attributes.

## LITERATURE CITED

- Bailey, R.L.; Dell, T.R. 1973. Quantifying diameter distributions with the Weibull function. *Forest Science*. 19: 97-104.
- Baldwin, V.C., Jr.; Feduccia, D.P. 1987. Loblolly pine growth and yield prediction for managed West Gulf plantations. Res. Pap. SO-236. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 27 p.
- Borders, B.E. 1989. Systems of equations in forest stand modeling. *Forest Science*. 35: 548-556.
- Cao, Q.V. 2004. Predicting parameters of a Weibull function for modeling diameter distribution. *Forest Science*. 50: 682-685.
- Cao, Q.V.; Burkhart, H.E.; Lemin, R.C. 1982. Diameter distributions and yields of thinned loblolly pine plantations. Research Publication FWS-1-82. Blacksburg, VA: Virginia Polytechnic Institute and State University, School of Forestry and Wildlife. 62 p.
- Frazier, J.R. 1981. Compatible whole-stand and diameter distribution models for loblolly pine plantations. Blacksburg, VA: Virginia Polytechnic Institute and State University, School of Forestry and Wildlife. 125 p. Ph.D. dissertation.
- Ochi, N.; Cao, Q.V. 2003. A comparison of compatible and annual growth models. *Forest Science*. 49: 285-290.
- Reynolds, M.R.; Burk, T.E.; Huang, W.C. 1988. Goodness-of-fit tests and model selection procedures for diameter distribution models. *Forest Science*. 34: 373-399.
- Wells, O.O.; Wakeley, P.C. 1966. Geographic variation in survival, growth, and fusiform-rust infection of planted loblolly pine. *Forest Science Monograph* 11. 40 p.

# VARIATION IN WOOD DENSITY BY STAND ORIGIN AND LOG POSITION FOR LOBLOLLY PINE SAWTIMBER IN THE COASTAL PLAIN OF ARKANSAS

Paul F. Doruska, David W. Patterson, and Travis E. Posey<sup>1</sup>

**Abstract**—A study was undertaken to investigate and report scaling factor variation for loblolly pine sawtimber in the Coastal Plain of Arkansas. Scaling factors for butt logs averaged 65.6 pounds per cubic foot for trees in stands of naturally seeded origin and 65.0 pounds per cubic foot for plantation trees. These scaling factors were not significantly different by stand origin at  $\alpha = 0.05$ . Scaling factors for the upper logs of trees in stands of naturally seeded origin averaged 70.5 pounds per cubic foot and those for plantation-grown trees averaged 71.0 pounds per cubic foot. These scaling factors were likewise not significantly different by stand origin at  $\alpha = 0.05$ . A seasonal trend was noted; treelength log scaling factors were numerically larger during spring and fall than those during fall and winter. These results should assist weight scaling of loblolly pine sawlogs in southern Arkansas.

## INTRODUCTION

The predominant method of buying and selling timber in Arkansas and the Southern United States is by weight. The Arkansas legislature recognized this in the 2003 legislative session by no longer requiring use of the Doyle log rule (a volume-based rule) as the only legal rule for sawlog timber transactions within the state. It is simply more efficient to determine log weight than log volume. This gain in efficiency does come at a cost; it is now more difficult for a landowner to receive a premium for higher-quality large logs as a high quality and low quality log of the same dimensions can have the same weight.

Many forest inventories are conducted in terms of the timber volume and not weight. The landowner or land manager must then convert from units of volume to units of weight in order to determine timber value. To aid in this process, individual tree weight equations have recently been developed for loblolly pine (*Pinus taeda* L.) in southern Arkansas and surrounding regions (Newbold and others 2001, Posey 2003).

Issues regarding the weight and thus scaling factor of merchandized logs are also important. Scaling factor, or the outside-bark weight of a log divided by the inside-bark volume, is of interest when weight scaling merchandized logs. Logs of the same dimensions can have different scaling factors based on specific gravity and moisture content. Specific gravity is known to vary by position in the bole (Ezell and Schilling 1980, Hamilton 1961, Taylor 1979) as well as geographic location (Koch 1972). Patterson and Wiant (1993) found that moisture content varies according to position in the bole, while Yerkes (1967) reported seasonal fluctuations in moisture content. Thus, knowledge of scaling factors by season of the year, log position in the bole, and perhaps stand origin will assist weight scaling for loblolly pine in southern Arkansas.

The specific objectives of this project were to (1) determine scaling factors for loblolly pine sawtimber trees in southern Arkansas and (2) quantify how the scaling factors in (1) are impacted by stand origin, season of the year, and position in the bole.

## SITES

A total 16 stands were visited during 2002 in conjunction with this project, with four unique stands visited per season of the year. Five stands were plantations, and the remaining 11 stands were of naturally seeded origin. The stands were scattered across Ashley, Cleveland, Drew, and Lincoln counties in southeastern Arkansas. The stands visited averaged 16 inches in quadratic mean diameter (range of 11 to 32 inches), possessed on average 51 pine trees per acre (range of 5 to 130), and had an average basal area of 67 square feet per acre (range of 17 to 135).

## PROCEDURES

The researchers visited each stand shortly before it was scheduled for harvest. At this initial visit, 20 loblolly pine sawtimber trees were selected as subject trees via systematic random sampling. Several measurements were taken on each subject tree, including d.b.h. (nearest 0.1 inch), total height (nearest foot), and the number of 17-foot plylogs it contained. Each tree was then marked with a unique combination of paint bands to be used for identification on the loading deck.

Each stand was revisited after harvest. The felled bole (4-inch top) of each tree was measured and weighed at the loading deck within 1 day of harvest. Trees were weighed in February, May, August, and November 2002, to represent the winter, spring, summer, and fall seasons, respectively.

The following measurements were made on each tree-length log prior to merchandizing by a logging crew: total length (nearest 0.1 foot), inside bark diameter (nearest 0.1 inch) at the large and small ends, diameter and bark thickness (nearest 0.1 inch, respectively) at 40 percent of total length, and age (years) as counted at the large end. The tree-length log was weighed using a load cell (Measurement Systems International, Challenger 2, Model 3360, 10,000 pound capacity, 2 pound precision) suspended from a loader. After the tree-length log was weighed, a logging crew merchandized the tree-length log into 1-, 1.5-, or 2-log plylogs. Each merchandized plylog bucked from the bole was subsequently measured and weighed using the same protocol outlined for the tree-length

<sup>1</sup> Associate Professor and Research Professor, respectively, Arkansas Forest Resources Center, University of Arkansas School of Forest Resources, Monticello, AR 71656; and Analyst, Mid-South Engineering, P.O. Box 1399, Hot Springs, AR 71902.

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log. The weight of any treelength log that exceeded the scale's capacity was determined by weighing the residual topwood and adding its weight to the weight of the merchandized plylogs from said bole.

Inside bark cubic-foot volumes were determined via a modified Newton's formula (using diameter at 40 percent of length as opposed to the true midpoint diameter) for each merchandized log. Scaling factors were then determined by dividing the outside-bark log weights by their respective inside-bark log volumes. T-tests ( $\alpha = 0.05$ ) were used to test for differences in scaling factor by stand origin.

## RESULTS AND DISCUSSION

A wide range in tree sizes composed the dataset used herein. Tree d.b.h.s ranged from 10 to 32 inches, total tree heights ranged from 45 to 120 feet, tree-length weights ranged from 800 to 17,000 pounds, and tree ages ranged from 30 to 100 years. The most prevalent merchandized butt log length was 1.5 plylogs; therefore, only results from such trees and/or tree boles are reported herein.

Scaling factors of the 1.5 plylog butt logs averaged 65.6 pounds per cubic foot (with a standard deviation of 6.8 pounds per cubic foot) for trees in stands of naturally seeded origin and 65.0 pounds per cubic foot (with a standard deviation of 5.7 pounds per cubic foot) for trees in plantations. These scaling factors were not significantly different at  $\alpha = 0.05$ .

Scaling factors of upper logs from 1.5 plylog butt log trees averaged 70.5 pounds per cubic foot (with a standard deviation of 5.1 pounds per cubic foot) for trees in stands of naturally seeded origin and 71.0 pounds per cubic foot (with a standard deviation of 6.6 pounds per cubic foot) for trees in plantations. These scaling factors also were not significantly different at  $\alpha = 0.05$ .

The approximate 5 pounds per cubic foot increase in scaling factor, butt logs versus upper logs, is large enough to warrant attention when weight scaling loblolly pine sawlogs. A truckload containing a mixture of upper logs and butt logs will yield less volume than a truckload (of equal weight) composed primarily or exclusively of butt logs.

An interesting pattern emerged when tree-length scaling factor was averaged across all trees by season (table 1). Treelength scaling factors were numerically largest in spring and fall when compared to those of winter and summer. Statistical tests were not performed on these data inasmuch as the same stands were not visited in each season of the year. Thus, the authors cannot rule out stand to stand variation as a cause of the varying scaling factors shown in table 1. However, Doruska and Patterson (in press) noted a similar

pattern in scaling factors of loblolly pine pulpwood trees in southern Arkansas when the same stands were visited seasonally. This trend suggests that truckloads of equal weight will contain more volume during winter and summer than during spring and fall.

The seasonal scaling factor pattern noted herein differs from that of the ponderosa pine (*Pinus ponderosa* Dougl.) work of Yerkes (1967), who reported moisture contents, and thus most likely scaling factors, were highest in February and March. The pattern of larger scaling factors with increasing height above ground is consistent with that found by Clark and Taras (1976) and Patterson and Wiant (1993).

## SUMMARY AND CONCLUSIONS

Loblolly pine sawtimber trees were measured, harvested, and weighed in 2002 to determine their scaling factors and to examine possible differences in scaling factor by stand origin. The scaling factors of butt logs averaged about 65 pounds per cubic foot and were not significantly different by stand origin. Scaling factors of upper logs averaged about 70 pounds per cubic foot and also were not significantly different by stand origin.

A seasonal trend was noted in tree-length scaling factors. Tree-length scaling factors tended to be numerically larger in spring and fall than in winter and summer. This trend should be considered when using the scaling factors previously described. The results of this project should assist those scaling loblolly pine sawlogs by weight in southern Arkansas and surrounding regions.

## ACKNOWLEDGMENTS

Funding for this project was provided by the University of Arkansas, Division of Agriculture and the Arkansas Forest Resources Center. In-kind services were provided by Georgia-Pacific Corporation, Plum Creek Timber Company, and logging contractors L.D. Long and Rob Jones. This paper is published with the approval of the Director, Arkansas Agricultural Experiment Station.

## LITERATURE CITED

- Clark, A. III; Taras, M.A. 1976. Biomass of shortleaf pine in a natural sawtimber stand in northern Mississippi. Res. Pap. SE-146. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 14 p.
- Doruska, P.F.; Patterson, D.W. [In press]. Individual-tree, outside-bark, green weight equations for loblolly pine pulpwood in southern Arkansas: preliminary results. In: Cieszewski, C., comp. Proceedings of the second international conference on forest measurements and quantitative methods and management and the 2004 southern mensurationists conference.
- Ezell, A.W.; Schilling, P.E. 1980. A note on within-tree variation of specific gravity in sweetgum (*Liquidambar styraciflua* L.). Wood and Fiber. 12: 80-87.
- Hamilton, J.R. 1961. Variation of wood properties in southern red oak. Forest Products Journal. 11: 267-271.
- Koch, P. 1972. Utilization of southern pines: volume 1, the raw material. Agric. Handb. 420. Washington, DC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 734 p.
- Newbold, R.A.; Baldwin, V.C., Jr.; Hill, G. 2001. Weight and volume determination for planted loblolly pine in north Louisiana. Res. Pap. SRS-26. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 22 p.

**Table 1—Seasonal pattern of tree length log scaling factor for loblolly pine sawtimber in southern Arkansas**

Season	Winter	Spring	Summer	Fall
- - - - pounds per cubic foot - - - -				
Scaling factor	63.7	66.2	64.4	66.9

Patterson, D.W.; Wiant, H.V., Jr. 1993. Relationship of position in tree to bulk density of logs whose volumes were measured by weighing while immersed. *Forest Products Journal*. 43: 75-77.

Posey, T.E. 2003. Individual-tree green weight equations and tables for loblolly pine (*Pinus taeda* L.) sawtimber in the Coastal Plain of Arkansas. Monticello, AR: University of Arkansas-Monticello. 89 p. M.S. thesis.

Taylor, F.W. 1979. Property variation within stems of selected hardwoods growing in the mid-south. *Wood Science*. 11: 193-99.

Yerkes, V.P. 1967. Effects of seasonal stem moisture variation and log storage on weight of Black Hills ponderosa pine. Res. Note RM-96. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 8 p.

# EFFECT OF ROTATION AGE AND PHYSIOGRAPHIC REGION ON WEIGHT PER CUBIC FOOT OF PLANTED LOBLOLLY PINE

Alexander Clark III, Richard F. Daniels, and Bruce E. Borders<sup>1</sup>

**Abstract**—Most harvested southern pine is sold by weight. We discuss how the weight of wood and bark per cubic foot of wood (the weight scaling factor) for plantation-grown loblolly pine (*Pinus taeda* L.) varies with tree age across the coastal and inland regions of the Southern United States. To determine the weight scaling factor for plantation trees in the Atlantic Coastal Plain, Gulf Coastal Plain, upper Coastal Plain, Piedmont, and Hilly Coastal Plain, we destructively sampled > 1,200 loblolly trees 5 to 17 inches in diameter at breast height and 10 to 45 years old. We cut cross-sectional disks at 4- to 8-foot intervals up the stem and determined the green weight of wood and bark per cubic foot. We weighted disk values by basal area to obtain a stem-weighted scaling factor. Our results show that the weight scaling factor averaged 2 percent higher for loblolly pine planted in the coastal region than loblolly planted in the inland region. In both regions, the weight scaling factor decreased significantly with tree age. This variation shows that the factors should be adjusted to account for differences in tree age at the time of harvest.

## INTRODUCTION

Southern pine saw logs and pulpwood are purchased on a weight basis at wood-processing plants. A truckload of harvested trees is weighed, and the weight of wood and bark is converted to cords, board feet, or cubic feet of wood using weight scaling factors. Early reports show that weight scaling has been used in the southern pine pulp market since the late 1920s. Strickland (1955) reported that Gaylord Container Corporation began purchasing all their pulpwood on a weight basis in 1928. Schumacher (1946) developed southern pine weight factors to convert the green weight of wood and bark to cords. He found that the volume-weight ratio for pulpwood varied significantly from one area to another, and a single conversion factor was inappropriate. During the late 1950s and early 1960s, weight scaling to convert the green weight of wood and bark to cords became common practice at most pine pulp mills in the South. In the mid 1960s, weight scaling became the accepted standard for buying and selling southern pine saw logs and veneer logs.

Page and Bois (1961) and Taras (1956) reported that southern pine weight factors differ between species and among locations. Lang (1962) found that weight factors varied between natural second-growth and old-growth southern pine. Examination of the variability of weight factors has continued. Patterson and others (2004) determined the green weight of wood and bark per cubic foot of wood (the weight scaling factor) for loblolly pine (*Pinus taeda* L.) plywood logs in southeast Arkansas. They found the weight scaling factor averaged 61.9 pounds for butt logs and 68.8 pounds for upper logs.

Because weight factors do vary by species, geographic location, and log position, wood processing plants continue to revise weight scaling factors. The common procedure is to weigh truckloads of logs, spread them in the yard, measure the diameter inside bark of each log, and then calculate the wood volume. The net weight of the logs (with bark) is then divided by the volume of wood in the load. For this study, we determined the weight scaling factor by cutting disks from along the stem of sampled trees. We discuss how weight

scaling factors for planted loblolly pine vary with tree age and by geographic region.

## PROCEDURE

The U.S. Department of Agriculture Forest Service's Southern Research Station at the Forestry Sciences Laboratory in Athens, GA, has sampled plantations across the South to determine the effects of silvicultural practices and environmental factors on the physical and mechanical properties of loblolly pine. We conducted our studies in cooperation with the Wood Quality Consortium, Pine Management Research Cooperative, and Consortium for Accelerated Pine Production Systems at the University of Georgia, the Auburn University Herbicide Cooperative, and the Growth and Yield Cooperative at Virginia Polytechnic Institute and State University. For the purpose of our analysis, we used the physical property data collected in those cooperative studies. Most sampled trees are within areas subjected to conventional management practices. Although some trees were within areas receiving total weed control, none included in our analysis received fertilization treatments.

We sampled loblolly pine plantations ranging from 10 to 45 years old on 323 locations across the South (fig. 1). One to 48 trees were felled and destructively sampled in each stand for a total sample of 1,220 trees. Cross-sectional disks 1 to 1.5 inches thick were collected at 4- to 8-foot intervals along the stem of each tree to a 4-inch diameter outside bark top to determine the green weight of wood and bark per cubic foot of wood. We calculated the disk weight scaling factor or green weight based on disk weight with bark and disk green volume without bark. Green volume without bark was determined by water displacement. We calculated stem scaling factors by weighting disk values in proportion to the disk's cross-sectional area.

We separated loblolly pine plantations sampled into two regions: coastal and inland (fig. 1). Trees sampled in the Atlantic and Gulf Coastal Plains were identified as from the coastal region; trees sampled in the upper Coastal Plain, Piedmont, and Hilly Coastal Plain as from the inland region.

<sup>1</sup> Wood Scientist, USDA Forest Service, Southern Research Station, Athens, GA 30602-2044; and Professors, Warnell School of Forest Resources, University of Georgia, Athens, GA 30602, respectively.

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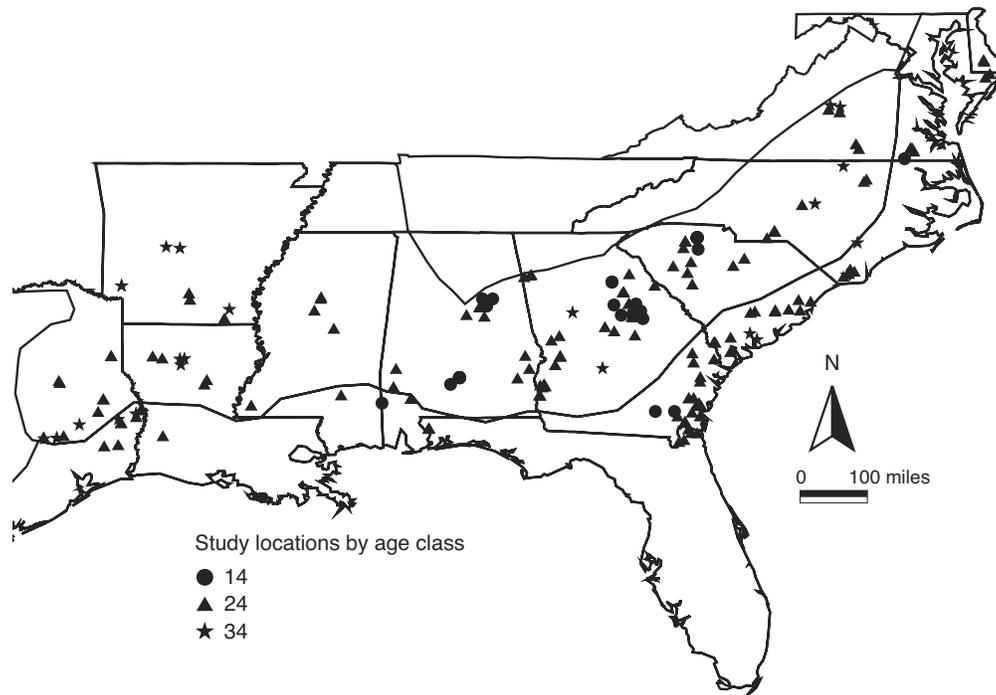


Figure 1—Location of loblolly pine plantations in the coastal and inland regions sampled for weight scaling factors by age class.

Trees sampled in each region were separated into 3 age classes: 14, 24 and 34 years. The 14-year age class (trees 10 to 18 years old) represented the first thinning, the 24-year age class (19 to 27 years old) represented the second thinning, and the 34-year age class (> 27 years old) represented the final harvest. The average and range of tree age, diameter, and total height in each region are shown in table 1 by age class. Confidence intervals at the 95 percent level were calculated for each region and age class mean weight scaling factor to determine which means were significantly different.

## RESULTS

The number of trees sampled in each region and age class varied, but the mean and range of tree ages and diameters sampled in each class were similar (table 1). The average diameter at breast height (d.b.h.) of sampled trees in the coastal region in the 14-, 24-, and 34-year classes was 7.2, 9.1, and 11.2 inches d.b.h., respectively, compared to 7.1, 8.6, and 10.9 inches for the inland trees. On average, the 24- and 34-year-old coastal trees were taller than the inland trees.

The weight of wood and bark per cubic foot of wood, across all age classes, averaged 68.12 pounds per cubic foot in the coastal region, or 2 percent higher than in the inland region, which averaged 66.61 pounds per cubic foot (table 2). The 95 percent confidence limits about the regional means show no significant difference in weight scaling factor between coastal and inland trees when averaged across age classes.

The weight scaling factor varied significantly among tree age classes within the two regions (table 3). In both it decreased significantly with increasing tree age. For the 14-year coastal trees, it was significantly higher than for the 24-year coastal trees, and for the 24-year coastal trees it was significantly higher than for the 34-year coastal trees. The coastal region's

Table 1—Average tree characteristics for plantation loblolly pine trees sampled

Region	Age class years	Trees sampled <i>no.</i>	Average	Range	
				Min.	Max.
<b>Tree age (years)</b>					
Coastal	14	98	14	12	18
	24	179	23	19	27
	34	68	37	29	45
Inland	14	273	14	10	18
	24	317	22	19	27
	34	285	35	28	43
<b>Tree d.b.h. (inches)</b>					
Coastal	14	98	7.2	5.3	9.9
	24	179	9.1	5.7	14.4
	34	68	11.2	5.8	16.9
Inland	14	273	7.1	5.0	11.1
	24	317	8.6	5.0	14.2
	34	285	10.9	5.8	18.0
<b>Total height (feet)</b>					
Coastal	14	98	46	36	68
	24	179	66	41	84
	34	68	80	50	108
Inland	14	273	47	24	69
	24	317	59	36	89
	34	285	74	29	91

**Table 2—Average, standard error, and 95 percent confidence limits for weight of wood and bark per cubic feet of wood for coastal and inland region plantation loblolly pine averaged across age classes**

Region	Stands	Trees	Average	Standard error of mean	95 percent confidence limit	
	sampled	sampled			Lower	Upper
	----- number -----			<i>lbs/ft<sup>3</sup></i>		
Coastal	70	345	68.12	0.61	66.91	69.33
Inland	253	875	66.61	0.37	65.89	67.32

**Table 3—Average, standard error, and 95 percent confidence limits for weight of wood and bark per cubic feet of wood for inland and coastal plantation loblolly pine by tree age class**

Region	Age class	Stands	Trees	Average	Standard error of mean	95 percent confidence limit	
		sampled	sampled			Lower	Upper
	years	----- number -----			<i>lbs/ft<sup>3</sup></i>		
Coastal	14	4	98	70.87	0.52	69.21	72.52
	24	59	179	67.69	0.26	67.16	68.22
	34	7	68	65.28	0.66	63.67	66.89
Inland	14	114	273	69.20	0.96	66.30	70.10
	24	121	317	67.03	0.27	66.50	67.56
	34	18	285	64.60	0.55	63.44	65.77

14-year trees averaged 70.87 pounds per cubic foot, or 4.7 percent more than the 24-year coastal trees, which averaged 67.79 pounds per cubic foot, and 8.6 percent more than the 34-year trees, which averaged 65.28 pounds per cubic foot.

In the inland region, the weight scaling factor for 14-year trees averaged 68.2 pounds per cubic foot and was not significantly different from the 24-year trees, which averaged 67.03 pounds per cubic foot (table 3). However, for a 34-year inland tree the weight scaling factor was significantly less than for a 24- or 14-year tree (averaging 64.6 pounds per cubic foot). The weight of wood and bark per cubic foot of wood decreased with tree age for two reasons: First, d.b.h. increases with tree age, so the proportion of weight in bark decreases, e.g., in the inland region the proportion of stem weight in bark averaged 12.8 percent for the 14-year class, 11.3 for the 24-year class, and 9.8 for the 34-year class. The proportion of stem weight in bark affects the weight scaling factor, because only bark weight is considered, not bark volume. Second, the weight scaling factor decreases with tree age because stem moisture content decreases with increasing tree age, e.g., the average moisture content in the inland trees decreased from 124 percent in 14-year trees to 114 percent in 24-year trees and to 104 percent in 34-year trees.

Using the correct weight scaling factor is important to both buyer and seller. For example, if the coastal weight scaling factor for 24-year-old trees (67.79 pounds per cubic foot) is used to buy 14-year first-thinning trees, which weigh 70.87 pounds per cubic foot, then the buyer is getting 4.6 percent less wood volume. If a seller sells 24-year second-thinning trees, which weigh 67.79 pounds per cubic foot, but the buyer is using the factor for 34-year-old trees, or 65.28 pounds per cubic foot, the seller is losing the value of 3.8 percent of the volume sold. Thus, it is important that the seller and buyer of

southern pine negotiate and agree on the proper weight scaling factor for each stand of timber sold.

## CONCLUSION

The weight scaling factors for plantation loblolly pine, i.e., the weight of wood and bark per cubic foot of wood, when averaged across age classes, are 2 percent higher in the coastal region than in the inland region. The factors decreased significantly with tree age in both regions. On average, the weight scaling factor for 24-year-old trees was 2 percent lower than for 14-year-old trees, and the weight scaling factor for 34-year-old trees was 4.6 percent lower than for 24-year-old trees. Thus it is important that both the seller and buyer of plantation loblolly pine timber understand how weight scaling factors vary with geographic location and tree age.

## LITERATURE CITED

- Lang, K.D. 1962. Selling stumpage by weight in the South. *Southern Lumberman*. 204(2540): 28-32.
- Page, R.H.; Bois, P.J. 1961. Buying and selling southern pine sawlogs by weight. Report. No. 7. [Place of publication unknown]: Georgia Forest Resource Council. 9 p.
- Patterson, D.W.; Doruska, P.F.; Posey, T. 2004. Weight and bulk density of loblolly pine plywood logs in southeastern Arkansas. *Forest Product Journal*. 54(12): 145-148.
- Schumacher, F.X. 1946. Volume-weight ratios of pine logs in Virginia—North Carolina Coastal Plain. *Journal of Forestry*. 44(8): 583-586.
- Strickland, C. 1955. Scaling pulpwood by weight. Paper presented at meeting of the Southwest Technical Committee of the American Pulpwood Association Beaumont, TX: [Publisher unknown]. [Not paged].
- Taras, M.A. 1956. Buying pulpwood by weight as compared with volume measure. Pap. 74. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 11 p.

# DEVELOPMENT OF A PHOTOGRAMMETRIC METHOD OF MEASURING TREE TAPER OUTSIDE BARK

David R. Larsen<sup>1</sup>

**Abstract**—A photogrammetric method is presented for measuring tree diameters outside bark using calibrated control ground-based digital photographs. The method was designed to rapidly collect tree taper information from subject trees for the development of tree taper equations. Software that is commercially available, but designed for a different purpose, can be readily adapted for use in this task. This paper presents the methods and procedures developed by the author.

## INTRODUCTION

Tree taper refers to a set of diameters or radii measured at multiple heights on a tree. This describes the shape or profile of the stem being measured. With these measurements, the volume of a single tree can be determined accurately. The measurements can also be used to develop taper equations to predict stem diameter at any point on a tree. Taper measurements have long been of interest to foresters for estimating the volume of trees.

Taper measurements traditionally are acquired by one of several methods: direct measurement, felled tree stem analysis, measurement with dendrometers, and other optical methods (Clark and others 2000, Dean 2003). All of these methods have some disadvantages. Direct measurement requires physically measuring the stem at several heights. Stem analysis requires destructive sampling of a tree. Stem measurement with dendrometers, while not destructive, is very time-consuming. For all methods, there are no simple ways to archive the samples for re-measuring if an error is found. For example, for stem analysis, wood cross-section disks must be stored and protected from drying and cracking. The other methods require returning to the research site and re-measuring sample trees.

In this paper I describe the development of a new method for measuring tree taper using digital photographs of the trees (fig. 1). Two important benefits of this method are (1) most of the measurement time is spent in the office, allowing measurements to be made more carefully, and (2) the photographs provide a permanent record of the subject tree on the day sampled. This new method also provides a mechanism for the data to be processed by more than one person so that the results can be independently compared. If the measurements contain errors, the photographs can be reprocessed usually without returning to the field. The total time to process a single tree currently seems comparable to the traditional methods for measuring taper. However, the photogrammetric method requires less time in the field.

## PRINCIPLE OF THE PHOTOGRAMMETRIC METHOD

The photogrammetric method produces a 3-dimensional model of the tree stem with a set of photographs. Unlike traditional stereo photography, the camera locations are not next to each other, and in fact, two images next to each other would produce very poor results. The analogy is to think of a clear

box with things of interest inside. You want to photograph the box from as many sides as possible to fully describe the objects in the box. You are using the spatial relationships stored in the photographs to describe the 3-dimensional space of this imaginary box.

Photographs are samples of reflected light energy that also record the spatial relationships among objects from a particular viewing point. I can construct a spatial model of the objects when at least three photographic samples from different viewing points are combined. The quality of the 3-dimensional model depends on how well the photographs are aligned and how well the known distortions are accounted for in the model. Ultimately the limitations on the resolution of the procedure are dependent on the pixel resolution in the digital images



Figure 1—Example of a winter photograph and with the cylinders marked on a subject tree. This tree is a northern red oak (*Quercus rubra* L.) from the Baskett Wildlife Research Area, Ashland, MO. This is the tree used in the summer-winter evaluation (figure 7).

<sup>1</sup> Associate Professor of Quantitative Silviculture, Forestry at the University of Missouri-Columbia, 203 Anheuser Busch Natural Resources Building, Columbia, MO 65211.

used in the model building process. In general, at the ranges used in this study, pixel sizes range from 0.04 to 0.8 inches, so positional accuracies within that range are possible.

If acceptable resolutions are possible, systematic error in the 3-dimensional model must be removed. Systematic errors come from three sources: the camera lens distortions, the orientation of the camera viewpoints, and in marking the object of interest. Camera lens distortion correction is a well-known problem that has been documented in the photogrammetry literature for many years (Thompson 1965). The procedure consists of imaging a fixed grid of targets from many angles. Through a series of steps, a matrix is created that describes the distortion space of a particular lens. This must be done on individual lenses as even two lenses of the same make and model will be slightly different. If using a zoom lens, a separate calibration for each magnification is required; because of this, most people use a single fixed zoom setting.

Orientation of the camera viewpoints is the most important part of the 3-dimensional model method, as errors from incorrectly aligned photographs are propagated to all other dimensional measurements. This step defines the spatial relationships in the 3-dimensional model. The procedure is to identify common visible points on all photographs, and these points are identified as being the same physical locations. Once at least six common points have been identified, the 3-dimensional model can be processed. For greater accuracy, the points should be distributed throughout the sampled area but near enough the center of the sample space to be visible. A good compromise between these two competing needs will produce the best outcome. Identifying more than six visible points will improve photo alignment, producing a better model. Additionally, some of the points must be a known distance apart. This provides scale to the 3-dimensional model. A set of poles with two visible endpoints for this as well as a standard 25-foot height measurement pole works well for these measurements.

Once the above steps are completed, the next step is to measure the objects of interest in the 3-dimensional model. To measure tree taper, a series of stacked cylinders are marked. In each photograph, the edges of the stem are marked at a specific height. After marking these edges in two or more images, the cylinder edges are linked. This allows multiple estimates of the diameter of the stem at specified height (fig. 2). Again, the accuracy of the measurements at this point depends on not only the accuracy of the marking of the stem in multiple images but also the alignment of the images from the previous step.

## APPLICATIONS

### Sites

Example data for this study come from three sources. The first dataset is a cherrybark oak (*Quercus pagoda* Raf.) and sycamore (*Platanus occidentalis* L.) plantation near Helena, AR. These data have been previously described in Clatterbuck and others (1987) and Oliver and others (1990). A second dataset is comprised of scarlet oak (*Q. coccinea* Muenchh.) and white oak (*Q. alba* L.) trees collected at University Forest near Wappapello, MO. A third dataset is made up of white oak and northern red oak (*Q. rubra* L.) trees from the Baskett Wildlife Research Area near Ashland, MO.

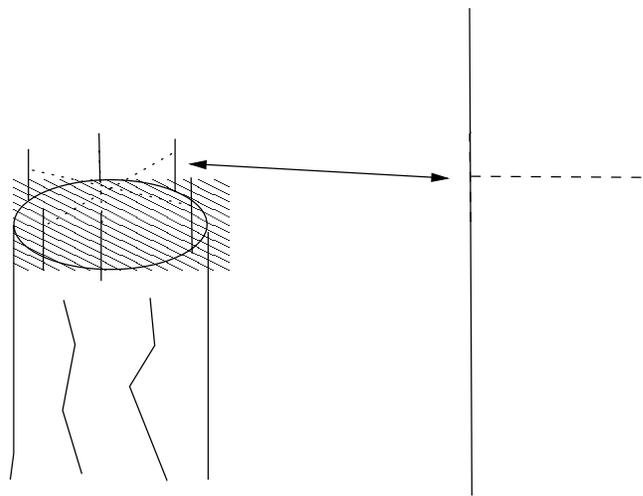


Figure 2—Illustration of how single marked silhouettes, which are marked on separate images, are used to estimate the diameter of a tree cylinder.

## PROCEDURES

To evaluate the methodology I applied the procedures to a number of hardwood trees with images taken both during the leaf-on and leaf-off seasons. D.b.h. was measured with a diameter tape to compare to the diameters obtained by the optical procedures. In general, only the first 25 feet of each the tree's stem was measured for taper in roughly 1-foot increments.

The software I used to process the images was Photomodeler® (Photomodeler Pro 5 2003). This software was not designed for constructing taper equations. It was designed to produce "as built" drawings of buildings for architects. Archeologists use the software to document historical ruins of building, and insurance agents and law enforcement personnel use it to document vehicle collisions. Using this software to construct taper models, as reported here, is a novel application and not easily accomplished in the current configuration of the software; however, the company has been very helpful making changes and additions to the software to allow it to be used to estimate tree taper data.

I calibrated the camera by photographing a target from multiple angles. An automated procedure of the software processed the images and produced a correction matrix for the camera and lens that I used for subsequent tree measurements. Once calibrated, all photographs taken with this particular camera and lens combination were tagged for this calibration file.

I used three, 6-foot-long poles with yellow foam practice golf balls at each end to provide both matching points at fixed distances in the scene. I also used a 25-foot telescoping height pole next to the subject tree. These items were carried by one individual, and set-up time took < 10 minutes per tree. Once the matching points were established in the area, they were not moved during the process of photographing the scene.

I took 12 to 16 images in a circle around each subject (fig. 3). Not all images were useable, some because the camera was aimed at the sun, creating too much contrast, and others because some of the targets were behind leaves or stems. Typically, out of 16 images, I used 4 to 6 good ones. To further

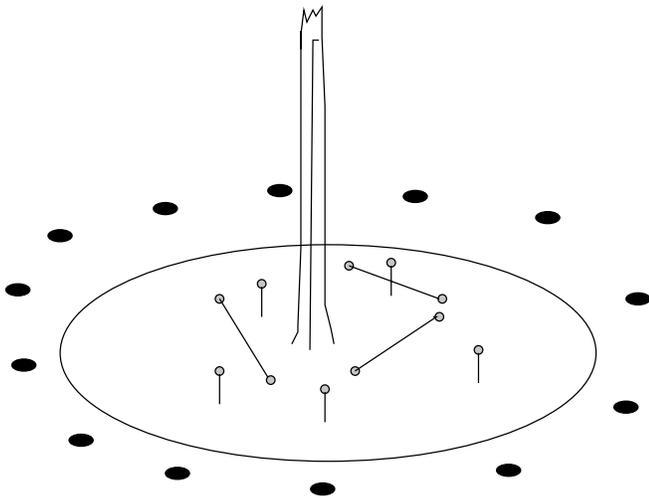


Figure 3—Illustration to describe the arrangement of control points around the subject tree. The black dots represent the potential photograph locations.

evaluate the method, images on one tree were taken in September and again in February. The procedures were the same each time.

Figure 4 shows the three images used to capture the sample space. In each photograph, the same point is marked. Each photograph must have 6 common points of known distance apart.

Figure 2 illustrates a single-stem silhouette tied together to produce a cylinder. It produced a cylinder having a diameter that was the average of three diameter measurements. If more images are used, the number of diameters averaged increases at one per additional image. The fact that the images are from very different angles improves the accuracy of the measurements.

## RESULTS AND DISCUSSION

Nine trees are presented as representative examples of the type of data that can be acquired from these photographs. Most of the taper trend lines extend just beyond the 25-foot pole height, but one example in the cherrybark oak dataset extends to almost 60 feet (fig. 5). The height that could be measured was limited by the view of the tree from multiple

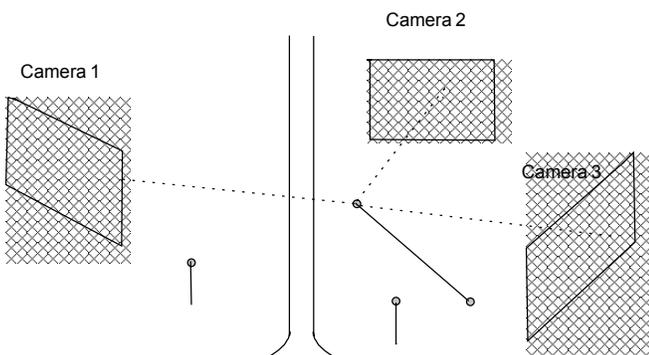


Figure 4—Illustration of how a single point is tied from three photographs to help create a 3-dimensional model.

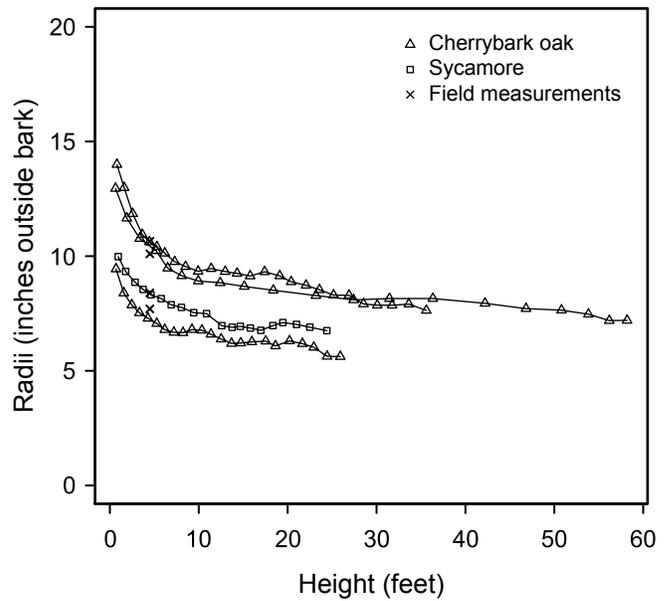


Figure 5—Graph of the taper data from the first dataset of cherrybark oak *Quercus pagoda* Raf.) and American sycamore (*Platanus occidentalis* L.) trees from plots near Helena, AR.

angles. Figure 6 illustrates the Missouri sample trees. The points labeled “field” are the diameter tape measurements for the sample trees. In most cases, they are the same value but sometime differ by as much as 0.2 inches. Several interesting points are evident. There is very good agreement between the diameters measured in the field and on the photograph, in most cases. Also, there was remarkable shape similarity among individuals of the same species. This has been noted elsewhere (Clark and others 2000), illustrating why taper equations are species specific.

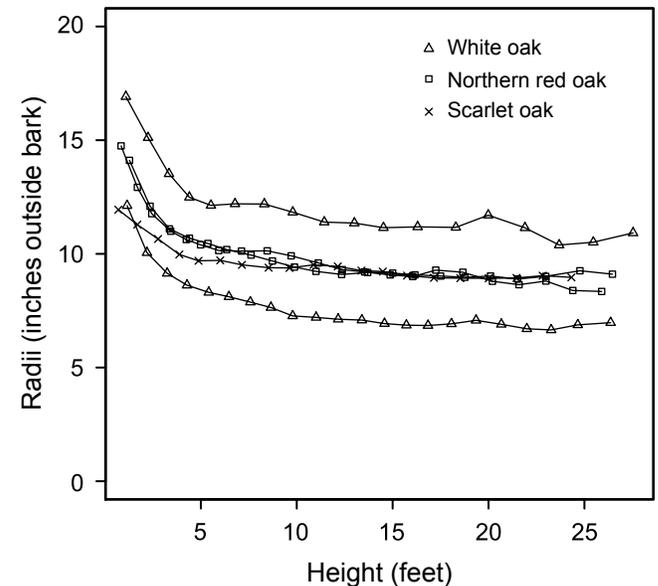


Figure 6—Graph of taper data from the second and third datasets of white oak (*Quercus alba* L.), scarlet oak (*Q. coccinea*, Muenchh.), and northern red oak (*Q. rubra* L.) collection at University Forest, Wappello, MO and Baskett Wildlife Research Area, Ashland, MO.

The measurement of the same tree during two different seasons (leaf-on versus leaf-off) showed the high degree of reproducibility (fig. 7). However, I found some differences in stem radii, particularly near the top of the stem. These differences appeared to be due to foliage or branches blocking the stem when the photos were taken (fig. 1). The procedure seemed to work best when images were taken during the winter when there was no foliage to obstruct the view and there was more light shining on the bole of the subject tree. Also, measurements made higher along the stem were subject to some distortion because there were fewer control points at heights near the top of the measured portion of the stem.

One of the most difficult problems when working with tree images is to have control points that can be uniquely identified in all images. In images of buildings, it is easy to identify many unique control points such as window corners, building corners, and building trim pieces. In the forest, it is difficult to distinguish one twig or leaf from another when viewing images taken from different angles. To address this, I added man-made objects to the sampling area. I found incidental items like notebooks, water bottles, and clothing all increased the number of control points to align images. Additionally, I found that marking-pins made of yellow foam practice golf balls glued to the ends of fiberglass rods were helpful for aligning the images. Using marking pins each with balls having a unique color would make it easier to distinguish among control points. I also found that using flagging to mark the breast height diameter and stump diameter was very helpful for locating these points on the images and provided a means for checking estimated diameters with those made on the actual tree.

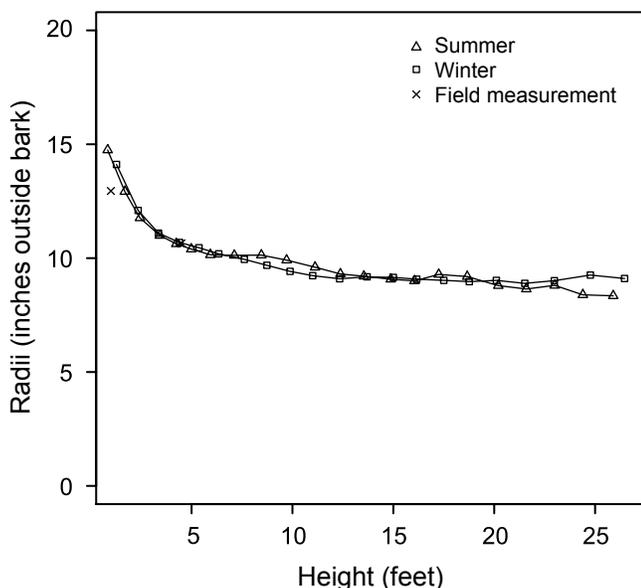


Figure 7—Graph of a single northern red oak (*Quercus rubra* L.) tree sampled in September and February to compare summer and winter measurements. The tree is from the Baskett Wildlife Research Area, Ashland, MO.

The procedure requires a fairly short set-up time to image a tree. I found that I could establish the control points, flag and measure the stump diameter and tree diameter, and take all the pictures in 20 minutes per tree. More time is required in the office as I generally spent about 2 hours per tree processing the images and generating the taper data. Thus, the amount of time required to generate taper data with this method is  $\leq$  the time required by traditional methods. Moreover, the method has the added advantage of retaining a permanent record of the data, thus providing the means for remeasuring the tree without having to return to the field.

## CONCLUSIONS

I believe that this photogrammetric method of measuring tree taper has accuracies comparable to traditional methods and has several advantages including: (1) creating a permanent record of the tree; (2) showing multiple sides of each tree to be measured; (3) allowing measurements to be done in the comfort of an office, not out in the cold, heat, or rain; and (4) providing a nondestructive method of obtaining tree taper measurements. Overall, the method appears to be a suitable and efficient one for obtaining tree taper measurements.

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## LITERATURE CITED

- Clark, N.A.; Wynne, R.H.; Schmoltdt, D.L. 2000. A review of past research on dendrometers. *Forest Science*. 46: 570-576.
- Clatterbuck, W.K.; Oliver, C.D.; Burkhart, E.C. 1987. The silvicultural potential of mixed stands of cherrybark oak and (American) sycamore: (spacing) is the key. *Southern Journal of Applied Forestry*. 11: 158-161.
- Dean, C. 2003. Calculation of wood volume and stem taper using terrestrial single-image close-range photogrammetry and contemporary software tools. *Silva Fennica*. 37: 359-380.
- Oliver, C.D.; Clatterbuck, W.K.; Burkhart, E.C. 1990. Spacing and stratification patterns of cherrybark oak and American sycamore in mixed, even-aged stand in the Southeastern United States. *Forest Ecology and Management*. 31: 67-79.
- Photomodeler Pro 5. 2003. User manual. V6J 1Y6. Vancouver, BC, Canada: EOS System, Inc. 488 p.
- Thompson, M.M., ed. 1965. *Manual of photogrammetry*. Third edition. Falls Church, VA: American Society of Photogrammetry. 1199 p.

# AN ECONOMIC COMPARISON OF SLASH AND LOBLOLLY PINE UNDER VARIOUS LEVELS OF MANAGEMENT IN THE LOWER ATLANTIC AND GULF COASTAL PLAIN

E. David Dickens, Coleman W. Dangerfield, Jr., and David J. Moorhead<sup>1</sup>

**Abstract**—Nonindustrial private forest (NIPF) landowners have perceived reduced product market availability and increased price uncertainty since late 1997 in the southeastern United States. Lower Atlantic and Gulf Coastal Plain NIPF landowners seek management options utilizing two commonly available pine species, loblolly (*Pinus taeda* L.) and slash (*Pinus elliottii* Engelm.), to enhance feasibility, profitability, and cash-flow of production forestry enterprises. At the same time, NIPF landowners desire heightened flexibility across time required to achieve marketable forest products. This paper examines feasibility, profitability, and cash-flow of 24-year rotation management options affecting wood-flow for slash and loblolly pine plantations. Modeled treatments include thinning, fertilization, and pine straw harvests under alternative levels of productivity and current (2004) product prices. Calculated financial measures of profitability include net revenue and internal rate of return using the Georgia Pine Plantation Simulator (GaPPS 4.20) growth and yield model developed at The University of Georgia Warnell School of Forest Resources.

## INTRODUCTION

Nonindustrial private forest (NIPF) landowners in the lower Atlantic and Gulf Coastal Plain from South Carolina to Mississippi question whether to plant slash or loblolly pine on cut-over and old-field sites. They also question making moderate to relatively large investments for intensive forest management under the current and anticipated stumpage prices and future economic uncertainty. To address these questions, we used the Georgia Pine Plantation Simulator (GaPPS 4.20) growth and yield model developed by Bailey and Zhao (1998). The majority of stand and tree data to develop the GaPPS growth and yield models for slash and loblolly were in the 10- to 25-year age classes. Therefore, we used a 24-year rotation age that had a mixed product class distribution of pulpwood and chip-n-saw (CNS). Generally, culmination of merchantable volume mean annual increment occurs for both species on average to good sites and moderate levels of management by age 20 to 25 (Pienaar and others 1996). Longer rotation ages are often financially attractive but will not be addressed in this paper.

## METHODOLOGY

### Common Assumptions

The rotation age was set at 24 years for slash and loblolly pine plantations. Net revenue (NR, sum of all revenues minus all costs in 2004 dollars) and internal rate of return (IRR) were calculated. Calculation of IRR assumes intermediate cash-flows are reinvested in the scenario at the IRR, not the discount rate. A discount rate of 8 percent was used for intermediate or annual costs and returns. Fire protection cost was set at \$2 acre<sup>-1</sup>year<sup>-1</sup>, stand management at \$2 acre<sup>-1</sup>year<sup>-1</sup>, and property taxes at \$5 acre<sup>-1</sup>year<sup>-1</sup>. Thus, the total annual costs for each year of the rotation were \$9 acre<sup>-1</sup>. This value cost goes in the transaction table as an annual cost during the rotation. The present value of this net, annual cost flow is \$94.75 during the 24-year rotation. Results are reported in constant dollars, before taxes. It is assumed that land is already owned.

### Site Preparation and Planting Costs

Three site preparation and planting (SP+PL) costs rise in increments of \$125 acre<sup>-1</sup> (\$125, \$250, and \$375 acre<sup>-1</sup>). These costs represent the following site preparation and planting scenarios: The low site preparation and planting cost of \$125 acre<sup>-1</sup> could include machine planting and the use of a post plant herbicide to control herbaceous weeds on an old-field site, glyphosate at 1 gallon acre<sup>-1</sup>, or prescribe burning (low level) site preparation and roughland planting on a cutover site. The moderate (\$250 acre<sup>-1</sup>) establishment cost could include a mechanical site preparation treatment, burn and plant, or a herbicide, burn, plant, and herbaceous weed control (Dubois and others 1999). The high (\$375 acre<sup>-1</sup>) establishment cost could include a combination of chemical and mechanical site preparation as can be the case on many flatwoods cutover sites.

Site preparation options and associated costs vary extensively by location, prior stand history, harvesting utilization, landowner objectives, monies available, and anticipated future stumpage value and demand. The assumption used was that level of site preparation intensity was matched to level of competition control needed so that wood-flows were comparable within site productivity levels, after site preparation and planting.

### Product Class Specifications

The three product class specifications are: (1) pulpwood (PW) at a d.b.h. of 4.6 to 9 inches to a 3 inch top, (2) CNS at a d.b.h. of 9 through 12 inches to 6 inch top, and (3) sawtimber (ST) with a d.b.h. > 12 inches to a 10 inch top (inside bark) (table 1).

Georgia stumpage prices, reported through Timber Mart-South<sup>®</sup> (TM-S 2004) for first quarter, year 2004 average, were used in this analysis for loblolly and slash. Prices were the net of property taxes at harvest (2.5 percent) and the net of marketing costs (8 percent). The low TM-S prices for pulpwood and CNS were used for thinning prices and average TM-S prices for pulpwood, CNS, and ST are used for the clearcut. Cash and net-converted prices are found in table 2.

<sup>1</sup> Forest Productivity Associate Professor, P.O. Box 8112 GSU, Statesboro, GA 30460; Forest Economics Professor, The University of Georgia, Warnell School of Forest Resources, Athens, GA 30602-2152; and Silviculture Professor, P.O. Box 748, Tifton, GA 31793, respectively.

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**Table 1—Product class specifications for pulpwood (PW), chip-n-saw (CNS), and sawtimber (ST)**

Product/Item	PW	CNS	ST
Small end diameter ( <i>inches</i> )	3	6	10
Minimum length ( <i>feet</i> )	5	8	8
Length increment ( <i>feet</i> )	1	4	8

**Table 2—Product prices, cash and net (net of property taxes and marketing costs) per cord stumpage prices used in the profitability analysis of slash and loblolly scenarios, Georgia State average, price per ton (1stQ TM-S 2004)**

Item, price level	Cash or net	Pulpwood	Chip-N-Saw	Saw-timber
----- \$ ton <sup>-1</sup> -----				
Low	Cash	5.04	21.36	35.91
	Net	4.51	19.12	32.14
Medium	Cash	6.42	25.80	40.97
	Net	5.75	23.09	36.51

### Species Specific Assumptions

The slash pine scenarios assumed 500 living trees per acre (TPA) at age 5. A base mean annual increment of 2.09 cords acre<sup>-1</sup>year<sup>-1</sup> (5.77 tons acre<sup>-1</sup>year<sup>-1</sup>) at age 24 without fertilization or thinning was assumed. The base slash scenario woodflow was approximately 15 percent less than base loblolly woodflow (Shiver and others 1999) at age 24. The assumed fertilizer applications increased merchantable volume by an average of 0.50 cord acre<sup>-1</sup>year<sup>-1</sup> (1.38 tons acre<sup>-1</sup>year<sup>-1</sup>) for 8 to 10 years following treatment (Jokela and Stearns-Smith 1993).

The loblolly pine survival was also assumed to be 500 TPA at age 5. The base mean annual increment for loblolly was assumed to be 2.35 cords acre<sup>-1</sup>year<sup>-1</sup> (6.48 tons acre<sup>-1</sup>year<sup>-1</sup>) through age 24 without fertilization or thinning. The base loblolly woodflow was approximately 15 percent greater than the slash base woodflow (Shiver and others 2000) at age 24. The assumed fertilizer applications increased merchantable volume by an average of 0.65 cord acre<sup>-1</sup>year<sup>-1</sup> (1.79 tons acre<sup>-1</sup>year<sup>-1</sup>) for 8 to 10 years (NCSUFNC 1998).

## FOREST MANAGEMENT ACTIVITIES

### Thinning

The thinning scenarios include no thinning or one thinning at 15 years (scenario # 2, 6 through 9). Total woodflow of scenario with thinning is approximately 95 percent of total woodflow of scenario without thinning for slash and loblolly without fertilization. Residual basal area (RBA), after thinning (fifth row with selection from below) is set at 65 square feet acre<sup>-1</sup>.

### Fertilization

A fertilizer and application cost of \$100 acre<sup>-1</sup> for slash and loblolly per application at age 6 and 16 was assumed. Fertilization

with 150 and then 200 N + 40 P (as diammonium phosphate and urea) per acre was part of this scenario to maintain pine straw production rates (Dickens 1999), to enhance wood volume (NCSUFNC 1998), and to change product class distribution (Dickens 2001, Peinaar and Rheney 1996). Fertilization timing at age 6 was 2 years prior to the initiation of straw raking (just prior to canopy closure). The second application, 10 years later, was just after a thinning (thinning scenario) and after the response (wood and straw) to the first application has become negligible. The periodic fertilizer application costs are converted to present values (PV) in year 1, then re-computed as annual equivalent values (AEV). These AEVs were then put in the transaction table as annual expense cash-flows (table 3).

Scenarios with fertilization for both loblolly and slash pine were set-up as follows: (#3) to delay fertilization cost, (#4) to maintain or enhance pine straw production from canopy closure (age 6 only), (#5) to maintain pine straw production (age 6 and 16) through the rotation with a higher annual revenue, (#6) to change product class distribution and put extra growth on best trees after thinning (age 16 only), (#7 and #8) to maintain or enhance pine straw production from just prior to canopy closure (age 6 only) to the first thinning, and (#9) to maintain or enhance pine straw production from just prior to canopy closure (age 6) to the first thinning and to change product class distribution and put extra growth on best trees after thinning (age 16).

### Pine Straw

The pine straw income assumptions included were as follows: \$50 and \$100 acre<sup>-1</sup> year<sup>-1</sup> raking income for the slash and loblolly scenarios has been noted in south (slash) and central (loblolly) Georgia between 1998 and 2003 (Doherty and others 2004). Pine straw is raked starting in year 8 (approximating canopy closure) for slash and loblolly pine. Periodic pine straw income was converted to present values (PV) in year 1, then re-computed as AEVs at the discount rate of 8 percent. These AEVs were then put in the transaction table as annual income cash-flows (table 4). There was an associated clean-up cost to get the stand rakeable of \$70 acre<sup>-1</sup> (\$20.43 present value and \$1.94 AEV acre<sup>-1</sup>) where pine straw was raked after the thinning (scenario #9). Scenarios that included pine straw income for both species are numbers 4, 5, and 7 through 9 (table 5a, 5b).

**Table 3—Fertilizer costs, \$100 acre<sup>-1</sup> per application cost levels, expressed as present values and annual equivalent values (AEV), as used in the profitability analysis for 24 year slash and loblolly scenarios**

Rotation	Applied	Present value of a periodic cost	Annual equivalent value of the periodic cost
---- years ----		\$ acre <sup>-1</sup>	\$ acre <sup>-1</sup> year <sup>-1</sup>
	6	63.02	5.99
24	16	29.19	2.77
	6, 16	92.21	8.76

**Table 4—Pine straw periodic per acre income levels expressed as present values and annual equivalent values (AEV) as used in the profitability analysis of slash and loblolly pine scenarios over a 24 year rotation**

Item rotation	Thin scenario	Periodic income acre <sup>-1</sup> year <sup>-1</sup> , raked	Present value of periodic income	AEV of periodic income
		----- \$ acre <sup>-1</sup> -----		\$ acre <sup>-1</sup> year <sup>-1</sup>
24 years	Thin at age 15	50 & 0 <sup>a</sup>	140.64	13.36
		100 & 0 <sup>a</sup>	281.28	26.72
		100 & 50 <sup>b</sup>	351.64	33.40
	No thin	50 <sup>c</sup>	239.11	22.71
100 <sup>c</sup>		478.21	45.42	

<sup>a</sup>With thinning, pinestraw raked in years 8 through 14.

<sup>b</sup>With thinning, pinestraw raked in years 8 through 14 and 17 through 23.

<sup>c</sup>With no thinning, pinestraw raked in years 8 through 23.

### Scenarios for the 24-year Rotation

The following are the nine slash (table 5a) and loblolly (table 5b) pine scenarios:

1. No thinning, no pine straw income, and no fertilization
2. Thin (at age 15 to 65 square feet acre<sup>-1</sup>), no pine straw, no fertilization
3. No thin, fertilize at age 16, no pine straw
4. No thin, fertilize at age 6 and rake pine straw from age 8 through age 23 at \$50 acre<sup>-1</sup>year<sup>-1</sup>
5. No thin, fertilize at ages 6 and 16 and rake pine straw from age 8 through age 23 at \$100 acre<sup>-1</sup>year<sup>-1</sup>
6. Thin, fertilize after the thinning (age 16), no pine straw
7. Thin, fertilize at age 6 and rake pine straw at \$50 or \$100 acre<sup>-1</sup>year<sup>-1</sup> from age 8 through 14
8. Thin, fertilize at age 6 and rake pine straw at \$50 or \$100 acre<sup>-1</sup>year<sup>-1</sup> from age 8 through 14
9. Thin, fertilize at ages 6 and 16, and rake pine straw at \$100 acre<sup>-1</sup>year<sup>-1</sup> in years 8 through 14 and \$50 acre<sup>-1</sup>year<sup>-1</sup> in years 17 through 23.

## RESULTS

### NR and IRR Ranges

NR ranged from \$1,187 (base slash pine scenario with highest site preparation and planting cost) to \$4,171 per acre (loblolly with pine straw at \$100 acre<sup>-1</sup>year<sup>-1</sup>, no thin, fertilize twice, and lowest site preparation and planting cost; table 5a, 5b). Ranking of scenarios by NR within a SP+PL level were as follows: 5 > 9 > 8 > 4 > 7 > 6 > 3 > 2 > 1 for both loblolly and slash pine. NR for slash pine (growing at approximately 15 percent less than loblolly) were 15 to 20 percent less than corresponding loblolly scenarios (table 5a, 5b).

IRR for both species and all scenarios (54 scenarios in all) had a very wide range, between 5.48 and 6.16 percent (base slash and loblolly scenarios with highest site preparation and planting cost, respectively) to 24.64 and 24.96 percent (slash and loblolly pine scenarios with the lowest site preparation and planting cost, no thin, fertilize twice, and rake straw at \$100 acre<sup>-1</sup>year<sup>-1</sup> from age 8 through 23, respectively) using

the aforementioned assumptions (table 5a, 5b). Ranking of scenarios by IRR within a SP+PL level were as follows: 5 > 9 > 8 > 4 > 7 > 6 > 3 > 2 > 1 for both loblolly and slash pine. Generally, these levels of forest management are economically justifiable in these cases, even using low to medium first quarter 2004 stumpage prices (TM-S 2004) for Georgia.

### Impact of Thinning on NR and IRR

Thinning increased total harvest revenues and NR by \$350 (slash) to \$409 acre<sup>-1</sup> (loblolly) compared to the unthinned counterpart. Thinning slash and loblolly pine stands increased IRR by 1.19 to 1.59 percent (slash, table 5a) and by 1.35 to 1.87 percent (loblolly, table 5b) over unthinned, unraked stands (scenario #1 versus 2).

### Impact of Pine Straw Income on NR and IRR

The pine straw income prior to thinning (age 8 through 14) increased NR by \$641 to \$1,010 acre<sup>-1</sup> (\$350 and \$70 is not pine straw income) in the thinned scenarios (scenario #7 and #8) over the thin, no pine straw scenario (scenario #2). When pine straw was raked before and after the thinning, (scenario #9) NR increased by \$1,515 to \$1,721 (\$780 acre<sup>-1</sup> in net straw income) over the thin, no pine straw scenario (#2) for slash and loblolly, respectively (table 5a, 5b). In unthinned stands, pine straw income and fertilization (age 8 through 23) increased NR by \$1,168 to \$2,480 acre<sup>-1</sup> for both species (\$700 and \$1400 acre<sup>-1</sup> in net straw income) (table 5a, 5b).

The addition of pine straw income for slash pine in the unthinned scenarios (#4 and #5) increased base scenario (#1) IRR from 5.48 (at \$375 acre<sup>-1</sup> SP+PL), 6.96 (at \$250 acre<sup>-1</sup> SP+PL), and 9.30 (at \$125 acre<sup>-1</sup> SP+PL) percent to 8.77, 10.95, and 15.16 percent at the \$50 acre<sup>-1</sup>year<sup>-1</sup> pine straw income rate in unthinned stands (table 5a). Raising the annual pine straw income to \$100 acre<sup>-1</sup>year<sup>-1</sup> from age 8 through 23 increased internal rates of return to 12.27 (at \$375 acre<sup>-1</sup> SP+PL), 15.71 (at \$250 acre<sup>-1</sup> SP+PL), and 24.64 (at \$125 acre<sup>-1</sup> SP+PL) percent (table 5a).

In thinned slash pine stands, pine straw income increased IRR from 6.67, 8.28, and 10.89 percent (thin, no straw; scenario #2) to 8.53, 10.46, and 13.83 percent, for three \$375, \$250, and \$125 acre<sup>-1</sup> SP+PL costs, respectively when \$50 acre<sup>-1</sup>year<sup>-1</sup>

**Table 5a—A comparison of slash pine plantation management scenarios<sup>a</sup> under a 24-year rotation and their effect on net revenue and internal rate of return (IRR), with site prep and plant (SP&PL) cost of \$125, \$250, and \$375 acre<sup>-1</sup>**

Treatment					SP&PL @ \$125		SP&PL @ \$250		SP&PL @ \$375	
Scenario #	Thin fertilize @ year			MIA <sup>b</sup>	Net revenue <sup>c</sup>	IRR <sup>d</sup>	Net revenue <sup>c</sup>	IRR <sup>d</sup>	Net revenue <sup>c</sup>	IRR
	15	Pine straw	PW	tons, cords						
		\$ acre <sup>-1</sup>	percent		\$ acre <sup>-1</sup>	percent	\$ acre <sup>-1</sup>	percent	\$ acre <sup>-1</sup>	percent
1	N	N	60	5.77, 2.09	1,437	9.30	1,312	6.96	1,187	5.48
2	N	Y	46	5.55, 2.01	1,787	10.89	1,662	8.28	1,537	6.67
3	Y, 16	N	48	6.28, 2.28	1,912	10.19	1,787	7.96	1,662	6.53
4	Y, 6	N	50 <sup>e</sup>	6.28, 2.28	2,805	15.16	2,680	10.95	2,555	8.77
5	Y, 6, 16	N	100 <sup>e</sup>	6.82, 2.48	3,686	24.64	3,561	15.71	3,436	12.27
6	Y, 16	Y	40	6.16, 2.23	2,162	11.51	2,037	9.00	1,912	7.43
7	Y, 6	Y	50 & 0 <sup>f</sup>	6.16, 2.23	2,447	13.83	2,322	10.46	2,197	8.53
8	Y, 6	Y	100 & 0 <sup>f</sup>	6.16, 2.23	2,797	18.12	2,672	12.87	2,547	10.31
9	Y, 6, 16	Y	100 & 50 <sup>g</sup>	6.57, 2.38	3,302	19.42	3,177	13.80	3,052	11.12

**Table 5b—A comparison of loblolly pine plantation management scenarios<sup>a</sup> under a 24-year rotation and their effect on net revenue and internal rate of return (IRR), with site prep and plant (SP&PL) cost of \$125, \$250, and \$375 acre<sup>-1</sup>**

Treatments					SP&PL @ \$125		SP&PL @ \$250		SP&PL @ \$375	
Scenario #	Thin fertilize @ year			MIA <sup>b</sup>	Net revenue <sup>c</sup>	IRR <sup>d</sup>	Net revenue <sup>c</sup>	IRR <sup>d</sup>	Net revenue <sup>c</sup>	IRR <sup>d</sup>
	15	Pine straw	PW	tons, cords						
		\$ acre <sup>-1</sup>	percent		\$ acre <sup>-1</sup>	percent	\$ acre <sup>-1</sup>	percent	\$ acre <sup>-1</sup>	percent
1	N	N	60	6.48, 2.35	1,701	10.04	1,576	7.66	1,451	6.16
2	N	Y	46	6.24, 2.26	2,110	11.91	1,985	9.18	1,860	7.51
3	Y, 16	N	48	7.15, 2.59	2,173	10.76	2,048	8.50	1,923	7.05
4	Y, 6	N	50 <sup>e</sup>	7.15, 2.59	2,871	15.62	2,746	11.42	2,621	9.24
5	Y, 6, 16	N	100 <sup>e</sup>	7.94, 2.88	4,171	24.98	4,046	16.24	3,921	12.85
6	Y, 16	Y	40	6.99, 2.53	2,481	12.44	2,356	9.81	2,231	8.17
7	Y, 6	Y	50 & 0 <sup>f</sup>	7.68, 2.78	2,751	14.63	2,626	11.16	2,501	9.18
8	Y, 6	Y	100 & 0 <sup>f</sup>	7.68, 2.78	3,101	18.83	2,976	13.51	2,851	10.91
9	Y, 6, 16	Y	100 & 50 <sup>g</sup>	7.68, 2.78	3,831	20.56	3,706	14.83	3,581	12.08

<sup>a</sup> Uninflated, 8% discount rate, before income taxes, GaPPS v 4.20.

<sup>b</sup> MAI = Mean Annual Increment of wood growth, Tons & Cords ac<sup>-1</sup>yr<sup>-1</sup>.

<sup>c</sup> Net Revenue = Harvest revenue(s) – SP+PL cost – (annual cost x 24 yrs) – fert cost(s) – clean up cost + pine straw revenues (2004 \$).

<sup>d</sup> IRR = internal rate of return of the investment scenario (percent).

<sup>e</sup> With no thinning, pinestraw raked years 8 through 23.

<sup>f</sup> With thinning, pinestraw raked years 8 through 14.

<sup>g</sup> With thinning, pinestraw raked years 8 through 14 and 17 through 23.

pine straw revenue was realized from age 8 through 14 (scenario #7, table 5a). Pine straw raking in the slash scenario prior to thinning only (age 8 through 14) at \$100 acre<sup>-1</sup>year<sup>-1</sup> produced internal rates of return of 10.31, 12.87, and 18.12 percent (scenario #8). Pine straw raking in the slash scenario prior to thinning (age 8 through 14) at \$100 acre<sup>-1</sup>year<sup>-1</sup> and after the thinning (ages 17 through 23) at \$50 acre<sup>-1</sup>year<sup>-1</sup> produced internal rates of return of 11.12, 13.80, and 19.42 percent (scenario #9).

The addition of pine straw income for loblolly pine in the unthinned scenarios (#4 and #5) increased base scenario (#1) internal rates of return from 6.16 (at \$375 acre<sup>-1</sup> SP+PL), 7.66 (at \$250 acre<sup>-1</sup> SP+PL), and 10.04 (at \$125 acre<sup>-1</sup> SP+PL) percent to 9.24, 11.42, and 15.62 percent at the \$50 acre<sup>-1</sup>year<sup>-1</sup>

pine straw income rate in unthinned stands (table 5b). Raising the annual pine straw income to \$100 acre<sup>-1</sup>year<sup>-1</sup> from age 8 through 24 increased internal rates of return to 12.85 (at \$375 acre<sup>-1</sup> SP+PL), 16.24 (at \$250 acre<sup>-1</sup> SP+PL), and 24.98 (at \$125 acre<sup>-1</sup> SP+PL) percent (table 5b).

In thinned loblolly pine stands (scenario #2), pine straw income increased internal rates of return from 7.51, 9.18, and 11.91 percent to 9.18, 11.16, and 14.63 percent, for three \$375, \$250, and \$125 acre<sup>-1</sup> SP+PL costs, respectively when \$50 acre<sup>-1</sup>year<sup>-1</sup> pine straw revenue was realized from age 8 through 14 years (scenario #7, table 5b). Pine straw raking in the loblolly scenario prior to thinning only (age 8 through 14) at \$100 acre<sup>-1</sup>year<sup>-1</sup> produced IRR of 10.91, 13.51, and 18.83 percent (scenario #8). Pine straw raking in the loblolly scenario

prior to thinning (age 8 through 14) at \$100 acre<sup>-1</sup>year<sup>-1</sup> and after the thinning (ages 17 through 23) at \$50 acre<sup>-1</sup>year<sup>-1</sup> produced IRR of 12.08, 14.83, and 20.56 percent (scenario #9).

### Impact of Fertilization on NR and IRR

In the unthinned scenarios, NR increased by \$470 to \$475 acre<sup>-1</sup> with fertilization at age 16 (scenario #3) compared to the no fertilization (scenario #1) for both species (table 5a, 5b). In the thinned scenarios, fertilization just after thinning (scenario #6) increased NR by \$370 to \$375 acre<sup>-1</sup> compared to the thin only (scenario #2) (table 5a, 5b) for loblolly and slash pine.

Fertilization in unthinned slash pine stands with 200 N + 40 P acre<sup>-1</sup> at age 16 (\$100 acre<sup>-1</sup> cost in year 16), increased IRR by about 1 percentage point across the three SP+PL levels (scenario #1 vs #3, table 5a). Fertilization at age 16 IRR (scenario #3) was about 0.10 to 0.70 percentage points below the thin only scenario (#2). The combination of thinning slash pine at age 15 and fertilization at age 16 (scenario #6) improved IRR by 0.62 to 0.76 percent over the thin only (scenario #2).

Fertilization in unthinned loblolly pine stands with 200 N + 40 P acre<sup>-1</sup> at age 16 (\$100 acre<sup>-1</sup> cost in year 16), increased IRR by a 0.74 to 0.89 percentage point across the three SP+PL levels (scenario #1 versus #3, table 5b). Fertilization at age 16 IRR (scenario #3) was about 0.46 to 1.15 percentage point below the thin only (scenario #2). The combination of thinning loblolly pine at age 15 and fertilization at age 16 (scenario #6) improved IRR by 0.53 to 0.65 percent over the thin only (scenario #2).

### Impact of Establishment Costs on NR and IRR

The impact of establishment costs (site preparation and planting; SP+PL) was straight-forward: net revenues differing by increments of \$125 acre<sup>-1</sup> within a scenario by species. Establishment cost impact on the time-value of money, though, was large.

Within a management level scenario, the impact of establishment costs was large enough to illustrate the importance of choosing the right SP+PL for a given site. The impact of SP+PL on IRR became larger as management inputs increased for both species. For example: The base slash pine scenario (#1) of no thinning, no fertilization, and no straw had IRRs of 5.48, 6.96, and 9.30 percent, differences of 1.48 and 2.34 percentage points. Slash pine scenario #5 had IRRs of 12.27, 15.71, and 24.64 percent, differences of 3.44 and 8.93 percentage points compared to the base scenario (#1, table 5a). The impact of SP+PL in the loblolly scenarios showed the same trend as the slash pine scenarios.

### Impact of Management Inputs on NR and IRR

Generally, increasing management, whether through a thinning or with fertilization or clean-up for pine straw after a thinning with their associated costs, increased NR and IRR for both species. Thinning improved NR by \$350 to over \$400 acre<sup>-1</sup> for slash and loblolly pine, respectively (table 5a, 5b). Fertilization increased NR by \$350 to \$475 acre<sup>-1</sup> over the unfertilized scenario counterparts. Adding pine straw increased NR by a wide range (from \$350 to \$1,400 acre<sup>-1</sup>; table 5a, 5b). In each case NR increased with increasing forest management within a given SP+PL level for both species.

The exception was scenario #3 (fertilization at age 16, no thinning, and no straw). The IRR for scenario #3 for slash (table 5a) and loblolly (table 5b) was lower by 0.14 to 1.15 percentage point than scenario #2 (no fertilization, thinning, and no straw). Thinning (scenario #2) improved IRRs for both species by 1.19 to 1.87 percent over the unthinned scenario (#1; table 5a, 5b).

Adding pine straw income greatly improved IRRs for both species, by 2.24 to 4.97 percent for slash pine (scenario #4 vs #3) and 2.19 to 4.86 percent for loblolly (scenario #4 versus #3) at the \$50 acre<sup>-1</sup>year<sup>-1</sup> from age 8 through 23 (no thinning; table 5a, 5b). The \$100 acre<sup>-1</sup>year<sup>-1</sup> pine straw revenue from age 8 through age 23 further improved IRRs by 3.50 to 9.48 percent for slash pine (scenario #5 vs #4) and by 3.61 to 9.36 percent for loblolly pine (scenario #5 vs #4) over the \$50 acre<sup>-1</sup>year<sup>-1</sup> income rate.

## SUMMARY

### Wood Flow, Fertilization Responses, and Pine Straw

The productivity levels at age 24 for slash [2.09 cords acre<sup>-1</sup>year<sup>-1</sup> (5.77 tons acre<sup>-1</sup>year<sup>-1</sup>)] and loblolly [2.35 cords acre<sup>-1</sup>year<sup>-1</sup> (6.48 tons acre<sup>-1</sup>year<sup>-1</sup>)] are very realistic on most cut-over sites with chemical site preparation and post-plant herbaceous weed control (Pienaar and Rheney 1996) and is conservative on most old-field sites. Exceptions would be problem soils such as deep sands (Typic Quartzipsamments) of the Sand Hills or shallow, rocky soils of the Piedmont physiographic region.

These scenarios illustrate, given the aforementioned base growth rates for slash pine and loblolly pine, that establishment expenditures must be carefully considered. In many cases the establishment phase decisions (site preparation type, timing, quality, site preparation effects on near- or long-site productivity, woody and herbaceous weed control efficacy, species selection, seedling genetics and size, seedling survival) can improve growth rates above those used here, therefore improving rates of return.

The average increase in wood production for slash [0.50 cord acre<sup>-1</sup>year<sup>-1</sup> (1.37 tons acre<sup>-1</sup>year<sup>-1</sup>)] and loblolly [0.65 cord acre<sup>-1</sup>year<sup>-1</sup> (1.79 tons acre<sup>-1</sup>year<sup>-1</sup>)] is consistent with published reports (Jokela and Stearns-Smith 1993, Martin and others 1999, NCSFNC 1999) with nitrogen plus phosphorus fertilization at ages 6 and 16. No increase in pine straw income per acre was assumed with fertilization. Fertilization studies (Blevins and others 1996, Dickens 1999) illustrate that pine straw production can be increased by an average of 40 to 50 percent over unfertilized stands on marginal-fertility soils. Fertilization was included in the pine straw production scenarios to maintain straw production as nutrients are removed/displaced with each raking.

When wood value only is considered, loblolly produced more wood of greater value and a higher NR and IRR with the aforementioned assumptions. Recent studies (Shiver and others 1999) have shown that loblolly will grow more wood than slash on a number of soils where both species are grown. Loblolly's superior wood volume yields do not necessarily equate to higher per acre or per unit wood stumpage prices. Clark and Daniels (2004) noted that slash pine yielded

more number one lumber, had a slightly greater (4 to 11 percent greater) density, and 4 percent less moisture content than loblolly pine growing in the same stand.

## DISCUSSION

NIPF landowners have attractive forest management options with both slash and loblolly pine even when at low to medium stumpage prices. Generally, increasing forest management activities (thinning, fertilization, adding pine straw) increased rates of return at the wood growth increments used.

If an internal rate of return of  $\geq 8$  percent is a landowner goal with the stumpage prices used (Georgia first quarter 2004, TM-S 2004) and the wood production rates of 2 cords acre<sup>-1</sup>year<sup>-1</sup> or better, then that can be achieved with thin scenario (#2) for both loblolly and slash pine at the lower two site preparation and planting establishment costs. At the highest SP+PL level, an IRR of  $\geq 8$  percent was achieved only when pine straw income at  $\geq \$50$  acre<sup>-1</sup>year<sup>-1</sup> was realized for both species (scenarios 4, 5, 7 through 9, table 5a, 5b).

If an IRR of  $\geq 10$  is a landowner objective under the aforementioned assumptions, then pine straw production to achieve \$100 acre<sup>-1</sup>year<sup>-1</sup> for both loblolly and slash pine is required at the highest SP+PL level. A  $\geq 10$  percent IRR can be realized at the moderate SP+PL cost with the rake at \$50 acre<sup>-1</sup>year<sup>-1</sup>, fertilize once, and thin or no thin scenarios (#4 and #7) for both species (table 5a, 5b). At the lowest SP+PL cost, all scenarios but scenario #1 for slash pine had an IRR  $> 10$  percent.

An IRR of  $\geq 12$  percent is realized at the highest SP+PL level when \$100 acre<sup>-1</sup>year<sup>-1</sup> pine straw income, no thinning, and fertilize twice is realized for slash and loblolly pine and at the \$100 acre<sup>-1</sup>year<sup>-1</sup> pine straw income, fertilize twice, thin, clean-up, and rake at \$50 acre<sup>-1</sup>year<sup>-1</sup> to clearcut scenario (#9) for loblolly. At the moderate SP+PL level, a IRR of  $\geq 12$  percent was realized with the rake at \$100 acre<sup>-1</sup>year<sup>-1</sup>, fertilize twice, no thin (scenario #5) or rake at \$100 acre<sup>-1</sup>year<sup>-1</sup> prior to thinning, fertilize, thin and rake or no-rake straw (scenarios #8 and #9) for loblolly and slash pine (table 5a, 5b).

## LITERATURE CITED

- Bailey, R.L.; Zhao, B. 1998. GaPPS (Georgia Pine Plantation Simulator) 4.20 Model. Athens, GA: University of Georgia, Warnell School of Forest Resources.
- Blevins, D.; Allen, H.L.; Colbert, S.; Gardner, W. 1996. Nutrition management for longleaf pine straw - woodland owner notes. Raleigh, NC: North Carolina Cooperative Extension Service Paper. 8 p.
- Clark, A., III; Daniels, R.F. 2004. Wood quality of slash pine and its effect on lumber, paper, and other products. In: Dickens, E.D.; Barnett, J.P.; Hubbard, W.G.; Jokela, E.J., eds. *Slash pine: still growing and growing!* Proceedings of the slash pine symposium. Gen. Tech. Rep. SRS-76. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 61-65.
- Dickens, E.D. 1999. The effect of inorganic and organic fertilization on longleaf tree growth and pine straw production. In: Haywood, J.D., ed. *Proceedings of the 10<sup>th</sup> biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 464-468.
- Dickens, E.D. 2001. The effect of one-time biosolids application in an old-field loblolly pine plantation on diameter distributions, volume per acre, and value per acre. In: Outcalt, K.W., ed. *Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 15-19.
- Doherty, B.A.; Teasley, R.J.; McKissick, J.C.; Givan, B. 2004. Two-thousand three farmgate value report. Staff report No. 6. Athens, GA: University of Georgia, College of Agriculture and Environmental Sciences, Center for Agribusiness and Economic Development Center. 160 p.
- Dubois, M.R.; McNabb, K.; Straka, T.K. 1999. Costs and cost trends for forestry practices in the South. *Forest Landowner Magazine*. March/April 1998: 3-8.
- Jokela, E.J.; Stearns-Smith, S.C. 1993. Fertilization of established southern pine stands: effects of single and split nitrogen treatments. *Southern Journal of Applied Forestry*. 17(3): 135-138.
- Martin, S.W.; Bailey, R.L.; Jokela, E.J. 1999. Growth and yield predictions for lower Coastal Plain slash pine plantations fertilized at mid-rotation. *Southern Journal of Applied Forestry*. 23(1): 39-45.
- Morris, L.A.; Jokela, E.J.; O'Connor, J.B., Jr. 1992. *Silvicultural guidelines for pine straw management in the Southeastern U.S.* Georgia Forest Research Paper #88. Macon, GA: Georgia Forestry Commission. 11 p.
- North Carolina State University Forest Nutrition Cooperative (NCSUFNC). 1998. 26<sup>th</sup> annual report. Raleigh, NC: North Carolina State University, School of Forest Resources. 23 p.
- Pienaar, L.V.; Rheney, J.W. 1996. Potential productivity of intensively managed pine plantations - final report. The Georgia Consortium for Technological Competitiveness in Pulp and Paper. 41 p.
- Pienaar, L.V.; Shiver, B.D.; Rheney, J.W. 1996. Yield prediction for mechanically site-prepared slash pine plantations in the Southeastern Coastal Plain. *Plantation Management Research Cooperative Technical Report 1996-3*. Athens, GA: University of Georgia, Warnell School of Forest Resources. 57 p.
- Shiver, B.D.; Rheney, J.W.; Hitch, K.L. 1999. Loblolly pine outperforms slash pine in southeast Georgia and northern Florida. *Southern Journal of Applied Forestry*. 24(1): 31-36.
- Timber Mart South (TM-S). 2004. Stumpage prices - 1<sup>st</sup> quarter South Georgia 2004. Athens, GA: University of Georgia, Warnell School of Forest Resources. 3 p.

# PARAMETER-BASED STOCHASTIC SIMULATION OF SELECTION AND BREEDING FOR MULTIPLE TRAITS

Jennifer Myszewski, Thomas Byram, and Floyd Bridgwater<sup>1</sup>

## INTRODUCTION

To increase the adaptability and economic value of plantations, tree improvement professionals often manage multiple traits in their breeding programs. When these traits are unfavorably correlated, breeders must weigh the economic importance of each trait and select for a desirable aggregate phenotype. Stochastic simulation allows breeders to test the effects of different breeding and selection strategies without the costs associated with empirical tests. However, most available simulation programs have limited applicability because they only model the management of a single trait. To solve this problem, we are developing a parameter-based stochastic simulation program that can model a variety of multiple-trait tree improvement strategies.

## METHODS

Five Excel<sup>TM</sup> and Simetar<sup>TM</sup>-based<sup>\*</sup> subprograms were written to simulate tree improvement for multiple traits in elite and mainline populations. Each subprogram incorporates a different mating design, but all have the same general organization. A variance/covariance structure is specified for a base population of undefined size, which serves as the initial source of genetic material for the tree improvement program. Then, either an elite breeding population is generated by selecting 30 trees at random from the base population, or a mainline population is generated by selecting 360 trees at random from the base population. All trees in the initial elite and mainline populations are assumed to be unrelated and non-inbred. Selections are crossed according to the designated mating designs to produce full- and half-sibling families for evaluation. Full-sibling families are ranked based on progeny mean index value, and the top individuals from the top families are selected for generation advancement. Where sublines are used, initial selections are first randomly assigned to different sublines; then all crosses and subsequent selections for generation advancement are made within sublines. In each generation, polymix tests are used to select individuals for the establishment of seed orchards. These tests are also used to rank selections for the positive assortative mating option based on breeding values. Selection, breeding, and testing are repeated for five generations, and summary statistics are output to a blank worksheet.

For the elite population simulations, four breeding strategies have been designed:

- 30 trees in one subline with trees randomly assigned to crosses and mated according to a circular mating design

- 30 trees in one subline with trees assigned to crosses using a positive assortative mating design where rankings are based on breeding value
- 30 trees in one subline with trees assigned to crosses using a positive assortative mating design where rankings are based on phenotypic value
- 30 trees divided into six sublines with trees randomly assigned to sublines and mated according to a five-tree modified half-diallel design

For the mainline simulations, only one breeding strategy has been designed thus far: 360 trees divided into 20 sublines (18 trees per subline) with trees randomly assigned to crosses within sublines and mated according to a circular mating design.

## DISCUSSION

In each subprogram, the user specifies the method of selection and defines the initial base population in terms of the phenotypic mean and the variance and covariance components of up to three traits. Selection options include direct selection for one or more traits, indirect selection for one or more traits, restricted selection for one trait while another trait is held constant, and modified base index selection in which economic weights and heritabilities are used. Simulations are run for a user-specified number of iterations, and the means and variances of each model variable (across iterations) are output to a blank spreadsheet. Model variables in the overall, selection, and seed orchard populations include the phenotypic mean of each trait; the additive, dominance, environmental, and phenotypic variances of each trait; and the mean level of inbreeding in the population. In the overall population, the heritability of each trait and the genetic correlations between traits are also calculated, while in the seed orchard population, the percent gain and estimated progeny mean phenotypes are calculated.

At present, the user determines which mating design is employed by running the corresponding subprogram. We hope to combine the subprograms into one general program and allow users to specify their breeding and selection strategies at start up. Future versions will allow users to apply different selection indices for generation advancement and for seed orchard establishment and will include additional breeding schemes for the mainline population.

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<sup>1</sup> Research Geneticist, Southern Institute of Forest Genetics, 23332 Highway 67, Saucier, MS 39574; Director, Western Gulf Forest Tree Improvement Program, Texas Forest Service, Texas A&M University, Forest Science Laboratory, Agronomy Road, College Station, TX 77843; and Research Geneticist (retired), Southern Institute of Forest Genetics, 23332 Highway 67, Saucier, MS 39574, respectively.

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# A NON-DESTRUCTIVE METHOD FOR QUANTIFYING SMALL-DIAMETER WOODY BIOMASS IN SOUTHERN PINE FORESTS

D. Andrew Scott, Rick Stagg, and Morris Smith, Jr.<sup>1</sup>

## Poster Summary

Quantifying the impact of silvicultural treatments on woody understory vegetation largely has been accomplished by destructive sampling or through estimates of frequency and coverage. In studies where repeated measures of understory biomass across large areas are needed, destructive sampling and percent cover estimates are not satisfactory. For example, estimates of change in net primary productivity on fixed plots and carbon and nutrient losses from fire both would be difficult to obtain using either visual coverage estimates or destructive sampling.

We developed a set of equations to estimate the biomass and nutrient content of woody understory species with main stems < 5-cm in diameter at breast height in southern pine stands. We destructively sampled 75 understory trees and shrubs from 5 pine stands in Louisiana and Mississippi and measured the height of the tallest stem to the nearest 15 cm, counted the number of stems in a rootstock, and noted the species and growth form (tree or shrub). We oven-dried and weighed the plants, then analyzed them for carbon, nitrogen, phosphorus, potassium, calcium, and magnesium. We used multiple linear regression with total height and number of stems in a rootstock as continuous regressors and plant growth type (shrub or tree) as a categorical regressor.

The study results surprised us; this simple regression was quite effective in predicting dry biomass and nutrient content (table 1). Although total height alone was a useful predictor (fig. 1), the number of stems also was a significant regressor

for dry biomass and nutrient content. Plant growth form was not significantly related to either dry biomass or nutrient content. Further, because oven-dry weight was predicted very well by field-wet weight, we will not need to oven-dry new samples. We plan to expand our database by incorporating site fertility, stand age, and management regime to examine how these factors interact to control biomass and nutrient content of understory vegetation in Coastal Plain pine forests.

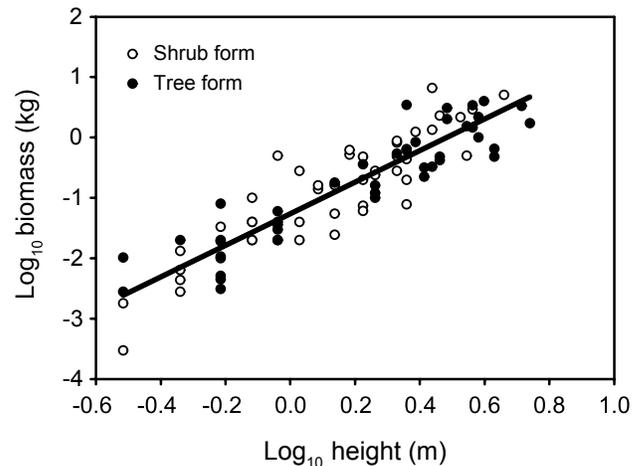


Figure 1. Biomass of understory vegetation in Gulf Coastal Plain pine forests relative to the total height of individual understory plants.

**Table 1—Model parameters and goodness-of-fit for estimating understory vegetation biomass and nutrient content in Gulf Coastal Plain pine stands**

Model <sup>a</sup>	Model parameters			
	B0	B1	B2	R2
Dry biomass <sup>b</sup> = B0+B1*height+B2*stems	-1.357	2.518	0.969	0.87
N content = B0+B1*height+B2*stems	-3.506	2.183	0.979	0.85
P content = B0+B1*height+B2*stems	-4.822	2.273	0.889	0.86
K content = B0+B1*height+B2*stems	-3.867	2.218	1.007	0.86
Ca content = B0+B1*height+B2*stems	-3.699	2.329	0.885	0.81
Mg content = B0+B1*height+B2*stems	-4.253	2.329	0.911	0.84
Dry biomass = B1*field-wet biomass	NA	0.526	NA	0.98

N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium.

<sup>a</sup> All regressors and response variables were log10 transformed except for the wet and dry biomass model (model 7).

<sup>b</sup> Dry biomass = oven-dried aboveground biomass in kg; height = total height of tallest stem in m; nutrient content = N, P, K, Ca, or Mg content of aboveground plant biomass in kg.

<sup>1</sup> Research Soil Scientist, Forester, and Forestry Technician, respectively, USDA Forest Service, Southern Research Station, Pineville, LA 71360.

# INDIVIDUAL TREE GROWTH MODELS FOR NATURAL EVEN-AGED SHORTLEAF PINE

Chakra B. Budhathoki, Thomas B. Lynch, and James M. Guldin<sup>1</sup>

**Abstract**—Shortleaf pine (*Pinus echinata* Mill.) measurements were available from permanent plots established in even-aged stands of the Ouachita Mountains for studying growth. Annual basal area growth was modeled with a least-squares nonlinear regression method utilizing three measurements. The analysis showed that the parameter estimates were in agreement with respect to both direction and magnitude to those published by Lynch and others (1999) with data for the first two measurements. Since the tree measurements within a plot were correlated, a linear mixed model (with log-transformed basal area growth as a response) with a compound symmetry covariance structure for trees within a plot was also fitted. The mixed model fitted the basal area growth well, although the least-squares nonlinear model and the linear mixed model were not directly comparable.

## INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) is an important pine species and has the widest range of any pine in the Southeastern United States. Prior to 1985, shortleaf growth studies were limited to temporary plots with full-stocking assumptions. Beginning in 1985, Oklahoma State University's Department of Forestry has cooperated with the USDA Forest Service's Southern Research Station and the Ouachita and Ozark National Forests to study growth and yield of shortleaf pine in even-aged natural stands. Over 200 permanent plots located in shortleaf pine natural stands have been established in southeastern Oklahoma and western Arkansas with repeated measurements (Lynch and others 1999). This paper presents the highlights of preliminary findings based on basal area growth modeling including the third measurement of the plots.

## METHODS

Tree measurements were repeated at an interval of 4 or 5 years on fixed-radius circular plots 0.2 acre in size. The details of plot establishment, tree measurements made, and growth and yield modeling from the first two measurements are described in Lynch and others (1999). They estimated parameters in the following nonlinear model:

$$G_i = \frac{b_1 B_i^{b_2} - (b_1 B_i / B_M^1 - b_2)}{1 + \exp(b_3 + b_4 B_s + b_5 A + b_6 R_i + b_7 B_i)} \quad (1)$$

where

- $G_i$  = annual basal area growth (square feet) of tree  $i$ ,
- $B_i$  = basal area (square feet) of tree  $i$ ,
- $A$  = stand age,
- $R_i$  = the ratio of quadratic mean stand diameter to the d.b.h. of tree  $i$ ,
- $B_s$  = stand basal area (square feet per acre),
- $B_M = 7.068384$  square feet (the maximum expected basal area for a shortleaf pine in managed stands), and
- $b_1, b_2, \dots, b_7$  = parameters.

This model was updated by including the third series of measurements using nonlinear ordinary least squares with SAS PROC NLIN.

In addition, an attempt was made to fit a linear mixed-effects model using SAS PROC MIXED. A linear mixed-effects model can be written as (Gregoire and others 1995):

$$Y_i = X_i \beta + Z_i \gamma_i + \varepsilon_i \quad (i=1, 2, \dots, p; p = \text{no. of plots}) \quad (2)$$

where

$Y_i$  = the vector of natural logarithm of annual basal area growth (square feet per tree per year) for  $i^{\text{th}}$  plot,

$\beta$  = the fixed-effects parameter vector,  $\beta = [\beta_0 \quad \beta_1 \quad \beta_2 \quad \beta_3]^T$ ,

$\gamma_i$  = the plot specific vector of parameters for random-effects,

$X_i$  = the  $t \times 4$  design matrix of fixed-effects variables stand age, stand basal area and quadratic mean diameter, including intercept;

$t$  = number of trees in a plot,

$Z_i$  = the  $t \times 1$  design matrix of random-effect variable (random-effect of  $i^{\text{th}}$  plot), and

$\varepsilon_i$  = the plot specific vector of errors.

It is assumed that  $\gamma_i \sim MN(0, \sigma^2 B)$ ,  $\varepsilon_i \sim MN(0, \sigma^2 W)$ , and  $\text{cov}(\gamma_i, \varepsilon_i) = 0$ , where  $B$  is a correlation matrix of random effects and  $W_i$  is a correlation matrix of within-plot errors.

## RESULTS AND DISCUSSION

The findings from the nonlinear ordinary least squares regression by including all the three measurements are presented in tables 1 and 2. All the coefficients were significantly different from 0 at  $P = 0.05$  level of significance. The signs of the coefficients were the same as those found by Lynch and others (1999), and the magnitudes were also comparatively consistent. Standard errors of the estimates are slightly increased compared to previous estimates. One reason for this might be that overall annual basal growth rate for two growth periods (1985 to 1990 vs. 1990 to 1995) was different (0.013 vs. 0.014 square feet per tree per year overall average).

<sup>1</sup> Graduate Research Assistant and Professor, respectively, Department of Forestry, Oklahoma State University, Stillwater, OK 74078; and Project Leader, USDA Forest Service, Southern Research Station, Hot Springs, AR 71902.

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**Table 1—Overall summary statistics for variables used in modeling (n = 14,564)**

Variable	Mean	Std. dev.	Minimum	Maximum
Annual basal area growth (ft <sup>2</sup> /tree/year)	0.0137	0.01124	0	0.0996
Basal area growth (ft <sup>2</sup> /acre/year)	4.1214	2.37575	0	8.7811
Basal area (ft <sup>2</sup> /acre)	121.30	35.797	14.9	200.4
Stand site index (ft)	56.9	9.46	38.9	87.5
Stand age (years)	44.9	19.95	18	103
Quadratic mean diameter (QMD, inches)	8.57	3.3979	3.54	20.73
DBH (inches)	8.34	3.9153	1.2	26.6
Ratio of QMD to DBH	1.11	0.3582	0.386	7.03

**Table 2—Parameter estimates and their standard errors, along with previous estimates (n = 14,564)**

Coefficient	Previous estimate	Current estimate	S.E. (current estimate)
$b_1$	0.07142	0.1127	0.00589
$b_2$	0.48038	0.5197	0.01910
$b_3$	-3.23628	-1.9430	0.15020
$b_4$	0.01577	0.0092	0.00029
$b_5$	0.02788	0.0188	0.00083
$b_6$	1.29452	1.2504	0.04420
$b_7$	-1.21269	-0.7747	0.04010

Another factor might be that Lynch and others (1999) used additional plots from a shortleaf pine thinning study. The residuals from the fitted model were plotted against 2-inch d.b.h. classes in figure 1. The figure shows that the spread of residuals increases with increasing d.b.h. classes, as expected. Future work will explore possibilities of accommodating the increasing variance with increasing d.b.h. classes. One alternative would be to use weighted least squares instead of ordinary least squares for the regression. Another possibility would be to use a mixed modeling technique.

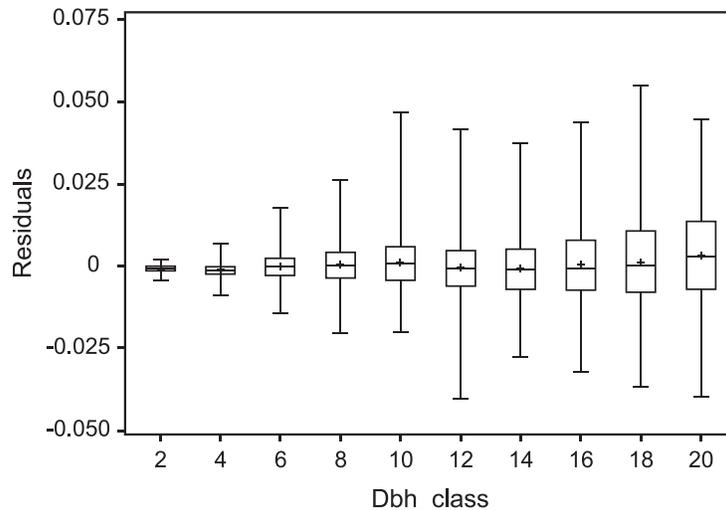


Figure 1—Boxplots of residuals plotted against 2-inch d.b.h. classes.

The parameter estimates and standard errors of the estimates from a preliminary analysis with mixed modeling are (number of plots = 187, total number of observations = 13,792):

$$\begin{bmatrix} \hat{\beta}_0 & \hat{\beta}_1 & \hat{\beta}_2 & \hat{\beta}_3 \end{bmatrix} = \begin{bmatrix} -1.0155 & 0.004077 \\ -2.3492 & -0.01024 \end{bmatrix}$$

$$\begin{bmatrix} \text{S.E.}(\hat{\beta}_0) & \text{S.E.}(\hat{\beta}_1) & \text{S.E.}(\hat{\beta}_2) & \text{S.E.}(\hat{\beta}_3) \end{bmatrix} = \begin{bmatrix} 0.1169 & 0.001405 & 0.04958 & 0.000694 \end{bmatrix}$$

Trees within a plot were assumed to have a compound symmetry covariance structure. This was an improvement on model 1, which assumed independence of trees within a plot. It was also assumed that plots had random effects, and other explanatory variables (stand age, stand basal area and quadratic mean diameter) had fixed effects. These three explanatory variables were found to significantly explain the variation in annual basal area growth, i.e. all the coefficients were significantly different from zero ( $P < 0.004$ ). Parameters were estimated using the restricted maximum likelihood (REML) method. The effect of period or time on annual growth rate, however, was not significant.

Since the study has generated unbalanced longitudinal data, a mixed-effects model has attractive properties. It will be interesting to investigate different covariance structures and

subsets of explanatory variables to model basal area growth. Because of the nature of the response variable and the relationship of predictors with the response, a mixed-effects model in which parameters enter in a nonlinear fashion might be a better approach to analyze such data despite the model complexity and computing challenges. For example, Hall and Bailey (2001) describe the techniques of nonlinear mixed-effects modeling in forestry problems. In addition to basal area growth, other appropriate response variables can possibly be modeled using the mixed-modeling technique to accommodate errors at different levels.

#### **LITERATURE CITED**

- Gregoire, T.G.; Schabenberger, O.; Barrett, J. 1995. Linear modelling of irregularly spaced, unbalanced, longitudinal data from permanent-plot measurements. *Canadian Journal of Forest Research*. 25: 137-156.
- Hall, D.B.; Bailey, R.L. 2001. Modeling and prediction of forest growth variables based on multilevel nonlinear mixed models. *Forest Science*. 47: 311-321.
- Lynch, T.B.; Hitch, K.L.; Huebschmann, M.M.; Murphy, P.A. 1999. An individual-tree growth and yield prediction system for even-aged natural shortleaf pine forests. *Southern Journal of Applied Forestry*. 23: 203-211.

# CALIBRATION OF D.B.H.-HEIGHT EQUATIONS FOR SOUTHERN HARDWOODS

Thomas B. Lynch, A. Gordon Holley, and Douglas J. Stevenson<sup>1</sup>

## Poster Summary

Data from southern hardwood stands in East Texas were used to estimate parameters for d.b.h.-height equations. Mixed model estimation methods were used, so that the stand from which a tree was sampled was considered a random effect. This makes it possible to calibrate these equations using data collected in a local stand of interest, by using d.b.h. and total height measurements from a particular stand to estimate random parameters appropriate for that stand. The calibrated d.b.h.-height equation provides an improved fit for the conditions in a particular stand with less data than would be required to estimate parameters in a new d.b.h.-height equation. These data were obtained from the western portion of the natural range for most southern hardwood species, where relatively little information concerning d.b.h.-height relationships exists for southern hardwoods.

Water oak (*Quercus nigra* L.) was selected to demonstrate calibration of d.b.h.-height relationships. Water oak d.b.h. and height measurements were obtained from 538 trees located in 61 stands in east Texas. Sample trees were selected from transects running across drainages using a BAF=10 point sampling angle gauge.

The mixed model was:

$$\ln(H_{ki} - bh) = b_0 + b_1/D_{ki} + a_{0k} + a_{1k}/D_{ki} + e_{ki}$$

$H_{ki}$  is total height (feet) of tree  $i$  in stand  $k$ ,  $D_{ki}$  is d.b.h. (inches) of tree  $i$  in stand  $k$ ,  $bh$  is breast height (4.5 feet),  $\ln(x)$  is the natural logarithm of  $x$ ,  $b_0$  and  $b_1$  are fixed population parameters,  $a_{0k}$  and  $a_{1k}$  are random parameters for stand  $k$ , and  $e_{ki}$  is random residual error for tree  $i$  in stand  $k$ . Estimates of the

fixed population parameters based on 538 trees for water oak were  $b_0 = 4.87952440$  (standard error=0.02678038),  $b_1 = -7.44722234$  (standard error=0.47185702), and the residual standard error was 0.1667. This mixed effects model formulation is similar to the model used by Lappi (1991) for Scots pine.

Calibration can be accomplished by sampling in a new stand to estimate values of the random parameters  $a_0$  and  $a_1$  for that stand. A matrix formula given by Lappi (1991) can be used to estimate these random parameters. The calibrated model provides improved height prediction for the stand from which data are obtained but requires less data than would be needed to develop a new d.b.h.-height equation.

The calibration procedure was tested by reserving all data associated with one of the 61 stands as a calibration data set. The fixed parameters, variance-covariance matrix for the random effects parameters, and residual standard error were estimated using data from the remaining 60 stands. Ten trees from the calibration stand were used to estimate random parameter values for that stand. The d.b.h.-height curve, which included the random parameter values obtained from calibration, provided substantially better height predictions than a d.b.h.-height model which used only estimates of the fixed parameters.

## LITERATURE CITED

Lappi, J. 1991. Calibration of height and volume equations with random parameters. *Forest Science*. 37(3): 781-801.

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<sup>1</sup> Professor, Department of Forestry, Oklahoma State University, Stillwater, OK 74078-6013; Assistant Professor, Louisiana Tech University, School of Forestry, Ruston, LA; and Senior Research Specialist, Oklahoma State University, Department of Forestry, Stillwater, OK, 74078-6013, respectively.

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# PREDICTING OAK DENSITY WITH ECOLOGICAL, PHYSICAL, AND SOIL INDICATORS

Callie Jo Schweitzer, Adrian A. Lesak, and Yong Wang<sup>1</sup>

**Abstract**—We predicted density of oak species in the mid-Cumberland Plateau region of northeastern Alabama on the basis of basal area of tree associations based on light tolerances, physical site characteristics, and soil type. Tree basal area was determined for four species groups: oaks (*Quercus* spp.), hickories (*Carya* spp.), yellow-poplar (*Liriodendron tulipifera* L.), and other species. Basal area of all species was also divided into three categories based on shade tolerance (shade tolerant, intermediate tolerance, and shade intolerant). Principal components analysis was used to explore the communalities among the measured site characteristics and the species and shade tolerance groups. Stepwise multiple linear regression modeled the extent to which the forest composition factors and physical and soil indicators predicted the density of oaks. Oak basal area responded negatively to basal area of all shade tolerance groups and the species groups that correlated with them. Elevation was related positively to oak density. Our results support the premise that oaks are weak competitors with species of various shade tolerance strategies.

## INTRODUCTION

The ecological and economic importance of oaks has resulted in an interest in their ecology, competitive capacity, and management. The oak-dominated forests of the mid-Cumberland Plateau are an excellent laboratory in which to study oak ecology under conditions of high physiographic and arboreal diversity. Many questions remain about the biology of oaks and the mechanisms by which their widespread dominance in forested landscapes throughout the Eastern United States is achieved and maintained. In few places is the importance of oaks to forest ecology greater than in the Cumberland Plateau region and its southern fringes.

The mechanisms that influence the composition of oak-dominated forests and the competitive interactions within these systems have been described for many regions and many stages of forest development. This study clarifies basic relationships between oak density and the density of coexisting species and ecological species groups in addition to characteristics of the physical environment in the oak-hickory forests in northeastern Alabama.

Exploratory predictive models focusing on ecologically important species and their ecological strategies in relation to potentially important abiotic factors could be used to gain an understanding of the complex dynamics of oak forests. Multivariate statistics can be used both to evaluate the influence of several environmental factors simultaneously and to identify interactions and correlations among those factors. The objective of this study was to determine whether differences in oak density can be predicted accurately on the basis of species composition, physical site attributes, and soil type.

## METHODS

### Study Area

The study area is located in northern Jackson County, AL, on property managed by Stevenson Land Company and the

Alabama Department of Conservation and Natural Resources, State Lands Division. Situated in the mid-Cumberland Plateau, the region is characterized by narrow, flat plateaus dissected by numerous deep valleys. In this study, data were collected at two sites, one located at Jack Gap (34°56'30" N, 86°04'00" W) and one at Miller Mountain (34°58'30" N, 86°12'30" W). The Jack Gap and Miller Mountain sites cover approximately 40 and 20 ha, respectively, for a total study area of 60 ha. The study sites are at upper- or mid-slope positions on the side of the plateau, and their elevation ranges from 260 to 520 m. Jack Gap has a predominately north slope aspect, while Miller Mountain has a south to southwesterly slope aspect. Mature upland hardwood forest is the dominant land cover in the northern half of Jackson County, where many large continuous tracts are present. The forest cover of the sites and much of the surrounding area is of the oak-hickory type (*Quercus* spp. and *Carya* spp.) with yellow-poplar (*Liriodendron tulipifera* L.), sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), and American beech (*Fagus grandifolia* Ehrh.) as associates (Hartsell and Vissage 2001). Stand age ranges from about 80 to about 110 years.

### Tree Measurements

Seventy-five 0.08-ha circular plots were randomly selected from 150 systematically arranged points located throughout the study area (50 plots at Jack Gap and 25 at Miller Mountain). Diameter at breast height (d.b.h.) and species were recorded for every tree  $\geq 14$  cm in diameter on each plot. Basal area [BA = cross-sectional area (m<sup>2</sup>)] for all trees in this d.b.h. class was calculated for each plot using d.b.h. measurements. Basal area totals for the individual species were summed for species groups (oak species, hickory species, yellow-poplar, and other species) and for shade tolerance groups (shade tolerant, intermediate tolerance, and shade intolerant). Species were assigned to tolerance groups based on classifications by a majority of four sources (Burns and Honkala 1990, Harrar and Harrar 1962, Johnson and others 2002, Loftis 1991).

<sup>1</sup> Research Forester, USDA Forest Service, Southern Research Station, Ecology and Management of Southern Appalachian Hardwood Forests, Normal, AL 35762; former student and Associate Professor, respectively, Alabama Agricultural and Mechanical University, Normal, AL 35762.

## Physical Data

Elevation for each measurement plot was derived from U.S. Geological Survey 1:24,000 Digital Elevation Model (DEM) data for the Estill Fork and Hytop quadrangles. The DEM data were converted to a three-dimensional triangulated irregular network (TIN) format to obtain the slope ( $^{\circ}$ ) and aspect ( $^{\circ}$ ) of each plot. Elevation extraction and conversion of DEM data to TIN was done with Arc geographical information system software (ESRI, Redlands, CA). Because the aspect measurements were based on circular values, each value was converted to a northness [ $\cos(\text{aspect})$ ] and eastness [ $\sin(\text{aspect})$ ] component for analysis purposes. For the northness component, 1 equals due north, and -1 due south. For eastness, 1 equals due east, and -1 due west. For ease of interpretation, either component may be multiplied by the inverse of its trigonometric function to be reconverted to the original value in degrees.

## Soil Data

Natural Resources Conservation Service personnel surveyed the soil profiles at several locations at each study site and outlined the major soil series on topographical maps that could be used to match soil types to the vegetation plots (Personal communication. Doug Clendendon. 2002. Soil Survey Project Leader, USDA Natural Resources Conservation Service, P.O. Box 1208, Normal, AL). In addition to individual samples and observations, 6 soil transects (4 at Jack Gap, 2 at Miller Mountain), each with 10 sample points, were used to delineate soil series boundaries on a finer scale than is available from conventional county soil maps. Transects were placed so that the range of representative land forms in the study area could be sampled. The soil characteristics of these physiographic features were then extrapolated to similar features (in appropriate topographic context) throughout the entire study area and boundaries drawn. Our study area was composed of three soil series: Bouldin stony loam, Enders gravelly loam, and Limrock gravelly loam.

## Statistical Analysis

**Principal components analysis**—Because of the potential correlation among the primary species groups, shade tolerance groups, and the site characteristics, we employed principal components analysis (PCA) to explore communalities among the dependent variables. Prior to PCA, we examined descriptive statistics to identify violations of the assumptions required for linear multivariate analyses. We used a matrix of all partial regression plots to assess the linear relationships among the variables. Large departures from linearity were not detected. Normality plots, histograms, and the Kolmogorov-Smirnov normality test all showed that elevation and BA of oak species had uneven but normal distributions. The BA values of shade tolerant species, intermediate tolerance species, shade intolerant species, hickory species, yellow-poplar, and other species were all non-normal with positive skewness as a result of many low and zero values. Square-root transformation brought all of these variables within normal parameters. None of the transformations (square-root, logarithmic, inverse, or reflection) that we applied to slope, northness, and eastness remedied their departures from normality, and the value of these variables were left unchanged.

Correlation analysis (excluding oak species BA) showed that a large number of variables were correlated, and this suggested that PCA could be used to group them. To solidify this

decision to proceed with PCA, measures of sampling adequacy (relating to the degree of intercorrelation with the other variables) for each variable were examined, and other species BA was excluded from the variable set to increase the overall Kaiser-Meyer-Olkin measure of sampling adequacy to 0.581. The Bartlett's Test of Sphericity was highly significant ( $X^2 = 251.048$ ,  $df = 36$ ,  $p < 0.0005$ ), further establishing the appropriateness of PCA. Factor extraction was limited to components with Eigenvalues  $> 1$ , and examination of a scree plot of Eigenvalues across the components was used to confirm inclusion. VARIMAX rotation was used to differentiate important variable loadings on each component, and factor scores based on the extracted component coefficients were calculated for later analysis. All analysis was conducted using SPSS version 10.0 (SPSS, Inc. 1999).

**Multiple linear regression**—The stepwise method of multiple linear regression, the principal component scores for each plot, and the three dummy-coded soil series were used to predict BA of oak species.

## RESULTS

On all 75 measurement plots combined, 1,703 trees of 33 species were recorded. Elevation of the plots ranged from 320 to 514 m, and the average slope was  $39^{\circ}$ . Aspects were primarily north and southwest with slightly more variation on the east-west axis than the north-south axis. Our plots overlaid three soil types (table 1).

Principal components analysis identified four factors that accounted for 75.59 percent of the total variance within the variable set (table 2). Principal component (PC) 1 explained 32.24 of this variance and had an Eigenvalue of 2.901. This component had high positive loadings for both BA of intermediate tolerance species and BA of hickory species (table 3). PC 2 (19.53 percent variance explained, Eigenvalue = 1.758) was highly associated with BA of yellow-poplar and BA of shade intolerant species. PC 3 (12.65 percent variance explained, Eigenvalue = 1.139) had high positive loadings for slope and eastness and high negative loading for northness. PC 4 (11.17 percent variance explained, Eigenvalue = 1.006) had positive loading for the elevation variable and negative loading for BA of shade tolerant species.

Extracted variables for the top four principal components and their loading direction (+ or -) are given below:

PC 1 = (+) BA intermediate tolerance species and (+) BA hickory species

PC 2 = (+) BA yellow-poplar and (+) BA intolerant species

PC 3 = (+) slope and (-) northness and (+) eastness

PC 4 = (+) elevation and (-) BA tolerant species

Stepwise multiple regression using the four principal component scores and three soil types resulted in a highly significant model with a relatively low predictive capacity ( $F = 13.231$ ,  $df = 3,71$ ,  $p < 0.0005$ ,  $R^2 = 0.359$ ). Low variance among the residuals, rather than the large sample size, probably explains the high significance level of this model, and this suggests that the model is a good fit despite its low predictive power. Examination of standardized residual and normality plots showed that this model fit the assumptions of normality, homoscedasticity, and linearity very well.

**Table 1—Descriptive statistics for primary species groups, shade tolerance groups, and site physical data used in predictive modeling; data from 75 plots sampled in Jackson County, AL**

Variable	N	Minimum	Maximum	Mean	Standard deviation	Variance
BA all oak species	75	0.00	33.43	10.05	6.81	46.43
Slope	75	28.04	43.45	38.70	4.89	23.91
Northness	75	-0.99	1.00	0.40	0.57	0.33
Eastness	75	-0.96	1.00	-0.16	0.71	0.50
Elevation	75	320.6	514.45	427.05	53.84	2,898.91
BA tolerant species <sup>a</sup>	75	0.00	3.55	1.70	0.88	0.77
BA intermediate <sup>a</sup> tolerance species	75	0.00	4.47	1.96	0.89	0.79
BA intolerant species <sup>a</sup>	75	0.00	4.22	1.60	1.07	1.16
BA hickory species <sup>a</sup>	75	0.00	3.59	1.55	0.88	0.78
BA yellow-poplar <sup>a</sup>	75	0.00	3.61	1.00	1.03	1.06
Other species <sup>a</sup>	75	0.00	5.22	2.37	0.81	0.65

BA = basal area.

<sup>a</sup> The square root of the basal area of the dependent variable and variable groups. Tolerant species included basswood (*Tilia heterophylla* Vent.), beech (*Fagus grandifolia* Ehrh.), and sugar maple (*Acer saccharum* Marsh.); intermediate tolerance species included ash (*Fraxinus* spp.), cucumber tree (*Magnolia acuminata* L.), red maple (*A. rubrum* L.), and elm (*Ulmus* spp.); intolerant species included black cherry (*Prunus serotina* Ehrh.), black locust (*Robinia pseudoacacia* L.), and sassafras [*Sassafras albidum* (Nutt.) Nees.]; hickory species included mockernut (*Carya tomentosa* Nutt.), pignut (*C. glabra* Sweet), red (*C. ovalis* Sarg.), and shagbark (*C. ovata* K. Koch.).

**Table 2—Principal components derived from the 9 dependent variables for 75 plots located in Jackson County, AL**

Principal component	Eigenvalue	Percent of variance explained	Cumulative percent
1	2.901	32.239	32.239
2	1.758	19.529	51.768
3	1.139	12.652	64.420
4	1.006	11.174	75.593
5	0.781	8.678	84.271
6	0.600	6.670	90.941
7	0.539	5.992	96.933
8	0.149	1.659	98.592
9	0.127	1.408	100.000

The resulting model included three of the principal components:

$$\text{BA of oak species} = 10.052 - 2.744(\text{PC } 1) - 2.690(\text{PC } 2) + 1.371(\text{PC } 4)$$

The negative value of PC 1 suggests that oak BA increases as BA of competitors with similar tolerance characteristics, such as hickories, decreases. The negative values of PC 2 suggest that oak BA increases as BA of yellow-poplar and other intolerant species decreases. The positive coefficient of PC 4 means that oak BA increases as elevation increases and BA of tolerant species decreases.

## DISCUSSION

The loading of variables in the different principal components provides some insight into correlations between vegetation and site characteristics. Not only did hickories and yellow-poplar correlate with their respective shade tolerance groups, but elevation and BA of shade tolerant species showed a negative relationship. Slope and aspect were also grouped together.

Multiple regression showed the selected variables combined into three components that modeled oak BA significantly but had low predictive power. Nevertheless, the model supports certain inferences. Oak BA tends to increase in importance in our study areas as elevation increases. This relationship has been confirmed in other studies of Alabama upland hardwoods. Oaks predominated mainly in upper slope positions (Golden and others 1999, Shostak and others 2004). This may reflect the drought tolerance of some oak species such as black (*Q. velutina* Lamark), scarlet (*Q. coccinea* Marsh.), chinkapin (*Q. muehlenbergii* Englem.), and to a lesser extent chestnut oak (*Q. montana* L.).

The soils on the top of the plateau are often thin and well-drained, while on the escarpment or side of the plateau, soil thickness and moisture increase (Smalley 1982). The underlying soil type appeared to have little influence on the density and composition of these stands.

In these mature forests, oaks compete with species in all three shade tolerance classes. There are different theories about mechanisms of succession from stand establishment to canopy dominance. The initial floristic model (Egler 1954) takes initial species composition as the starting point and details how species dominance changes as species grow at different rates. Relay floristics (Egler 1954) suggests that

**Table 3—Final principal component loadings using the rotation method Varimax with Kaiser normalization correlating the principal component and each original variable; data from 75 plots sampled in Jackson County, AL**

Variable	Component			
	1	2	3	4
Slope			0.789	
Northness			-0.689	
Eastness			0.671	
Elevation				0.833
BA tolerant species <sup>a</sup>				-0.758
BA intermediate <sup>a</sup> tolerance species	0.948			
BA intolerant species <sup>a</sup>		0.921		
BA hickory species <sup>a</sup>	0.923			
BA yellow-poplar <sup>a</sup>		0.937		

BA = basal area.

<sup>a</sup> The square root of the basal area of the dependent variable and variable groups. Tolerant species included basswood (*Tilia heterophylla* Vent.), beech (*Fagus grandifolia* Ehrh.), and sugar maple (*Acer saccharum* Marsh.); intermediate tolerance species included ash (*Fraxinus* spp.), cucumber tree (*Magnolia acuminata* L.), red maple (*Acer rubrum* L.), and elm (*Ulmus* spp.); intolerant species included black cherry (*Prunus serotina* Ehrh.), black locust (*Robinia pseudoacacia* L.), and sassafras [*Sassafras albidum* (Nutt.) Nees.]; hickory species included mockernut (*Carya tomentosa* Nutt.), pignut (*C. glabra* Sweet), red (*C. ovalis* Sarg.), and shagbark (*C. ovata* K. Koch.).

species composition changes as later successional species disperse and grow into stands, taking advantage of the conditions created by earlier ones. Our findings are consistent with both of these models. Nevertheless, our results do show that differences in shade tolerance strategies among the species studied do not appear to alleviate competition in these forests.

### Future Considerations

To improve the predictive ability of our model, an expanded set of variables measured at a greater sample size would be helpful. Inclusion of more sample plots with a wider range of aspects, slopes, and elevations may clarify the influence of these factors. Other models constructed from our data may predict the change in BA of other important species.

### CONCLUSIONS

Our efforts to model the dominance of oak using topographical and ecological factors confirm the reputation of oaks as poor competitors. Many of our stands in north Alabama are at or near rotation, and it may be desirable to regenerate them to oak. As this study shows, successful regeneration to oak will require careful consideration of competing vegetation.

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### LITERATURE CITED

- Burns, R.M.; Honkala, B.H., tech. coords. 1990. *Silvics of North America: Hardwoods*. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service. 877 p. Vol. 2.
- Egler, F.E. 1954. Vegetation science concepts. 1. Initial floristic composition: a factor in old-field vegetation development. *Vegetatio*. 4: 412-417.
- Golden, M.S.; Dubois, M.R.; Stockman, J.L. 1999. Oak regeneration following three cutting treatments on mountain slopes in north Alabama. In: Haywood, J.D., ed. *Proceedings of the 10<sup>th</sup> biennial southern silviculture research conference*. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 8-14.
- Harrar, E.S.; Harrar, J.G. 1962. *Guide to southern trees*. New York: Dover Publications. 709 p.
- Hartsell, A.J.; Vissage, J.S. 2001. *Forest statistics for North Alabama, 2000*. Resour. Bull. SRS-64. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 50 p.
- Johnson, P.S.; Shifley, S.R.; Rogers, R. 2002. *The ecology and silviculture of oaks*. New York: CABI Publishing. 503 p.
- Loftis, D.L. 1991. Regeneration of southern hardwoods: some ecological considerations. In: *Silvicultural challenges and opportunities in the 1990s: proceedings of the national silviculture workshop*. Washington, DC: U.S. Department of Agriculture, Forest Service, Timber Management: 139-143.
- Shostak, D.I.; Lowenstein, E.F.; Dubois, M.R. 2004. Topographic position and site index: an oak regeneration relationship. In: Connor, K.F., ed. *Proceedings of the 12<sup>th</sup> biennial southern silviculture research conference*. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 243-248.
- Smalley, G.W. 1982. *Classification and evaluation of forest sites on the Mid-Cumberland Plateau*. Gen. Tech. Rep. SO-38. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 123 p.
- SPSS, Inc. 1999. *SPSS Base 10.0 applications guide*. Chicago, IL: SPSS, Inc. 426 p.

# INCLUSION OF CLIMATIC VARIABLES IN LONGLEAF PINE GROWTH MODELS

Jyoti N. Rayamajhi and John S. Kush<sup>1</sup>

**Abstract**—The Regional Longleaf Growth Study was established by the USDA Forest Service to study the dynamics of naturally regenerated, even-aged longleaf pine (*Pinus palustris* Mill.) stands. The study accounts for growth change over time by adding new sets of plots in the youngest age class every 10 years. To detect possible changes in productivity with time, a series of timerep plots in youngest age class were established and periodically re-measured. Stand level and growth models were fitted to individual timerep data sets. Parameter stability analyses indicated that model parameters changed significantly from one time period to the next. Further tests identified particular parameters that were most sensitive to time and in need of modification. Climate variables were added as covariates to models to improve stability of modeling parameters, since climatic indices are correlated with residuals. There have been changes in productivity of these plots which may be related to changes in climate.

## BACKGROUND

From 1964 to 1967, the USDA Forest Service established the Regional Longleaf Pine Growth Study (RLGS) in the Gulf States. The original objective of the study was to obtain a database for the development of growth and yield predictions for naturally regenerated, even-aged longleaf pine stands. Plots were installed to cover a range of ages, densities, and site qualities. The plots are inventoried on a 5-year cycle and are thinned at each inventory, as needed, to maintain the assigned density level. The study accounts for growth change over time by adding a new set of plots in the youngest age class every 10 years.

Plots cover a range of age classes from 20 to 130 years, 6 site index classes ranging from 40 to 80 feet at 50 years, and 5 density classes ranging from 30 to 150 square feet acre<sup>-1</sup>. A new class, “free to grow”, has recently been added to determine the maximum density longleaf pine stands can attain prior to onset of mortality. Densities are established and maintained by low thinning. Within this distribution are five main replications of the youngest age class. All five replications are located on the Escambia Experimental Forest (EEF) in Brewton, AL.

## TIMEREP PLOTS

The increasing concerns in recent years by researchers and the public about the changes in forest growth can be explained by examining the stability of growth and yield model parameters. In order to detect possible changes in productivity over time, a series of plots termed “timereps” were established on the EEF in Brewton, AL, in young, naturally regenerated longleaf pine stands that have been periodically measured (Kush and others 1987). The basic purpose of these plots was to investigate potential differences in growth due to differences in climatic factors (represented by different time periods) after reducing the differences in initial stand characteristics as much as possible. The controlled nature and the close proximity of the timerep plots already isolate concomitant effects induced by the stand characteristics.

The timerep plots are the subset of periodically measured growth data obtained from the RLGS (Kush and others 1987).

The study was initiated in the mid-1960s to monitor growth and yield of naturally regenerated, even-aged longleaf pine stands (Farrar 1978); three periods of timerep plots were available for the following analyses. In a study by Rayamajhi and others (1998), the parameters of projection models were tested and found to be unstable and in need of modification by incorporating suitable variables that will account for the change.

## METHODS

In order to measure the effect of climate on longleaf pine productivity, groups of 3 timerep plots were established every 10 years on the EEF in Brewton, AL. A subset of timerep band plots were selected in which all stand variables (site index, trees acre<sup>-1</sup>, and age) were isolated; the difference of basal area increment year<sup>-1</sup> (BAIPYR) among the timereps could then be measured without confounding the measurement. For statistical analysis of data, timerep-period differences were compared using analysis of covariance (ANCOVA), containing terms for timerep (treatment) and basal area, with and without the climate variables of precipitation and maximum and minimum temperature (as covariates). Primary treatment comparisons were pairwise comparisons between the different timereps (1, 2, and 3) based on least-squares means from the ANCOVA. The assumptions of these analyses were to observe effect of climate in the very basic basal area model consisting of stand characteristics. Based on the results, longleaf pine growth and yield models are provided with predictor variables to account for changes in climatic variables.

## RESULTS AND DISCUSSIONS

The observed mean basal area acre<sup>-1</sup> (BA), its statistics, and the change from one period to another are presented in table 1. The sample sizes were not the same among the timereps; however, the stand characteristics were controlled to be homogeneous. The change column exhibits an increased BAIPYR for timerep 3, differentiating it from other two timereps. The observed means and its statistics for precipitation in inches, and maximum and minimum temperatures in °F are presented in table 2 for each timerep.

<sup>1</sup> Statistician, Independent, Fishers, IN 46038; and Research Associate, Auburn University, School of Forestry and Wildlife Sciences, Auburn, AL 36849, respectively.

**Table 1—Average basal area (square feet acre<sup>-1</sup>) for the first time period of each timerep and the average change in basal area (square feet acre<sup>-1</sup> year<sup>-1</sup>) at the start of the second time period. Timerep plots are located on the Escambia Experimental Forest in Brewton, AL**

Timerep	N	Period 1					Change				
		Mean	STD	Median	Min	Max	Mean	STD	Median	Min	Max
1	28	47.29	24.9	51.5	11.4	97.3	4.70	1.22	4.29	2.64	7.10
2	60	59.21	20.1	59.2	23.9	101.2	5.24	1.38	5.26	3.07	8.33
3	21	57.75	16.7	60.4	24.8	81.5	7.42	1.49	7.34	4.18	9.55

**Table 2—Observed means of climatic variables for the three timereps on the Escambia Experimental Forest in Brewton, AL**

Timerep	Variable	N	Mean	STD	Median	Min	Max
1	Precip ( <i>in</i> )	20	70.27	6.4	11.4	56.7	77.0
2		60	76.33	13.8	59.2	65.1	98.6
3		21	63.90	—	60.4	63.9	63.9
1	Max temp (°F)	20	76.39	0.27	66.4	76.0	77.6
2		60	77.07	0.26	70.8	76.8	77.5
3		21	77.92	—	63.9	77.9	77.9
1	Min temp (°F)	20	50.24	0.96	49.8	49.3	51.7
2		60	51.07	1.09	51.4	49.4	52.1
3		21	53.01	—	53.0	53.0	53.0

A mean change analysis of covariance is performed to find the difference among the three timereps so that the effect of any climate variable could be compared with and without climatic variables. The dependent variable was BAIPYR; the independent variable consisted of basal area at period 1, as a covariate, and the timereps. The mean change analysis showed overall significance among the timereps and non-significance for covariate (table 3). Least Square (LS) mean

pairwise change indicates timerep 3 was different from timereps 1 and 2. However, the mean change analysis including climatic variables, such as mean minimum temperature, showed that the timereps were not different (table 4). The LS means pairwise change was not significantly different among the timereps. This indicates significance of including climatic variables in the very basic growth model. The ongoing changes can be explained by including some form of climatic variables

**Table 3—Analysis of mean change for the three timereps (without climatic variables) on the Escambia Experimental Forest in Brewton, AL**

Main effects (type II SS)	ndf <sup>a</sup>	ddf <sup>b</sup>	p-value
Basal area at Period 1	1	105	0.3535
Timerep	2	105	<0.0001

Treatment	LS means for change	Std. error
Timerep 1	4.7515	0.2636
Timerep 2	5.2156	0.1775
Timerep 3	7.4072	0.2980

Pairwise Comparison of LS Means			
Treatment	Difference	Two-sided 95% CI	p-value
Timerep1-Timerep2	-0.4641	(-1.1013, 0.1732)	0.1518
Timerep1-Timerep3	-2.6557	(-3.4478,-0.86.5)	<0.0001
Timerep2-Timerep3	-2.1916	(-2.8779,-1.5053)	<0.0001

<sup>a</sup> Numerator degrees of freedom.

<sup>b</sup> Denominator degrees of freedom.

**Table 4—Analysis of mean change (including mean minimum temperature) for the three timereps on the Escambia Experimental Forest in Brewton, AL**

Main effects (Type II SS)	df <sup>a</sup>	ddf <sup>b</sup>	p-value
Basal area at Period 1	1	104	0.0002
Timerep	2	104	0.1031
Mean minimum temperature	1	104	<0.0001

Treatment	LS means for change	Std. error
Timerep 1	5.7666	0.2675
Timerep 2	5.3002	0.1493
Timerep 3	5.8120	0.3443

Pairwise Comparison of LS Means			
Treatment	Difference	Two-sided 95%CI	p-value
Timerep1-Timerep2	0.4664	(-0.1341, 1.0669)	0.1265
Timerep1-Timerep3	-0.0454	(-1.0613, 0.9704)	0.9295
Timerep2-Timerep3	-0.5118	(-1.2707, 0.2470)	0.1839

<sup>a</sup> Numerator degrees of freedom.

<sup>b</sup> Denominator degrees of freedom.

or indices. Timereps 1 and 2 were more similar when precipitation was included, but timerep 3 remained unchanged (table 5).

Since climatic variables are correlated with residuals of the basal area projection or increment models (Rayamajhi 1996), the following climate models were obtained using the full RLGS dataset. Climatic variables were represented by a climatic index  $f_1(x)$ , representing precipitation and the mean minimum temperature.

### Climate Models

(1) Basal Area Projection Model:

$$BA_2 = BA_1 \left( \frac{A_1}{A_2} \right)^{-1.637+4.046f_1(x)}$$

$$e^{5.3752 \left[ 1 - \left( \frac{A_1}{A_2} \right)^{-1.637+4.046f_1(x)} \right]}$$

**Table 5—Analysis of mean change for the three timereps (including total precipitation) on the Escambia Experimental Forest in Brewton, AL**

Main effects (Type II SS)	ndf <sup>a</sup>	ddf <sup>b</sup>	p-value
Basal area at Period 1	1	104	0.0006
Timerep	2	104	<0.0001
Total Precipitation	1	104	<0.0001

Treatment	LS means for change	Std. error
Timerep 1	4.9786	0.2337
Timerep 2	4.9222	0.1632
Timerep 3	7.9424	0.2765

Pairwise Comparison of LS Means			
Treatment	Difference	Two-sided 95% CI	p-value
Timerep1-Timerep2	0.0564	(-0.5287, 0.6414)	0.8489
Timerep1-Timerep3	-2.9638	(-3.6643,-2.2632)	<0.0001
Timerep2-Timerep3	-3.0201	(-3.6840,-2.3562)	<0.0001

<sup>a</sup> Numerator degrees of freedom.

<sup>b</sup> Denominator degrees of freedom.

(2) Basal Area Increment Model:

$$BAI = 0.2349 + 0.0036 \left( \frac{BA_1}{A_1} \right) - 0.1511 \left( \frac{N_1}{A_1} \right) + 0.7152 \left( \frac{S}{A_1} \right) + 0.2094 f_2(x) \left( \frac{N_1}{A_1} \right)$$

(3) Individual Tree Growth Model:

$$bai = 19.83 e^{-0.0941BA^{0.5}} e^{-0.0037BAL} e^{[0.3048(1 - e^{-0.3498DBH}) - 0.3119]A} e^{-0.4261 \frac{f_3(x)}{3}}$$

where

$$f_1(x) = \sum \text{Precipitation}(01,10,11,12) / \sum \text{Min. Temp.}(04,07,08,09)$$

$$f_2(x) = \sum \text{Precipitation}(02,4,11,12) / \sum \text{Min. Temp.}(04,06,07,12)$$

$$f_3(x) = \sum \text{Precipitation}(02,06,08,09) / \sum \text{Min. Temp.}(04,09,11)$$

### Summary of Findings

A subset (band) of three time replication plots were selected from time replication plots on the EEF. The stand characteristics, age, density, and site quality were isolated in order to make a comparison of BAIPYR over three time periods. The analysis of variance showed a statistically significant difference among the three timereps. An ANCOVA was performed, adding the climatic variables total precipitation and minimum and maximum temperatures, as covariates. The results reduced the statistical significance, resulting in non-significance when a climatic variable like minimum temperature was considered. This shows that climatic variables such as total precipitation and minimum and maximum temperature can be used to account for variation in the timereps. Based on the correlation of climatic variables with the residuals, growth models containing climatic variables are suggested.

### CONCLUSIONS

There was an increased growth trend in terms of BAIPYR for longleaf pine due to changes in climatic factors based on these data. Parameters of growth and yield models do not remain stable for long projection periods and need to be modified to account for the variable that is responsible for the change. Climatic variables, such as precipitation, and maximum and minimum temperatures, or climatic indices derived from these variables should be used in the growth and yield model. The model then incorporates, rather than ignores, any changes ongoing because of the effects of climate. Furthermore, addition of climatic variable strengthens the robustness of the predictability of the models.

### LITERATURE CITED

- Farrar, R.M., Jr. 1978. Silvicultural implications of the growth response of naturally regenerated even-aged stands of longleaf pine (*Pinus palustris* Mill.) to varying stand age, site quality, and density and certain stand measures. Athens, GA: University of Georgia. 132 p. Ph.D. dissertation.
- Kush, J.S.; Meldahl, R.S.; Dwyer, S.P.; Farrar, R.M., Jr. 1987. Naturally regenerated longleaf pine growth and yield research. In: Phillips, D.R., ed. Proceedings of fourth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 343-344.
- Rayamajhi, J.N. 1996. Productivity of natural stands of longleaf pine in relation to climatic factors. Auburn, AL: Auburn University. 192 p. Ph.D. dissertation.
- Rayamajhi, J.N.; Meldahl, R.S.; Kush, J.S. 1998. Stability of parameters that predict growth and yield of natural stands of longleaf pine (*Pinus palustris* Mill.). In: Waldrop, T.A., ed. Proceedings of ninth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 509-514.

# THE APPLICATION OF NIRVANA TO SILVICULTURAL STUDIES

Chi-Leung So, Thomas Elder, Leslie Groom, John S. Kush,  
Jennifer Myszewski, and Todd Shupe<sup>1</sup>

**Abstract**—Previous results from this laboratory have shown that near infrared (NIR) spectroscopy, coupled with multivariate analysis, can be a powerful tool for the prediction of wood quality. While wood quality measurements are of utility, their determination can be both time and labor intensive, thus limiting their use where large sample sizes are concerned. This paper will demonstrate the applicability of the NIRVANA system to such studies, in particular the automated property assessment of increment cores. This system has been successfully applied to a set of longleaf cores obtained from a variety of sites within the Southeastern United States. Mechanical property models based on longleaf pine were applied to the NIR data, from which modulus of elasticity (MOE) and modulus of rupture (MOR) predictions were obtained for the cores. These initial results, while promising, did indicate the need for the inclusion of some of the new samples (from the various sites) into the calibration set to provide more robust models.

## INTRODUCTION

The use of rapid assessment techniques for the characterization of wood has gained considerable interest throughout the forest products industry. Near infrared (NIR) spectroscopy, coupled with multivariate analysis, has been shown to be rapid, nondestructive, and requiring minimal sample preparation, making it ideal for process monitoring and quality control applications (So and others 2004). Multivariate analytical techniques, such as projection to latent structures (PLS) regression, have been used to develop calibration models for a variety of properties, utilizing both NIR and traditionally acquired data. These include: physical properties such as density (Gindl and others 2001, Hoffmeyer and Pedersen 1995, Thygesen 1994, Via and others 2003); mechanical properties such as modulus of elasticity (MOE) and modulus of rupture (MOR) (Gindl and others 2001; Hoffmeyer and Pedersen 1995; Kelley and others 2004a, 2004b; Thumm and Meder 2001; Via and others 2003) and wet chemistry (Kelley and others 2004b). Similarly, NIR spectroscopy has been very successfully applied to wood property data obtained from SilviScan. This instrument utilizes a combination of X-ray diffractometry, X-ray densitometry, and image analysis for the rapid determination of a range of wood properties at high spatial resolution. Schimleck, Evans, and coworkers, have used NIR spectra combined with SilviScan data to plot the variation of density, MFA, and MOE across increment cores (Jones and others 2005; Schimleck and Evans 2002a, 2002b, 2003; Schimleck and others 2002).

A system for the automated property assessment of increment cores, known as Near InfraRed Visual and Automated Numerical Analysis (NIRVANA), has been developed using this technique. This process utilizes a NIR spectrometer and a motorized stage linked together via various software and hardware systems. A software program was written to integrate the apparatus and is controlled by a user-friendly interface. For real-time property determination, various control

settings (including choosing appropriate PLS models) must be input prior to scanning. The spectral data are collected and processed through the PLS models from which property values are instantaneously predicted. These are displayed in the form of real-time plots showing the variation of the selected properties as a function of distance along the core.

There is a range of applications suited to NIRVANA, one of which is to relate the wood quality of longleaf pine to growth and yield data. Since longleaf pine can exhibit relatively slow growth rates, intensive silvicultural treatments such as weed control, fertilization, thinning, and pruning may be needed to increase productivity. While these practices can result in large gains, questions arise over the quality of the wood that is produced by accelerated growth. NIRVANA aims to develop integrated information on growth, yield, and wood quality of longleaf pine subjected to varying levels of silvicultural inputs.

## METHODS

The longleaf specimens used in the models for MOE and MOR were obtained from 10 longleaf trees selected from a plantation in Harrison Experimental Forest, Saucier, MS, located at longitude 89°10' W and latitude 30°60' N. The sample preparation and mechanical testing methods are fully described elsewhere (Via and others 2004).

The prediction set of 58 cores with unknown properties was collected from a variety of longleaf pine stands throughout the Southeastern United States (table 1). These stands represent ages between 20 and 100 years with site indices between 50 and 80. Some of these stands are part of the Regional Longleaf Pine Growth Study (RLGS), established in the Gulf States by the U.S. Forest Service, in which the original objective was to obtain a database for the development of growth and yield predictions for naturally regenerated, even-aged longleaf pine stands. The cores were air dried, mounted, and surfaced with the radial face protruding.

<sup>1</sup> Postdoctoral Researcher, School of Renewable Natural Resources, Louisiana State University Agricultural Center, Baton Rouge, LA 70803; Research Forest Products Technologist and Project Leader, USDA Forest Service, Southern Research Station, Pineville, LA 71360; Assistant Professor, School of Forestry and Wildlife Sciences, 108 M. White Smith Hall, Auburn University, Auburn, AL 36849; Research Geneticist, USDA Forest Service, Southern Research Station, Saucier, MS 71360; and Associate Professor, School of Renewable Natural Resources, Louisiana State University Agricultural Center, Baton Rouge, LA 70803, respectively.

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**Table 1—Stand descriptions for longleaf cores used for prediction**

Site	Site location	No. of cores	Site index	Basal area	Latitude (N)	Longitude (W)
Cyrene	Cyrene Turpentine Co., GA	16	80-85	30, 60, 90, 130 or 150	30°86'	84°38'
Southlands	Southlands Exp. Forest, GA	7	85-89	120 or 150	30°48'	84°42'
Escambia	Escambia Exp. Forest, AL	23	low 70s	60s	31°01'	87°04'
Flomaton	Flomaton Natural Area, AL	9	Unknown	Unknown	31°01'	87°14'
McClellan	Fort McClellan, AL	3	low 50s	40s	33°40'	84°45'

The cores were then placed on a Newport motorized stage (Newport, Irvine, CA), and spectra were collected at 2-mm intervals along the cores using an ASD Field Spec Pro (Analytical Spectral Devices, Boulder, CO) spectrometer. The spot size at the sample surface was approximately 2 mm with the spectra collected at wavelengths between 350 and 2,500 nm. This was achieved using a fiber optic probe oriented perpendicular to the sample surface while illuminated with a DC lamp oriented at 30° above the surface. The calibration specimens were scanned more than a year earlier using a similar method.

Partial least squares (PLS) analysis of the NIR data was performed using Unscrambler (version 8.0) software (CAMO, Corvallis, OR). The NIR data were reduced to 10 nm wavelength spacing by averaging prior to analysis. The calibration models for MOE and MOR were generated using full cross-validation (Martens and Naes 1989). The 469 calibration specimens were separated into a calibration set of 352 and a validation set of 117.

## RESULTS AND DISCUSSION

The longleaf models employed in this study have been used to predict MOE and MOR values for a set of longleaf cores harvested from various sites in the southeast. This parallel study, when compared to the work on the Harrison Experimental Forest, will help establish more general trends and indicate the utility of such models across broader geographic areas. The relationship between the predicted and measured MOR and MOE is shown in figures 1(a) and 1(b), respectively. It can be seen that the  $R^2$  values for both the calibration (352 specimens) and the validation (117 specimens) sets were high. The models obtained from the calibration sets were then used to predict the mechanical properties of the 58 cores in the prediction set.

The variation of predicted MOE along a typical longleaf core is shown in figure 2, with its corresponding image (inset). A general trend was observed of low MOE near the pith with higher values towards the bark. However, the values appear to peak near the transition region from wide to much narrower rings. Each NIR spectrum collected, after the transition region, is an average over many narrow growth rings as compared with those collected near the pith. Furthermore, the localized variation of MOE with earlywood and latewood bands is clearly evident in the pith region. This plot was repeated for each of the cores and also replicated for MOR. The NIRVANA system can produce these plots in real time, thus making it suitable for use in quality control applications. It was also observed that the inverse of the mechanical properties closely mirrors the annual growth of the tree. Both factors exhibit large variability during the formation of juvenile wood, followed by a sharp reduction in variability as growth continues (fig. 3).

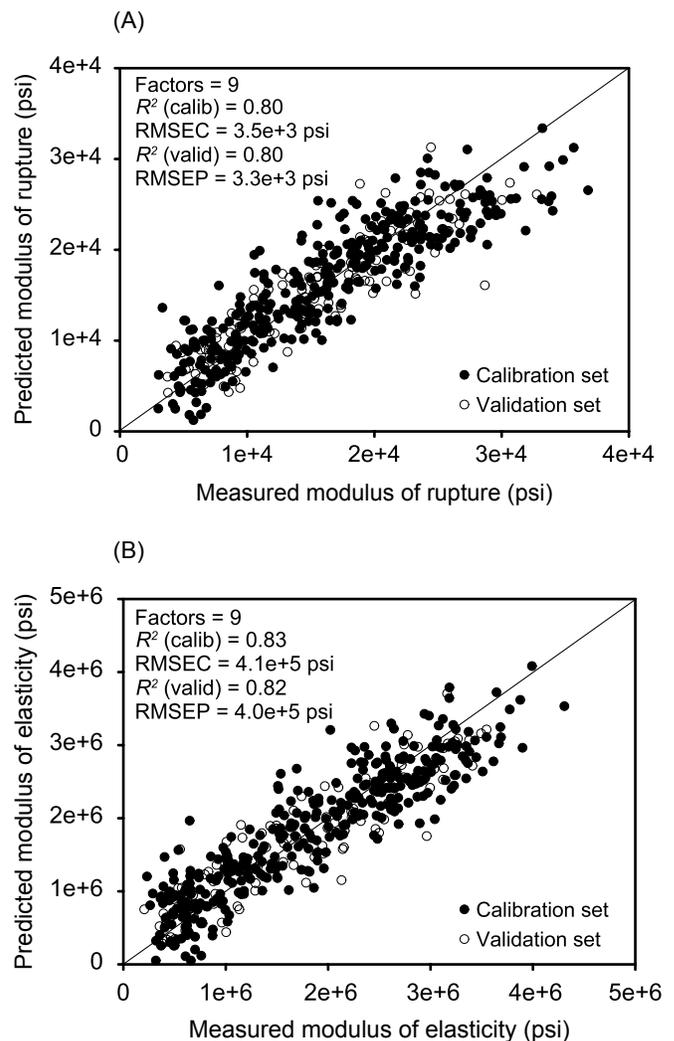


Figure 1—Relationship between predicted and measured (A) Modulus of Rupture and (B) Modulus of Elasticity.

This can be related to the image in figure 2 in which wide growth rings were present during juvenile wood formation followed by much narrower rings with the development of mature wood.

The determination of a single average value for each core may often be necessary for silvicultural or genetic studies in which thousands of increment cores may be extracted. This was carried out for MOE and MOR using both an area-weighted average as well as a simple numerical average. It was concluded that both methods yielded similar results for these

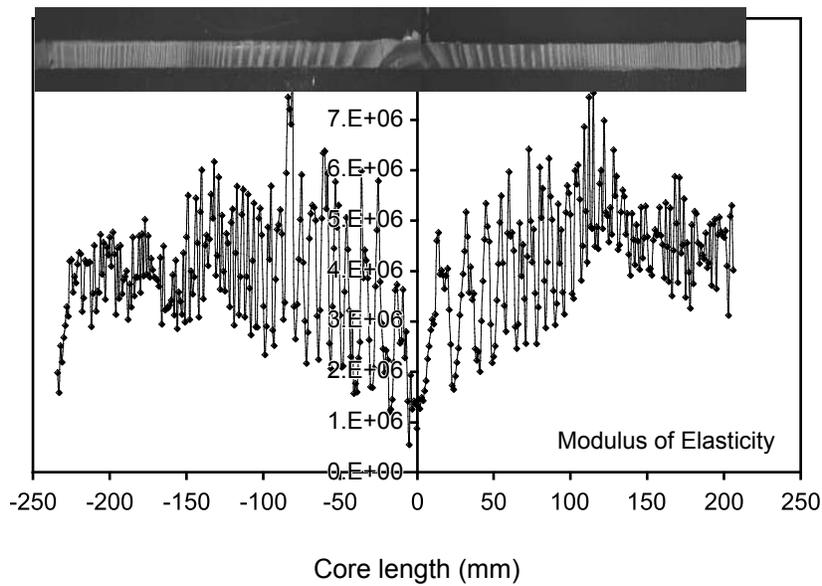


Figure 2—Modulus of Elasticity variation across an increment core.

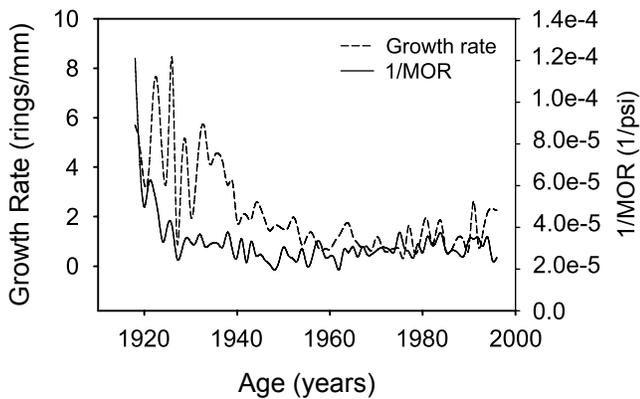


Figure 3—Variation of 1/Modulus of Rupture and growth by year.

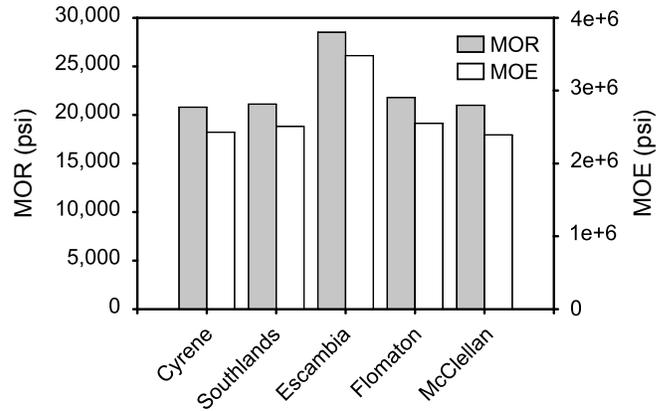


Figure 4—Summary of average mechanical properties by site.

cores. This data was further summarized by averaging these properties by site. The initial results indicate there are relatively large differences in mechanical properties between the cores from the Escambia Experimental Forest compared with those from the other sites (fig. 4). Further analysis of the growth and yield data is required to understand these results.

The predicted results for this initial study were based on a calibration set obtained from longleaf pine stands in the Harrison Experimental Forest, Saucier, MS. This sample set, however large, does have limited variation. It must be determined whether this variation is large enough to encompass that of the prediction set, i.e., cores from the sites listed in table 1. The mechanical properties for the prediction set are unknown and have only been predicted using the models from the calibration set. It was observed that a significant number of MOE values in figure 2 were greater than those for the calibration samples in figure 1(b). This indicates that the calibration set may not provide enough variation to produce robust calibration models that can be applied to the prediction set. It has been reported that the addition of a single specimen from the prediction set significantly decreased the error in the wood

property predictions (Jones and others 2005). The authors concluded that the enhancement was not so much due to the increase in variability of the wood properties in the calibration, but rather to the slight variability in the spectra from each stand due to the unique growing conditions at each site. These studies utilized Silviscan to determine the measured wood properties for both the calibration and prediction sets. However, in this study, it was not possible to obtain measured mechanical properties from trees used in the prediction set.

The purpose of this paper was to demonstrate the applicability of the NIRVANA system for wood quality studies and relating these results to growth and yield data. The NIRVANA software is presently undergoing an upgrade from a visual basic- to a Labview™-based program, greatly enhancing its functionality. The incorporation of a high-resolution video camera, integrated into the new software, will permit the automated visual recognition of individual growth rings, thus allowing the property variation along the core to be determined on a growth ring basis. This can be carried out simultaneously with the collection of growth and yield data from the core.

## CONCLUSIONS

The rapid assessment of solid wood properties using NIR has broad implications in relation to wood quality and ultimately, tree improvement. The NIRVANA system provides data rapidly and economically and thus is ideally suited to both silviculture and genetic programs with their use of large-scale sampling. It can also be used for real-time monitoring of property changes along an increment core. While NIRVANA has been successfully applied to this study, in order to produce robust calibration models for the prediction of wood properties, good sampling techniques must be employed, which, in this case, may mean the inclusion of a few samples from each of the sites into the calibration models.

## LITERATURE CITED

- Gindl, W.; Teischinger, A.; Schwanninger, M.; Hinterstoisser, B. 2001. The relationship between near infrared spectra of radial wood surfaces and wood mechanical properties. *Journal of Near Infrared Spectroscopy*. 9: 255-261.
- Hoffmeyer, P.; Pedersen, J.G. 1995. Evaluation of density and strength of Norway spruce by near infrared reflectance spectroscopy. *Holz Roh Werkst*. 53: 165-170.
- Jones, P.D.; Schimleck, L.R.; Peter, G.F. [and others]. 2005. Nondestructive estimation of *Pinus taeda* L. wood properties for samples from a wide range of sites in Georgia. *Canadian Journal of Forest Research*. 35: 85-92.
- Kelley, S.S.; Rials, T.G.; Groom, L.H.; So, C-L. 2004a. Use of near infrared spectroscopy to predict the mechanical properties of six softwoods. *Holzforschung*. 58: 252-260.
- Kelley, S.S.; Rials, T.G.; Snell, R. [and others]. 2004b. Use of near infrared spectroscopy to measure the chemical and mechanical properties of solid wood. *Wood Science and Technology*. 38: 257-276.
- Martens, H.; Naes, T. 1989. *Multivariate calibration*. Chichester, UK: John Wiley and Sons. 419 p.
- Schimleck, L.R.; Evans, R. 2002a. Estimation of wood stiffness of increment cores by near infrared spectroscopy: the development and application of calibrations based on selected cores. *IAWA Journal*. 23: 217-224.
- Schimleck, L.R.; Evans, R. 2002b. Estimation of microfibril angle of increment cores by near infrared spectroscopy. *IAWA Journal*. 23: 225-234.
- Schimleck, L.R.; Evans, R. 2003. Estimation of air-dry density of increment cores by near infrared spectroscopy. *Appita Journal*. 56: 312-317.
- Schimleck, L.R.; Evans, R.; Ilic, J.; Matheson, A.C. 2002. Estimation of wood stiffness of increment cores by near-infrared spectroscopy. *Canadian Journal of Forest Research*. 32: 129-135.
- So, C-L.; Via, B.K.; Groom, L.H. [and others]. 2004. Near infrared spectroscopy in the forest products industry. *Forest Products Journal*. 54(3): 6-16.
- Thumm, A.; Meder, R. 2001. Stiffness prediction of radiata pine clearwood test pieces using near infrared spectroscopy. *Journal of Near Infrared Spectroscopy*. 11: 137-144.
- Thygesen, L.G. 1994. Determination of dry matter content and basic density of Norway spruce by near-infrared reflectance and transmission spectroscopy. *Journal of Near Infrared Spectroscopy*. 2: 127-135.
- Via, B.K.; Shupe, T.F.; Groom, L.H. [and others]. 2003. Multivariate modeling of density, strength and stiffness from near infrared spectra for mature, juvenile and pith wood of longleaf pine (*Pinus palustris*). *Journal of Near Infrared Spectroscopy*. 11: 365-378.

# A NEW TYPE OF DENSITY-MANAGEMENT DIAGRAM FOR SLASH PINE PLANTATIONS

Curtis L. VanderSchaaf<sup>1</sup>

**Abstract**—Many Density-Management Diagrams (DMD) have been developed for conifer species throughout the world based on stand density index (SDI). The diagrams often plot the logarithm of average tree size (volume, weight, or quadratic mean diameter) over the logarithm of trees per unit area. A new type of DMD is presented for slash pine (*Pinus elliottii* var. *elliottii*) plantations where SDI is plotted over age. This proposed DMD eliminates two existing problems with current DMDs: (1) the need to estimate age from other measures found on traditional DMDs, and (2) a second variable also directly dependent on either age or SDI can be placed on a third axis. Plotting SDI over age clearly shows when thinnings need to be conducted to obtain a certain tree size-density objective both in terms of stand density and age. Yet this proposed DMD does not violate the well-known principle that DMDs are independent of age. Understory models are usually developed using an overstory density measure that includes both trees per unit area and a diameter measure (i.e. basal area per unit area or SDI per unit area) making it difficult to include them on current DMDs. Plotting SDI over age allows understory vegetation development to be easily included on a DMD. This provides a natural resource manager the ability to see what impacts a particular tree size-density objective has on understory vegetation production over time. An understory vegetation model was developed to demonstrate the applicability of the proposed DMD.

## INTRODUCTION

The use of stand density index (SDI) in density management diagrams (DMDs) is a useful tool to help achieve desired tree size-volume objectives. Many papers have discussed the theory and reasoning behind SDI and associated DMDs (Dean and Baldwin 1993, Dean and Chang 2002, Dean and Jokela 1992, Drew and Flewelling 1979, Long 1985, Mack and Burk 2002, McCarter and Long 1986, Reineke 1933, Williams 1994). It is not the purpose of this paper to agree or contradict these principles but rather to develop a new way of presenting them.

By plotting SDI over age, two problems with traditional DMDs are eliminated. First, age need not be estimated from other variables (Dean and Baldwin 1993, Dean and Chang 2002, Mack and Burk 2002) for traditional DMDs. This is generally done by placing dominant height curves on traditional DMDs, which can make the graphs rather complex and “busy”. Secondly, another variable directly dependent on age or SDI can be more easily included on a third axis. For example, understory vegetation is usually predicted using a measure that includes both tree density per area and stem diameter, such as SDI, and not by using quadratic mean diameter (qmd) and trees-per-acre (tpa) as separate independent variables (Grelen and Lohrey 1978, Moore and Dieter 1992, Wolters 1982, Wolters and Schmidting 1975). Therefore, it is rather difficult to include understory vegetation on traditional DMDs, which often plot the logarithm of qmd over the logarithm of tpa. This proposed DMD, plotting SDI over age also presents SDI as stand density development over age, which is familiar to most foresters. This provides a much clearer picture of the age(s) at which thinning(s) should be conducted to obtain a certain tree size-density management objective.

To those familiar with SDI and traditional DMDs, plotting growth trajectories over age may seem contradictory to principles associated with DMDs. It is a tenet of DMDs that they

are independent of age (Dean and Baldwin 1993, Long 1985). This can be a somewhat misleading statement. Therefore, a brief explanation of the principles associated with traditional DMDs and how the creation of this new type of DMD relates to them is provided. The proposed DMD is not new because it plots stand density development (represented by SDI) over age, but rather because it also includes the management zones generally associated with DMDs over age as well. No published literature could be found that presents a DMD in this manner. For demonstration purposes, a traditional DMD (Dean and Jokela 1992) developed for slash pine (*Pinus elliottii* Engelm. var. *elliottii*) plantations in the southeastern United States was altered.

DMDs can be created by first determining the Maximum-size density relationship (MSDR) for a particular species (i.e., slash pine) in a specific geographical region (i.e., Southeastern United States): In the case of Dean and Jokela’s (1992) slash pine DMD, this is a SDI value of 450 (Dean and Baldwin 1996). Usually, at least two relative numerical values to this MSDR are determined which have various names (Dean and Jokela 1992, Long 1985). Dean and Jokela (1992) determined two relative numerical values to the MSDR which are defined in this current paper as consistent with Long (1985): lower limit of “full-site occupancy” (25 percent of 450 = 112.5), and the lower limit of self-thinning (50 percent of 450 = 225). These values correspond, respectively, to the numerical values of SDI for all slash pine plantations in this region (in theory) where trees begin to fully occupy a site and the point at which competition related mortality due to excessive stand density begins (Dean and Jokela 1992, Long 1985).

When it is stated that SDI is independent of age, foresters are referring to the MSDR and the two relative management zones. Thus, whenever a stand’s SDI growth trajectory enters into 1 of these 2 relative management zones or approaches the Maximum-size density line, whether it is at age 10 or at

<sup>1</sup> Research Assistant, Virginia Polytechnic Institute and State University, Department of Forestry, Blacksburg, VA 24061.

age 35, the underlying principles behind each relative management zone and the Maximum-size density line apply. Site quality, moisture amounts, planting density, thinnings, seedling stock morphology, genetics, competing vegetation, etc. all play a role in what age plantation growth trajectories first enter these relative management zones, how long trajectories remain in these relative management zones, and the age at which growth trajectories begin to approach the Maximum-size density line. Kumar and others (1995) presents a more complete description of how age relates to the MSDR and relative management zones.

## DERIVATIONS AND DISCUSSION

A DMD developed by Dean and Jokela (1992) for slash pine was manipulated by placing age as the independent variable and SDI, calculated using equation (1), as the dependent variable:

$$SDI = tpa * (qmd/10)^{1.6} \quad (1)$$

where

tpa = trees-per-acre

qmd = quadratic mean diameter (inches)

The MSDR, the relative numerical values of the Lower limit of "full site occupancy", and the Lower limit of self-thinning to the MSDR are maintained. Data from a long-term slash pine planting density trial in Georgia were used to demonstrate SDI development (Jones 1987). Planting densities were 1,210 tpa (6 feet x 6 feet), 907 tpa (6 feet x 8 feet), 871 tpa (5 feet x 10 feet), 681 tpa (8 feet x 8 feet), 605 tpa (6 feet x 12 feet), 436 tpa (10 feet x 10 feet), 387 tpa (7.5 feet x 15 feet), and 194 tpa (15 feet x 15 feet). Measurement ages were 10, 15, 20, 25, and 30 years. As seen in figure 1, the new type of DMD provides the same information as traditional DMDs as to when stands are within the three management zones.

There may be some question when plotting SDI over age whether self-thinning can be graphically determined. Self-thinning is defined as when plantations are experiencing competition-induced mortality (Mack and Burk 2002) brought about by excessive stand density. This phenomenon is assumed to begin when a stand's SDI growth trajectory enters the Lower limit of self-thinning management zone. On traditional DMDs, generally a stand growth trajectory moving vertically (parallel to the y-axis) indicates the plantation is not self-thinning, while a stand growth trajectory that is moving to the left indicates a plantation is self-thinning. What about on the new type of DMD? It appears that generally, stand growth trajectories that parallel the x-axis (age) or that are moving down on the new type of DMD are self-thinning (fig. 1) when compared to the traditional DMD.

Two long-term planting density studies for loblolly pine (*Pinus taeda* L.) were examined using a DMD developed by Dean and Baldwin (1993). One study was located in South Carolina (Balmer and others 1975, Buford 1991, Harms and Lloyd 1981, Harms and others 2000), and the other study was located in Louisiana (Sprinz and others 1979). Self-thinning of SDI growth trajectories for both of these studies on the proposed DMD appears similar to the slash pine study when compared to traditional DMDs – parallel to the x-axis or when the trajectory has a downward path.

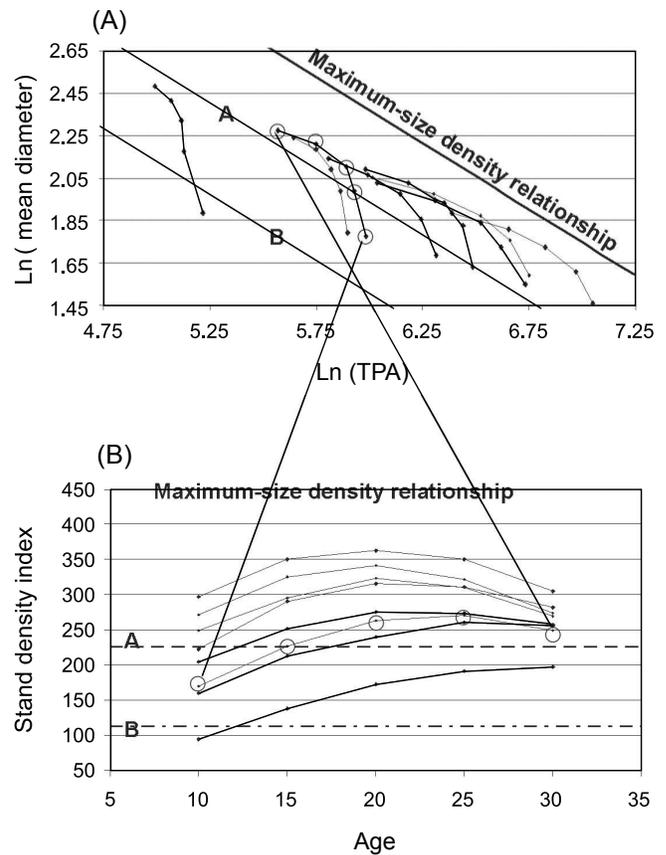


Figure 1—Natural logarithm of quadratic mean diameter in inches [Ln (Mean diameter)] over natural logarithm of trees per acre (LnTPA) (A) and stand density index over age (B) for eight different planting densities of slash pine. Where: A = Lower limit of self-thinning [50 percent of Maximum-Size Density Relationship (MSDR) of 450 = 225], B = Lower limit of "full site occupancy" (25 percent of MSDR of 450 = 112). The circles and connecting lines show how stand development is observed for stands that are either not self-thinning or self-thinning for both types of Density Management Diagrams using the planting density of 436 trees per acre.

Although this is an important consideration, this topic in itself does not invalidate or validate the proposed DMD. The main purpose of the new type of DMD is to provide foresters the ability to graphically see when a plantation's SDI growth trajectory has entered a particular management zone without having to estimate the age at which it occurs.

One disadvantage to using this new type of DMD is the loss of the ability to graphically see the maximum size (qmd)-density (tpa) relationship. By plotting the natural logarithm (ln) of qmd over ln tpa, you can see that as tpa decreases, the largest qmd that can occur increases. This is lost on the new type of DMD. Additionally, equation (1) assumes a constant slope (1.6). Many studies have shown the slope can have different values (Tang and others 1994, VanderSchaaf 2004, Zeide 1985) than the 1.6 proposed by Reineke (1933). Therefore, one of the main uses of the new type of DMD may be to help students, landowners, and foresters unfamiliar with DMDs to manage plantations using the principles of the relative management zones. By eliminating the need to estimate age, thus reducing the complexity of DMDs since dominant height curves are not needed, DMDs can be a more useful tool to field managers.

For example, when explaining management regimes to private landowners for their stand's particular growth trajectory, a user can clearly see at what age thinnings need to be conducted to achieve a tree size-density target to meet the landowner's objective. Traditional DMDs can still be used to clarify the maximum-size density principle.

### AN APPLICATION OF THE PROPOSED DMD

To better show how the proposed DMD can be useful, estimates of understory vegetation from models presented below were plotted along with overstory density development over age (fig. 2). Estimates of understory vegetation can provide managers information about effects of density on wildlife and domestic grazing animals. By using AUMs and AUM equivalents (VanderSchaaf 1999), managers can quantify how different density management regimes affect the animal carrying capacity of a site. Other publications have used DMDs with SDI to relate stand density to wildlife habitat (Lilieholm and others 1994, McTague and Patton 1989, Smith and Long 1987, Sturtevant and others 1996). Published understory vegetation data were obtained from a long-term unthinned slash pine plantation study located in Georgia (Lewis 1989). Overstory density (tpa and qmd) and herbaceous vegetation production (pounds per acre) were measured annually beginning at age 8 until age 26. Herbaceous vegetation was divided into two lifeforms, grasses and grass-likes (i.e., *Cyperus* spp.) or forbs. Ordinary least squares models (equations 2 and 3) were developed using SDI as the independent variable:

$$\text{grass} = 8561.277 - 1479.530 \cdot \ln(\text{SDI}) \quad (2)$$

where

$n = 19$

MR = mean absolute value of the residual -  $(\sum|\text{actual} - \text{predicted}|)/n$  or in this case 164.7 pounds per acre)

Adj.  $R^2 = 0.8767$

grass = production (pounds per acre) of grasses and grass-likes

$\ln$  = natural logarithm

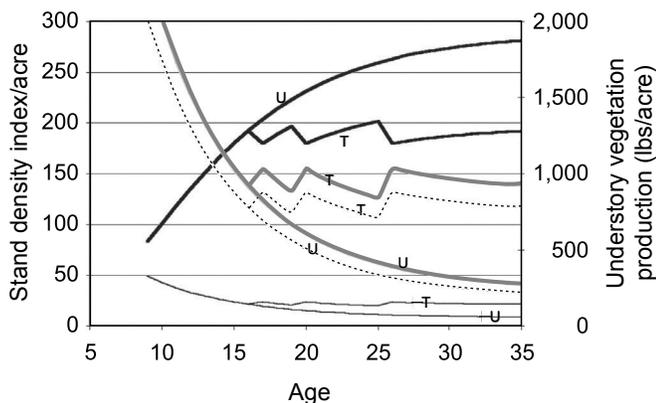


Figure 2—Stand density index and understory vegetation production over age. The dark solid line is overstory stand density development, the gray solid line is total understory herbaceous vegetation production (grasses, grass-likes, and forbs), the dashed lighter line is grass and grass-like vegetation production, and the solid lighter line is forb vegetation production. U = unthinned, T = thinned.

$$\text{forb} = 1305.267 - 221.155 \cdot \ln(\text{SDI}) \quad (3)$$

where

$n = 19$

MR = 57.0 pounds per acre

Adj.  $R^2 = 0.5822$

forb = production (pounds per acre) of forbs

SDI was checked to make sure that it was significant at the  $\alpha = 0.05$  level. Many different model forms were tested that included  $\ln$ , square-root, and exponential transformations of the dependent and independent variables as well as simple straight linear regressions. The final model form selected was based on the MR, error residual trends, and biological correctness of the coefficients. Error residuals showed no adverse trends for the final model form selected. Qmd and tpa as individual independent variables were not significantly different from 0 ( $\alpha = 0.05$ ) using any model form. Yet SDI explained a substantial amount of variation in understory vegetation. This is in agreement with my previous experience with understory vegetation modeling (VanderSchaaf 1999). Of course this is somewhat counterintuitive because it makes sense that a stand with a SDI of 150 composed of 6,000 tpa and a qmd of 1 inch would have a different impact on understory vegetation production than a stand with a SDI of 150 composed of 150 tpa and a qmd of 10 inches. Nonetheless, since traditional DMDs plot  $\ln qmd$  over  $\ln tpa$ , it is hard to include estimates of understory vegetation on them because of the statistical insignificance of  $\ln qmd$  and  $\ln tpa$  in understory vegetation models.

A natural resource manager can get a clear picture of how a particular tree size-density objective would affect understory vegetation over time in unthinned and thinned stands (fig. 2). In order to predict understory vegetation production following thinning, equation (4) (Pienaar and Harrison 1989) was developed to estimate stand density production over time using SDI data from Lewis (1989):

$$\text{SDI} = \text{PrevSDI} \cdot \left[ \frac{1 - \exp[-0.146 \cdot \text{Age}]}{1 - \exp[-0.146 \cdot \text{Prevage}]} \right]^3 \cdot 979 \quad (4)$$

where

$n = 18$

MR = 3.3

Adj.  $R^2 = 0.9941$

PrevSDI = SDI at the previous measurement age

Prevage = previous measurement age

Residual errors showed no adverse trends. Despite being developed using unthinned data, this model allows us to reasonably predict stand density development after thinning so that we can estimate understory vegetation response following this treatment. Information obtained from figure 2 can provide valuable information about wildlife habitat, such as fuel management for fire control, etc. As an example: A forester wants to maintain a relative overstory density between 40 (180 SDI) and 45 percent (202 SDI) of the MSDR up to age 35. Figure 2 shows that thinning can greatly increase herbaceous production based on the equations presented in this paper. At age 35, total herbaceous production in the thinned stand is 646 pounds greater than total herbaceous production in the unthinned stand on a per acre basis. Managers can use the proposed DMD to adjust stand density to meet an overstory requirement as well as to achieve an understory vegetation objective.

Some researchers have modeled understory production as a function of age (Mengak and others 1989). Although this approach may have applicability (perhaps due to different nutrient requirements of trees through time, etc.), stand density impacts understory production much more than stand age. For instance, understory production at age 5 in 2 stands where 1 stand was planted at 300 tpa and the other was planted at 2,500 tpa would most certainly be greater in the 300 tpa planted stand. In a model using age as a regressor, age would be a surrogate for stand density, although only a useful surrogate within a limited range of stand densities. The DMD proposed in this paper could relate understory production to SDI, and then by relating SDI to age, one could obtain an estimate of understory production at various ages (fig. 2). More complex understory models could examine specific understory species production relative to overstory stand density. This proposed type of DMD can be developed for plantations and perhaps for naturally regenerated even-aged stands of any overstory species or combination thereof. It should be remembered that either type of DMD (traditional or the type proposed here) does not take into account economics and is most useful to those who want to achieve a certain tree size-density objective to meet management criteria. Other variables dependent on SDI or age could be included on the proposed DMD. For example, perhaps coarse-woody debris amounts could be plotted over age to provide a clear picture of how overstory density affects decomposition over time.

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## LITERATURE CITED

- Balmer, W.E.; Owens, E.G.; Jorgensen, J.R. 1975. Effects of various spacings on loblolly pine growth 15 years after planting. Res. Note SE-211. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 7 p.
- Buford, M.A. 1991. Performance of four yield models for predicting stand dynamics of a 30-year-old loblolly pine (*Pinus taeda* L.) spacing study. Forest Ecology and Management. 46: 23-38.
- Dean, T.J.; Baldwin, V.C. 1993. Using a stand density-management diagram to develop thinning schedules for loblolly pine plantations. Res. Pap. SO-275. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 7 p.
- Dean, T.J.; Baldwin, V.C. 1996. The relationship between Reineke's stand-density index and physical stem mechanics. Forest Ecology and Management. 81: 25-34.
- Dean, T.J.; Chang, S.J. 2002. Using simple marginal analysis and density management diagrams for prescribing density management. Southern Journal of Applied Forestry. 26: 85-92.
- Drew, T.J.; Flewelling, J.W. 1979. Stand density management: An alternative approach and its application to Douglas-fir plantations. Forest Science. 25: 518-532.
- Dean, T.J.; Jokela, E.J. 1992. A density-management diagram for slash pine plantations in the lower Coastal Plain. Southern Journal of Applied Forestry. 16: 178-185.
- Grelen, H.E.; Lohrey, R.E. 1978. Herbage yield related to basal area and rainfall in a thinned longleaf plantation. Res. Note SO-232. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 4 p.
- Harms, W.R.; Lloyd, F.T. 1981. Stand structure and yield relationships in a 20-year-old loblolly pine spacing study. Southern Journal of Applied Forestry. 5: 162-165.
- Harms, W.R.; Whitesell, C.D.; DeBell, D.S. 2000. Growth and development of loblolly pine in a spacing trial planted in Hawaii. Forest Ecology and Management. 126: 13-24.
- Jones, Jr., E.P. 1987. Slash pine plantation spacing study – age 30. In: Phillips, D.R., comp. Proceedings of the fourth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 45-49.
- Kumar, B.M.; Long, J.N.; Kumar, P. 1995. A density management diagram for teak plantations of Kerala in peninsular India. Forest Ecology and Management. 74: 125-131.
- Lewis, C.E. 1989. Herbage yield response to the maturation of a slash pine plantation. Journal of Range Management. 42: 191-195.
- Liliehalm, R.J.; Long, J.N.; Patla, S. 1994. Assessment of goshawk nest area habitat using stand density index. Studies in Avian Biology. 16:18-23. Available at: [http://elibrary.unm.edu/condor/cooper/sab\\_016.html](http://elibrary.unm.edu/condor/cooper/sab_016.html).
- Long, J.N. 1985. A practical approach to density management. Forestry Chronicle. 61: 23-27.
- Mack, T.J.; Burk, T.E. 2002. User's manual for *Resinosa* – an interactive density management diagram for red pine in the Lake States. Department of Forest Resources. Staff Paper Series No. 158. St. Paul, MN: University of Minnesota, College of Forestry. 25 p.
- McCarter, J.B.; Long, J.N. 1986. A lodgepole pine density management diagram. Western Journal of Applied Forestry. 1: 6-11.
- McTague, J.P.; Patton, D.R. 1989. Stand density index and its application in describing wildlife habitat. Wildlife Society Bulletin. 17: 58-62.
- Mengak, M.T.; Van Lear, D.H.; Guynn, D.C., Jr. 1989. Impacts of loblolly pine productivity on selected wildlife habitat components. In: Miller, J.H., comp. Proceedings of the fifth biennial southern silvicultural research conference. Gen. Tech. Rep. SO-74. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 612-618.
- Moore, M.M.; Deiter, D.A. 1992. Stand density index as a predictor of forage production in northern Arizona pine forests. Journal of Range Management. 45: 267-271.
- Pienaar, L.V.; Harrison, W.M. 1989. Simultaneous growth and yield prediction equations for *Pinus elliottii* plantations in Zululand. South African Forestry Journal. 149: 48-53.
- Reineke, L.H. 1933. Perfecting a stand-density index for even-age forests. Journal of Agricultural Research. 46: 627-638.
- Smith, F.W.; Long, J.N. 1987. Elk hiding and thermal cover guidelines in the context of lodgepole pine stand density. Western Journal of Applied Forestry. 2: 6-10.
- Sprinz, P.; Clason, T.; Bower, D. 1979. Spacing and thinning effects on the growth and development of a loblolly pine plantation. Forestry Research Report. Homer, LA: Northern Louisiana Hill Farm Experiment Station. 90 p.
- Sturtevant, B.R.; Bissonette, J.A.; Long, J.N. 1996. Temporal and spatial dynamics of boreal forest structure in western Newfoundland: silvicultural implications for marten habitat management. Forest Ecology and Management. 87: 13-25.
- Tang, S.; Meng, C.H.; Meng, F.; Wang, Y.H. 1994. A growth and self-thinning model for pure even-age stands: theory and applications. Forest Ecology and Management. 70: 67-73.
- VanderSchaaf, C.L. 1999. Operational fertilization effects on understory vegetation. Moscow, ID: University of Idaho. 157 p. MS Thesis. (pdf file available at <http://filebox.vt.edu/users/cvanders/>).
- VanderSchaaf, C.L. 2004. Can planting density have an effect on the maximum-size density line of loblolly and slash pine? In: Doruska, P.F.; Radtke, P., comps. Proceedings of the northeastern mensurationist organization and southern mensurationists joint conference. Blacksburg, VA: Department of Forestry, Virginia Polytechnic Institute and State University: 115-126. (pdf file available at <http://filebox.vt.edu/users/cvanders/>).
- Williams, R.A. 1994. Stand density management diagram for loblolly pine plantations in north Louisiana. Southern Journal of Applied Forestry. 18: 40-45.
- Wolters, G.L. 1982. Longleaf and slash pine decreases herbage production and alters herbage composition. Journal of Range Management. 35: 761-763.
- Wolters, G.L.; Schimdtling, R.C. 1975. Browse and herbage in intensively managed pine plantations. Journal of Wildlife Management. 39: 557-562.
- Zeide, B. 1985. Tolerance and self-tolerance of trees. Forest Ecology and Management. 13: 149-166.

# FORECASTING ECONOMIC GAINS FROM INTENSIVE PLANTATION MANAGEMENT USING UNREALISTIC YIELD OVER INPUT CURVES

David B. South, Curtis L. VanderSchaaf, and Larry D. Teeter<sup>1</sup>

**Abstract**—Some researchers claim that continuously increasing intensive plantation management will increase profits and reduce the unit cost of wood production while others believe in the law of diminishing returns. We developed four hypothetical production models where yield is a function of silvicultural effort. Models that produced unrealistic results were (1) an exponential curve and (2) a linear curve where the cost of growing a cubic foot of wood was inversely related to the discounted cost of intensive silviculture. Although increasing silvicultural effort will often result in producing more wood, the increase is sometimes not enough to prevent a reduction in net present value of the stand. Harvesting intensively managed stands at ages 14 to 16 years might not prove economical for a private, nonindustrial landowner if the costs of establishment are too high or if no local mills will purchase logs that contain a high percentage of juvenile wood.

## INTRODUCTION

Intensive management can affect volume growth of loblolly pine (*Pinus taeda* L.) plantations (Borders and Bailey 2001; Haywood and Tiarks 1990; Miller and others 1991; NCSFNC 1996, 2000). Although there are a few exceptions (Miller and others 2003, South and others 1995), increasing inputs at time of establishment typically increases volume production. Some believe that increasing silvicultural inputs will decrease the unit cost of wood production (Allen 2002). If this occurs, then increasing stand management inputs will result in greater profits (Yin and Sedjo 2001). Our concern is whether continuously increasing silvicultural inputs (e.g., soil tillage, fertilizers, herbicide applications, morphologically improved seedlings, improved genetics, irrigation, pest management, rooted-cuttings, container-grown stock, etc.) will result in enough additional yield to increase profits for a nonindustrial private forest landowner.

There are three schools of thought regarding the relationship between silvicultural inputs and wood yield. One school believes volume growth increases at an increasing rate (as silvicultural effort increases). For example, some believe increases in silvicultural inputs have increased volume growth by about 3 percent per year (Binkley 2003) and will continue to do so into the near future (Binkley and others 2005). This rate of increase might result in 1,000 percent gain in productivity when comparing the yield of natural stands in 1950 to intensively managed plantations in 2030 (Wallinger 1993). The second school believes volume gains are linearly related to inputs (Allen 2002, Larsen 1976). As a result, increasing inputs from \$300 per acre to \$350 per acre would equal gains achieved by increasing inputs from \$200 per acre to \$250 per acre. The third school follows the law of diminishing returns (Chapman and Meyer 1947, Spillman and Lang 1924). The point at which the diminishing returns begin to operate can be difficult to ascertain, which may explain why some believe in linear or exponential type relationships.

If the debate over these volume-over-input curve shapes were purely academic, there would be little need to examine potential economic outcomes. However, plantation managers sometimes invest in additional silvicultural practices without

waiting for end-of-rotation research results. As a result, accountants sometimes ask managers to use short-term data to predict long-term gains. The managers might choose an optimistic volume-over-input curve in order to justify their prior expenditures.

## PROCEDURES

Four contrasting models of loblolly pine merchantable volume-over-input curves were developed. All four models assume standing volume at age 15 years increases as silvicultural inputs increase (fig. 1). Model 1 assumes that yield increases at a decreasing rate as silvicultural effort increases. This model adheres to the law of diminishing returns. Model 2 assumes an exponential function, where yield increases at an increasing rate with increases in silvicultural effort. Models 3 and 4 assume yield is linearly related to the cost of silvicultural inputs. For model 3, the cost per unit of volume production increases as silvicultural costs increase. For model 4, the per-unit cost of volume production decreases as silvicultural costs increase. Graphically, the slope of the line for model 3 will be less than the slope for model 4.

Data from a paper by Borders and Bailey (2001) were used to develop the models. The moist site at Waycross, GA, was selected because it provided the greatest growth response to silvicultural inputs. Treatments at this site included: (1) a no chemical control; (2) treatment with annual fertilization; and (3) treatment with annual fertilization plus 3 years of herbicides to control herbaceous and woody vegetation.

Merchantable cubic foot volumes per acre for each treatment were extrapolated to age 15 years. The estimated volumes were then plotted over the sum of discounted costs per acre (using a real interest rate of 6 percent) for each treatment. Functions were then developed for each site so they would approximate each of the four models (fig. 1). Costs for the treatments included: site preparation at \$150 per acre, seedling and planting costs of \$70 per acre, fertilization cost of \$60 per acre per application, and herbicide costs of \$60 per acre per application. Discounted costs per acre were used as a proxy for silvicultural intensity.

<sup>1</sup> Professor, School of Forestry and Wildlife Sciences, Alabama Agricultural Experiment Station, Auburn University, Auburn, AL 36849-5418; Graduate Student, Virginia Polytechnic Institute and State University, Department of Forestry, Blacksburg, VA 24061; and Professor, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL 36849-5418.

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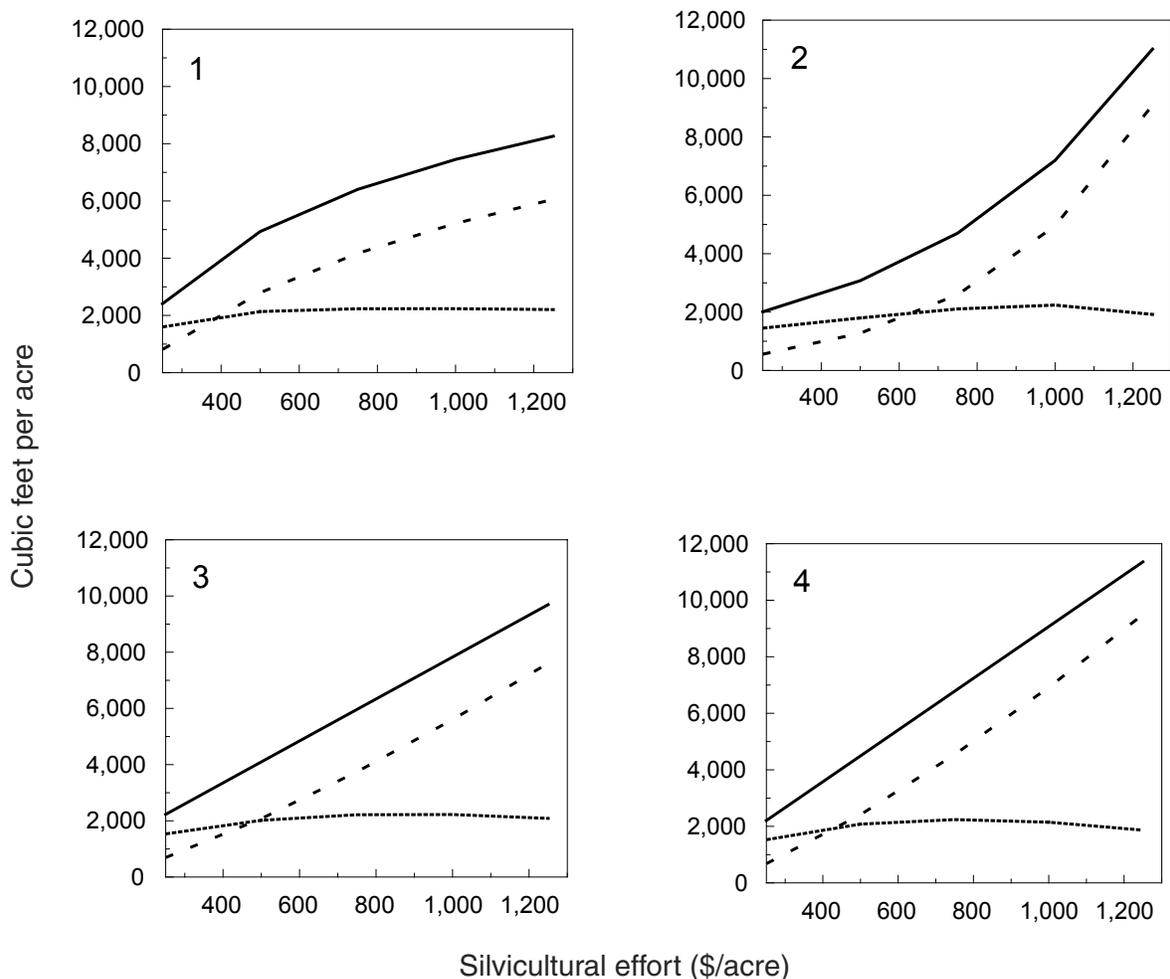


Figure 1—Volumes at age 15-years as affected by four theoretical volume-over-input models. Model #1 adheres to the law of diminishing returns. Model #2 assumes an exponential relationship between volume and inputs. Model #3 assumes a linear relationship with an increasing cost of producing a unit of wood. Model #4 assumes a linear relationship but with a decreasing cost of producing a unit of wood. Silvicultural effort is measured by total discounted costs of all silvicultural inputs. The upper solid line represents total cubic foot volume production, the lower dotted line is pulpwood volume production, and the dashed line represents chip-n-saw volume production.

After volume-over-silvicultural input curves were developed, the total volume was divided into two product classes: pulpwood [diameter at breast height (d.b.h.)  $\geq$  4.5 inches but not  $>$  9 inches] and chip-n-saw (d.b.h.  $>$  8.9 inches). A growth and yield simulator (Acorm) developed in Georgia (Dangerfield and Moorhead 1996) was used to determine the product mix. The simulator estimates the product distribution for a given rotation age and site productivity.

We used two stumpage price scenarios. The first scenario assumed the landowner could sell pulpwood for \$21 per 100 cubic feet (cunit) and could sell 15-year-old chip-n-saw for \$104 per cunit. The second scenario assumed a mill would only pay \$21 per cunit for juvenile wood, regardless of the d.b.h. We used a stand-level economic model rather than a forest-level economic model (e.g., Yin and others 1998), since the private landowner in our example only has one 40-acre stand. Since rotation age is the same in each case, we compared the models using before-tax, net-present-values (NPV).

After volume-over-input models were developed, realized 15-year data were obtained for the Waycross site and for the

site at Tifton, GA. The Tifton site was selected because it was unresponsive to fertilization with diammonium phosphate and potassium chloride. These data were used to calculate before-tax NPVs for both sites.

## RESULTS

When all wood was sold as pulpwood, the NPVs were generally negative (fig. 2a). In fact, at \$21 per cunit, none of alternatives at the Waycross site produced a positive NPV (with silvicultural inputs  $<$  \$1,250 per acre). However, with extrapolation past the data (and assuming no limit to carrying capacity), the exponential model (#2) will eventually produce a positive NPV.

Regardless of model selected, the NPVs obtained by selling pulpwood plus chip-n-saw increased with additional inputs (fig. 2b). However, the diminishing returns model (#1) appears close to reaching an optimal silvicultural effort near \$1,250 per acre. The NPV curves for the remaining three models suggest that higher NPVs would be achieved when inputs are  $>$  \$1,250 per acre.

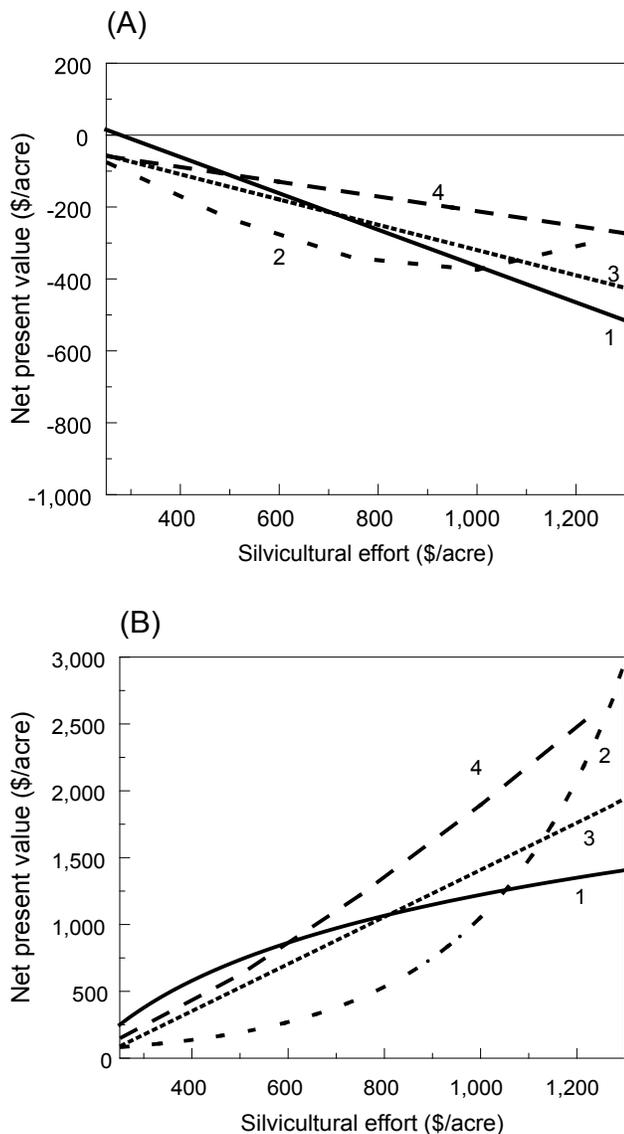


Figure 2—Net present value per acre for the four alternative models: 1 = diminishing returns; 2 = exponential; 3 = linear (increasing cost per cubic foot); 4 = linear (decreasing cost per cubic foot). In (A), all wood is sold as pulpwood at \$21 per cunit. In (B), wood is merchantized and pulpwood is sold for \$21 per cunit while chip-N-saw is sold for \$104 per cunit. The level of intensive management increases as the discounted costs for the inputs (i.e silvicultural effort) increases.

The discounted cost per unit of wood produced at harvest is of interest to some plantation managers. In our examples, the cost per unit of wood tended to increase with models #1 and #3 (fig. 3). With the more optimistic models (#2 and #4), the discounted cost of wood was reduced as inputs increased.

Realized gains at age 15 years varied by site. Fertilization plus the use of herbicides increased volume growth by 28 cunits per acre at the Waycross site but the increase was only 9 cunits per acre at the Tifton site (table 1). At both sites, annual fertilization (with or without the use of herbicides) increased the discounted cost of a cubic foot of wood.

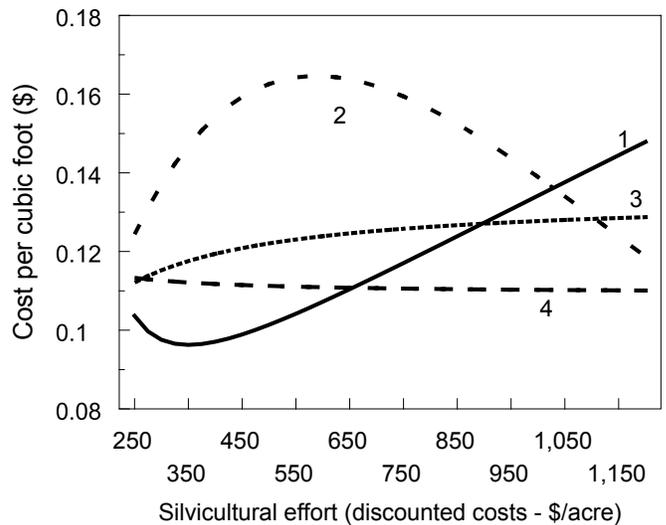


Figure 3—Discounted silvicultural costs (at a 6 percent interest rate to year zero) per cubic foot as affected by the amount of silvicultural effort for four alternative models: 1 = diminishing returns; 2 = exponential; 3 = linear (increasing cost per cubic foot); 4 = linear (decreasing cost per cubic foot). Of the models presented here, only two reduce the unit cost of wood production as silvicultural inputs exceed \$600 per acre.

## DISCUSSION

This paper does not present specific models to estimate growth response to intensive management. Instead, we are trying to make managers aware of the various outcomes that can result when predictions about future volume gains differ. Therefore, this paper takes a simplistic view of “intensive” plantation management. Our four hypothetical production functions (fig. 1) do not represent actual production curves but rather only a few examples of many shapes of curves that may exist. Although many curve shapes could be fitted to response data, we are only interested in the shape of “boundary layer” curves. Hopefully, this paper will shed light on how different schools of thought might affect projected NPVs.

## Model Comparisons

By design, three of the models predict a harvest volume of 70 to 80 cunits per acre with \$1,000 of silvicultural effort (fig. 1). However, at this level of input, model 4 predicts over 90 cunits per acre, but this is because a steep slope was required to maintain a declining cost of wood production (fig. 3). Therefore, model #4 is the most liberal in predicting volume production and produces the highest NPVs (with inputs ranging from \$750 to \$1,250). Since this model does not fit the Waycross data well, we believe this model is unrealistic. It seems unlikely that the unit cost of wood production will continue to decline as silvicultural inputs are increased (as some have suggested).

The exponential model predicts that once \$600 per acre is expended, the unit cost of wood production will also decline with additional inputs (fig. 3). In fact, when extrapolating to an input level of \$1,500 per acre, this model produces the highest NPV and cheapest wood cost. However, realized gains at both the Waycross and Tifton sites show an increase in the unit cost of wood with increasing treatment costs (table 1).

**Table 1—Effect of increasing silvicultural inputs on volume yields and mean annual increment (MAI) at age 15 years at a wet site at Waycross, GA and a site near Tifton, GA (Borders and Bailey 2001). A Yield-Cost Index (YCI) is provided in green tons per acre per year (g). Discounted treatment costs and net present values per acre (NPV) are provided (at 6 percent interest rate; \$21 per cunit of pulpwood; \$104 per cunit of chip-n-saw)**

Location	Treatment	Yield ---- ft <sup>3</sup> /acre ----	MAI	YCI <sub>15</sub>	Discounted costs/acre	Discounted costs/cunit	NPV pulpwood only	NPV
		----- \$ -----						
Waycross	No fertilization; no herbicides	2,869	191	6g-2	220	7.67	31	490
	Annual fertilization	6,454	430	13g-7	693	10.74	-127	1,474
	Annual fertilization plus three herbicide applications	7,007	467	15g-9	854	12.19	-240	1,547
Tifton	No fertilization; no herbicides	4,380	292	9g-2	220	5.02	164	1,157
	Annual fertilization	4,151	277	9g-7	693	16.69	-329	585
	Annual fertilization plus three herbicide applications	5,299	353	11g-9	854	16.12	-390	885

Results from slash pine (*Pinus elliottii* Engelm.) plantations also indicate the unit cost of wood production can increase as silvicultural inputs increase (Yin and others 1998). In addition, an exponential model inherently assumes no “carrying-capacity” limit. For these reasons, we conclude an exponential model is also unrealistic.

This leaves two models: the diminishing return model (#1) and a linear model (#3). Both models predict similar volume gains (fig. 1.1 versus 1.3), but they differ in their unit cost curves (fig. 3). Although both models show a general trend of increasing unit costs with increasing inputs, the diminishing return model shows an initial decrease in unit costs. The “diminishing return” curve (#1) not only fits the realized gains well (table 1), but it also is similar to the curve reported by Crutchfield (1991). We predict that in the long-run, a “diminishing return” curve will prove to be more appropriate than a linear model. Yields per acre per year tends to level off after the leaf-area index reaches a maximum level.

### Stumpage Price

Costs and stumpage prices are the major factors determining whether increases in silvicultural inputs will be worth the investment for a private landowner. For example, when stumpage prices for pulpwood are expected to rise to \$55 to \$110 per cunit (Abt and others 1995), intensive management becomes attractive. However, at \$21 per cunit, an investment of \$800 per acre to produce 15-year-old pulpwood is not attractive (table 1; fig. 2a). In the second quarter of 2003, regions paying less than \$21 per cunit for pine pulpwood included Arkansas, and parts of South Carolina, Tennessee, and Texas. For chip-n-saw, the only region with stumpage more than \$104 per cunit was in south Mississippi (Norris Foundation 2003).

Some justify the added expense of intensive silviculture by assuming the stumpage price paid to private landowners for 14- to 16-year-old logs is the same as that paid for logs (with the same large-end diameter) that are 24- to 30-years-old.

But in the real world, mill managers know that harvest age affects the juvenile to mature wood ratio. Some pulpmills pay 9 to 13 percent less per cunit for juvenile pulpwood because they know that young logs with more juvenile wood have higher moisture contents than older logs. Others limit their wood acquisitions to ages 15 to 18 years because the price is lower than larger 24-year-old logs, and their product favors the use of juvenile wood. In fact, “juvenile wood chips will pulp more rapidly and produce higher yields at a given kappa number compared with the heavier cellulose yielding mature wood” (Zobel and Sprague 1998). Although an inherent relationship between growth rate and specific gravity does not exist for loblolly pine (Megraw 1985), harvesting at younger ages will lower specific gravity. Since lumber cut from the center of a 15-year-old tree might not meet design requirements due to the amount of juvenile wood, some sawmills pay less for young logs while others do not even purchase logs that are < 17- to 23-years-old. Therefore, if private landowners plan to invest heavily in silviculture and harvest at 15 or 16 years, they should make sure the local mills are willing to pay a decent price for logs with a high percentage of juvenile wood.

### Site Differences

Site selection is very important if a landowner decides to invest \$800 per acre in silvicultural treatments. Although volume gains can be expected with annual fertilization and weed control, some sites will show a reduction in NPV. For example, intensive silviculture at the Tifton site reduced NPV even when wood was merchandized and large-diameter trees were sold for \$104 per cunit (table 1). Since there is an interaction between site and NPV response to silvicultural treatments, one company (located in east central Alabama) has decided to restrict the application of certain silvicultural practices to only medium sites. Therefore, they do not apply intensive silviculture on their best sites.

## Economic Approach

Some economic approaches used to justify intensive silviculture are different from the one presented here. Others have used a reduction in rotation age and a reduction in acreage managed to justify the added expense of intensive silviculture. In our example, we assumed a landowner had 40 acres of land and plans to harvest the trees in 15 years. Therefore, we used a fixed rotation of 15 years and did not use a “forest-level” economic model (Yin and others 1998). We did not consider volume production past age 15 years because we did not want to predict trends more than 4 years past the observed data. Therefore, we are not suggesting that the rotation age or management scenarios presented here are optimal.

## YCI Terminology

The term “intensive plantation forestry” is often poorly defined. Since it represents a wide range of meanings, it has become an almost meaningless term. For example, one reference states that “Intensive plantation forestry is practiced by industry on 14.0 million ha in the southeastern United States.” The authors assumed that all pine plantations in the Southeast are intensively managed by “industry.” Of course this claim is not true since (1) industry only owns about 7.7 million ha in the “southeast”; (2) only about 63 percent of industry land is in plantations; and (3) not all pine plantations owned by industry are managed intensively (Siry 2003). Without definitions, terms like “superior” and “high-yield” are not very informative when discussing increasing silvicultural effort. A more professional method of communication is needed.

Some simply use mean annual increment as a measure of silvicultural effort, but this can be misleading since some sites produce more than 3 cunits per acre per year with very little silvicultural effort (South and others 1985). Therefore, to improve communication, we have proposed a “yield-cost index” (YCI) that combines both mean annual increment and inputs (discounted costs of silvicultural treatments) for a given base-age (South 2004). For example, if a yield of 4 cunits per acre per year resulted from an investment of \$540 per acre (i.e. \$540 is equal to the costs of all silvicultural inputs discounted to year 0), the YCI (base age 15 years) would be 4u-5. Likewise, if a yield of 5 green U.S. tons per acre per year was expected from an investment of \$360, the YCI15 would be 5g-4 (discounted dollar values are rounded to the nearest hundred dollars to encourage use by industry). Examples of YCI15 values are presented in table 1. Since providing site index values (e.g., 80 feet – base age 25 years) is better than saying the site is “very productive”, providing a YCI15 value (e.g., 12g-5) will be more informative than saying the management intensity is “superior.”

## CONCLUSIONS

Due to advances in silviculture, plantation managers can produce more than 8 green tons per acre per year on sites where 1940 plantations produced only 3 green tons per acre per year (Stanturf and others 2003). Despite this ability, it must be understood that certain sites and certain economic situations will not justify large capital investments in silviculture. Yield-over-input models that follow the law of diminishing returns will produce results that indicate a limit in NPV. Models that follow an exponential form or certain linear models might produce no NPV limit.

Employing intensive silviculture can increase the mean annual increment of a stand, but in some cases, a reduction in NPV can result. Therefore, intensive silviculture should be thought of as a tool that should be applied to certain sites; it is not a panacea that will produce attractive economic returns on all sites and all markets.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Abt, R.C.; Cabbage, F.W.; Pacheco, G. 1995. The timber supply situation in the Southeast: implications for intensive management. In: Weir, R.J.; Hatcher, A.V., comp. Proceedings of the 23<sup>rd</sup> forest tree improvement conference. Publication No. 45 of the southern forest tree improvement committee. Raleigh, NC: North Carolina State University Cooperative Tree Improvement Program: 1-15.
- Allen, H.L. 2002. Silvicultural treatments to enhance productivity. Chapter 6, volume II. In: Evans, J., ed. The forests handbook. Oxford, UK: Blackwell Science Ltd.: 129-139.
- Binkley, C.S. 2003. Forestry in the long sweep of history. In: Teeter, L.D.; Cashore, B.; Zhang, D., eds. Forest policy for private forestry: global and regional challenges. New York: CABI Publishing: 1-7.
- Binkley, C.S.; Aronow, M.E.; Washburn, C.L.; New, D. 2005. Global perspectives on intensively managed plantations: implications for the Pacific Northwest. *Journal of Forestry*. 103(2): 61-64.
- Borders, B.E.; Bailey, R.L. 2001. Loblolly pine-pushing the limits of growth. *Southern Journal of Applied Forestry*. 25(2): 69-74.
- Chapman, H.H.; Meyer, W.H. 1947. Forest valuation. New York: McGraw-Hill. 521 p.
- Crutchfield, D.M. 1991. Site-specific pine plantation establishment procedures. In: Menzies, M.I.; Parrott, G.E.; Whitehouse, L.J., eds. Efficiency of stand establishment operations. FRI Bulletin 156. Wellington, New Zealand: New Zealand Ministry of Forestry: 204-207.
- Dangerfield, C.W., Jr.; Moorhead, D.J. 1996. Evaluating forest management options for conservation reserve program pine plantations with WINYIELD and ACORM software systems. In: Zazueta, F.S., ed. Sixth international conference on computers in agriculture. Publication 701P0396. St. Joseph, MI: American Society of Agricultural Engineers: 387-393.
- Haywood, J.D.; Tiarks, A.E. 1990. Eleventh-year results of fertilization, herbaceous, and woody plant control in a loblolly pine plantation. *Southern Journal of Applied Forestry*. 14: 173-177.
- Larsen, S. 1976. Does the law of diminishing returns still apply? *Ugeskrift for Agronomer, Hortonomer, Forstakandidater og Licentiat*. 121: 883-895.
- Megraw, R.A. 1985. Wood quality factors in loblolly pine. Atlanta, GA: Tappi Press. 88 p.
- Miller, J.H.; Zutter, B.R.; Zedaker, S.M. [and others]. 1991. A regional study on the influence of woody and herbaceous competition on early loblolly pine growth. *Southern Journal of Applied Forestry*. 15: 169-179.
- Miller, J.H.; Zutter, B.R.; Zedaker, S.M. [and others]. 2003. Growth and yield relative to competition for loblolly pine plantations to mid-rotation- a Southeastern United States regional study. *Southern Journal of Applied Forestry*. 27: 237-252.
- NCSFNC. 1996. Effects of site preparation and early fertilization and weed control on 14-year loblolly pine growth. NCSFNC Research Note No. 36. Raleigh, NC: North Carolina State University, Department of Forestry. 113 p.
- NCSFNC. 2000. Loblolly pine growth response to early fertilization. NCSFNC Research Note No. 45. Raleigh, NC: North Carolina State University, Department of Forestry. 32 p.
- Norris Foundation. 2003. Summary standing timber. *Timber Mart-South*. 28(2): 1.

- Siry, J.P. 2003. Intensive timber management practices. In: Wear, D.N.; Greis, J.G., eds. Southern forest resource assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 327-340.
- South, D.B. 2004. Defining terms. *Journal of Forestry*. 102(6): 1.
- South, D.B.; Boyer, J.N.; Bosch, L. 1985. Survival and growth of loblolly pine as influenced by seedling grade 13-year results. *Southern Journal of Applied Forestry*. 9: 76-81.
- South, D.B.; Zwolinski, J.B.; Allen, H.L. 1995. Economic returns from enhancing loblolly pine establishment on two upland sites: effects of seedling grade, fertilization, hexazinone, and intensive soil cultivation. *New Forests*. 10: 239-256.
- Spillman, W.J.; Lang E. 1924. *The law of diminishing returns*. Yonkers-on-Hudson, N.Y.; Chicago, IL: World Book Co. 178 p.
- Stanturf, J.A.; Kellison, R.C.; Broerman, F.S.; Jones, S.B. 2003. Productivity of southern pine plantations. Where are we and how did we get here? *Journal of Forestry*. 101(3): 26-31.
- Wallinger, S.R. 1993. Private-sector leadership for a changing nation. *Journal of Forestry*. 91(1): 20-23.
- Yin, R.; Piennar, L.V.; Arnow, M.E. 1998. The productivity and profitability of fiber farming. *Journal of Forestry*. 96(11): 13-18.
- Yin, R.; Sedjo, R.A. 2001. Is this the age of intensive management? A study of loblolly pine on Georgia's Piedmont. *Journal of Forestry*. 99(12): 10-17.
- Zobel, B.J.; Sprague, J.R. 1998. *Juvenile wood in forest trees*. New York: Springer-Verlag. 300 p.

## **Water Quality**

*Moderator:*

**JIM SHEPARD**  
Mississippi State University



# DRY CREEK LONG-TERM WATERSHED STUDY: EFFECTS OF TIMBER HARVEST ON HYDROLOGY AND SEDIMENT EXPORT IN HEADWATER STREAMS IN SOUTHWEST GEORGIA

W.B. Summer, C. Rhett Jackson, D. Jones, and M. Miwa<sup>1</sup>

**Abstract**—Properly established streamside management zones (SMZs) reduce potential impacts of timber harvesting on stream hydro-period and sediment fluxes. Effects of upland silvicultural practices on stream hydrology and effects of partial harvesting within SMZs on water quality are not well documented. The objectives of this study are to determine the effects of these forest practices on hydrology and sediment export of first-order streams. The study design includes two reference and two treatment watersheds. After 29 months of baseline data collection, the treatment watersheds were harvested, except for SMZs, which were divided into upper and lower sections. The upper section remained as an intact SMZ, while the lower section was thinned to 50 square feet of basal area per acre. Flow and sediment concentrations were continuously monitored at the outlet of treatment and control watersheds. Sediment data has not been analyzed in time for this conference. Twenty-nine months of pretreatment flow data and 12 months of post-treatment data will be discussed in addition to results of breakthrough and windthrow surveys.

## INTRODUCTION

Sediment is the largest contributor by volume to non-point source water pollution in the United States (Neary and others 1988) and the most important potential pollutant from managed operational forested lands (Phillips 1989). When soil is exposed as a result of a timber harvest or site preparation, sediment has an increased potential of being transported down slope and into a stream. Elevated sediment inputs can bury gravel and cobble substrates, reducing the quality of habitat for macro-invertebrates and fish. This process, known as sedimentation, typically causes a reduction in biodiversity and biomass in aquatic systems (Waters 1995).

Much of the land use in the Southeastern United States is currently in forestry. In Georgia alone there are 23.6 million acres of commercial forest land, comprising nearly 10 percent of the state (Georgia Forestry Commission 1999). Thousands of miles of waterways could potentially be impacted by forestry activities.

## BACKGROUND

Like most States that have significant forestry operations, Georgia has developed a set of best management practices (BMPs) to minimize non-point source pollution from forestry activities. BMPs are defined as methods, measures, practices, and techniques designed to maintain water quality within forested watersheds (Aust and others 1996). An example of a BMP is a streamside management zone (SMZ). SMZs are areas adjacent to a stream in which vegetation is managed and maintained to protect stream water quality (Georgia Forestry Commission 1999). SMZs are intended to reduce the amount of sediment and other pollutants from surface runoff from reaching the stream. Intact vegetation in SMZs is expected to slow runoff, which in turn allows water to infiltrate into the ground and reduces its capacity to transport sediment (Hewlett 1982). For example, more and larger sediment particles are trapped at the edges of SMZs than are deposited within SMZs (Cooper and others 1987). This implies that the ability of storm

flow to carry sediment is reduced as it enters the SMZ. SMZs have been shown to be an effective BMP for reducing the effects of timber harvesting on sediment flux in streams (Rivenbark and Jackson 2004, Ward and Jackson 2004).

BMP standards vary from State to State, as do requirements for SMZ widths. Georgia's recommended buffer width for a perennial stream begins at 40 feet and increases as slope of the adjacent hillside increases (Georgia Forestry Commission 1999). Georgia's recommendations allow some timber to be harvested within SMZs. This practice, known as thinning or partial harvesting within SMZs, may be conducted until there is a minimum of 50 square feet of basal area per acre or 50 percent canopy cover remaining. The effects of this practice are not well-known, and few studies include partial harvesting treatments.

Research publications regarding buffer effectiveness are numerous. However, few studies have been conducted in the coastal plain of the Southeastern United States. Furthermore, the effects of partial harvesting within SMZs on water quality are not well-documented. Researchers need to fill in gaps in knowledge that currently exist regarding SMZ effectiveness in the coastal plain and effects of partial harvesting within SMZs. The objective of this study is to evaluate the hydrology and sediment transport behavior of four headwater streams and their initial response to timber harvest and site preparation. Results from this study will aid regulatory agencies in determining/revising forestry BMPs and provide needed information about the effects of particular forest practices on stream hydrology in the coastal plain.

## METHODS

### Study Site

The study site is located in the southwestern corner of Georgia in the Coastal Plain physiographic province approximately 16 km south of Bainbridge, GA (fig. 1). The physiographic

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<sup>1</sup> M.S. Candidate and Associate Professor, University of Georgia, Warnell School of Forest Resources, Athens, GA 30602; and Research Associate and Forest Hydrologist, International Paper, Southlands Forest, Bainbridge, GA 31717, respectively.

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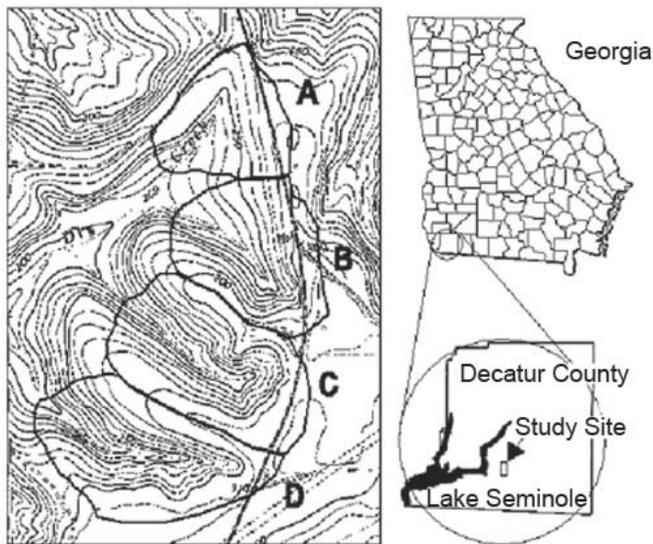


Figure 1—The study site, located 16 km south of Bainbridge, GA.

district of the study site is the Pellham escarpment, which is the scarp between the Tifton upland and the Dougherty plain. The soils in the study sites are dominated by Ultisols, with the riparian area being comprised of the Cheifland and Esto series which are classified as well-drained fine sands over clay loams. The slopes are Eustis series soils, which are loamy sands over sandy loams and classified as somewhat excessively well-drained. The upland soils are comprised of Wagram, Norfolk, Lakeland, Orangeburg, and Lucy, which are generally well-drained loamy sands over sandy clay loams, with the exception of the Lakeland Unit which has a sandy texture throughout and is characterized as excessively well-drained (International Paper soil survey, unpublished).

The streams in this study drain four adjacent watersheds with similar aspect, size, shape, soils, and vegetative cover type. One of the few apparent differences is the valley floor geometry. Watersheds A and B have broader, flatter valley floors with several wetlands areas, while C and D have more channelized streams running through steeper, v-shaped valleys. These geomorphologic differences were used to pair the watersheds into what was initially believed to be the most optimal groups (A+B and C+D).

### Study Design

This study is part of a larger multi-disciplinary study designed to examine the effects of forest practices. The statistical design is BACI (Before After Control Impact) consisting of two watershed pairs. The contributing area for these streams varies

from 26 to 48 ha (table 1). Watersheds A and D were selected as references and did not receive any silvicultural treatments. The remaining two watersheds (B and C) were clearcut in the fall of 2003, with the exception of the SMZs, which were divided into an upstream and downstream section. The upstream section remains completely intact while the downstream section was thinned in accordance with Georgia BMPs. We chose to use basal area as a guideline for thinning and measured every tree to meet minimum BMP guidelines.

### Data Collection

Most of the data is automatically collected at six sites: one in the stream at the outlet of each watershed (4 sites) and one in the stream at the lower boundary of the upstream SMZ treatment (2 sites). Stream stage and discharge is recorded every 15 minutes by Isco Model 4230 Bubbler Flow Meters connected to a 9-inch Parshall flume. Sediment samples are collected by an Isco Model 6712 automated sampler storm-flow on 15-minute intervals and are analyzed for total suspended solids (TSS) and organic and inorganic portions. Precipitation, temperature, relative humidity, wind speed, wind direction, and solar radiation are recorded at the weather station which is located on a ridge. There is also a second tipping-bucket rain gage located on the other side of the study site to detect any spatial variation in precipitation.

Several surveys were performed to quantify and record other events such as windthrow and sediment breakthrough. The windthrow survey was performed 8 months after the harvest to determine how many trees were lost to windthrow. The break-through surveys were done before and several times after the harvest to assess where water and sediment were flowing across the SMZ boundary. The boundary was walked, and details of any occurrence were recorded, such as evidence of sediment movement intruding into the SMZ.

## RESULTS AND DISCUSSION

### Hydrology

The calibration period revealed variation in hydrologic characteristics between watersheds that were contrary to some expectations: Similarities in watershed size and morphology were not reflected in the hydrology. The assumptions were that adjacent watershed pairs with similar geometry and size would have similar base flow and storm response in relation to catchment area.

Using peakflow data from 54 storms which resulted in peakflow values > 10 L per second in all of the four watersheds, a pre- and post-treatment relationship was established within each of the pairs of reference and treatment watersheds (figs. 2 and 3). The data suggest an increase in peakflow trend

Table 1—Watershed characteristics for pre-treatment period

Watershed	Area	Min Q	Mean Q	Max Q	Zero flow days
	ha	L/s/ha	L/s/ha	L/s/ha	(#/822 days)
A	25.8	0	0.055	8.37	163 (20%)
B	34.7	0	0.074	14.08	6 (0.07%)
C	42.7	0	0.073	9.91	2 (0.02%)
D	48	0	0.042	7.17	206 (25%)

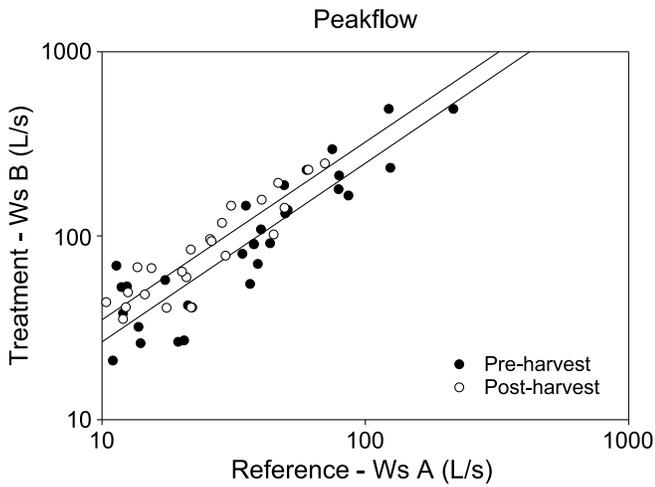


Figure 2—Pre- and post-treatment peak flow relationships between watersheds A and B. Regression slope and y-intercept are not statistically different.

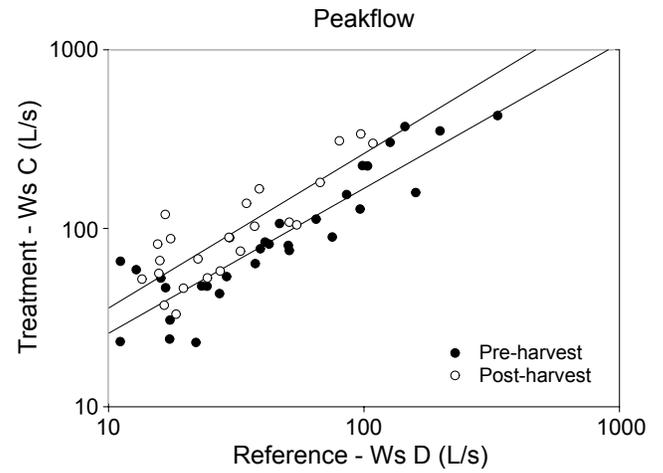


Figure 3—Pre- and post-treatment peak flow relationships between watersheds C and D. Regression slope and y-intercept are not statistically different.

due to treatment, but analysis using ANCOVA reveals that the pre- and post-treatment regressions are not significantly different at  $\alpha = 0.05$ . This could be due a high variance among the data sets, and there may be potential to improve the relationship by using additional factors. Such factors would account for different responses due to antecedent moisture or seasonal differences. Preliminary comparisons of the cumulative flow data and cumulative rain fall indicate an increase in the overall flow of the treatment watersheds following harvest (fig. 4). However, the amount of increase is not yet clear due to differences in the predictions based on the reference watersheds. These results show that the actual relationships among

these four streams were different, indicating a potential difference in groundwater interaction or near-surface geology. Though the flow characteristics were different in magnitude, useful predictive relationships were established.

**Breakthrough**

The breakthrough surveys revealed little evidence of sediment or concentrated flow movement across the proposed SMZ boundary before the harvest in any of the four watersheds. The historic agricultural gullies, though present, were stable and showed no signs of activity. There were expectations of potential re-activation of these gullies after the harvest, though

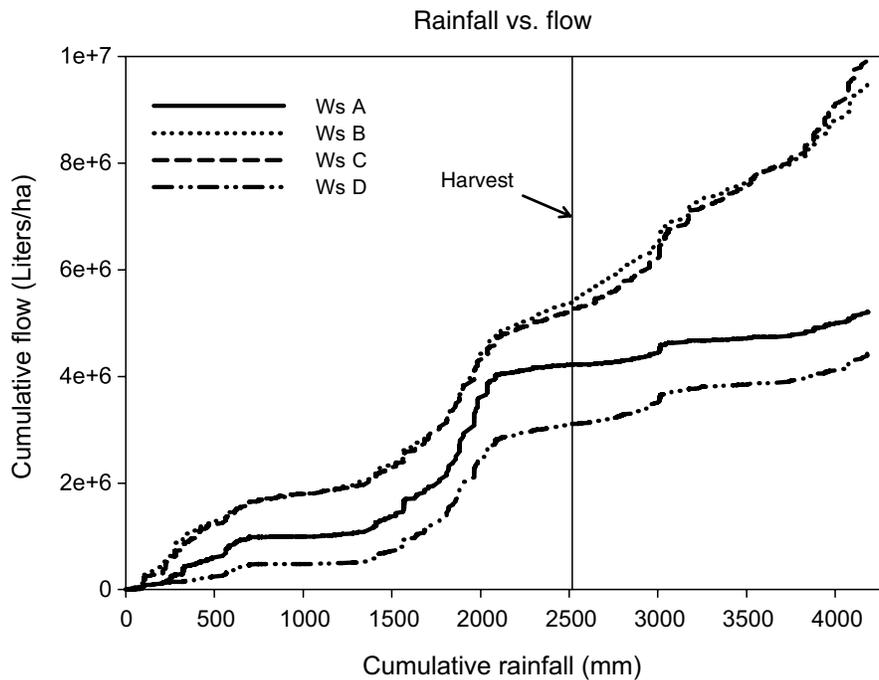


Figure 4—Relation between cumulative rainfall and cumulative flow. Effects of harvest on overall flow are suggested by a change in the slope of the lines representing the treatment watersheds shortly after the harvest.

very few showed any change in the year after harvest and before site preparation.

There were many seeps that appeared in the treatment watersheds. Many of them occurred at the toeslope within approximately 10 m of the SMZ boundary, on average, and flowed across the boundary into the stream. Because they occurred at the bottom of the slope, they likely lack any real power to entrain and move sediment. However, they do increase the variable source area and are therefore of some management concern. Care needs to be taken to avoid application of forest chemicals in those areas to prevent the seeps from functioning as a direct pathway for herbicide to enter the stream.

### Windthrow

Reference watersheds had no windthrow within the boundary of what would have been an SMZ for those watersheds had they been harvested. Treatment watersheds had a total of 36 stems fall, with average and maximum d.b.h.s of 13.9 and 25.9 inches, respectively. Thinned sections of SMZ had more basal area loss per acre and more stem loss per foot than those of unthinned counterparts on both harvested watersheds (figs. 5 and 6).

The harvested watersheds as a whole lost many trees to windthrow, while the reference watersheds lost none. This can be attributed to two things: (1) loss of shelter and support from mature forest and (2) loss of soil “strength” due to elevated water tables. The largest and most abundant trees in the SMZ are the tulip poplar (*Liriodendron tulipifera* L.) and swamp tupelo (*Nyssa sylvatica* var. *biflora*). However, one out of every two trees to succumb to windthrow was a tulip poplar, while only three total (8 percent) were tupelo (two of which were knocked over by other trees). The conditions in the SMZ as a result of the harvest seem to favor trees adapted to a swampy environment, such the tupelo with its buttressed trunk.

When examined individually, the partially harvested sections of SMZ lost more trees than the unthinned SMZ. While the effects of the thinning (less canopy, more machine traffic, and less wind protection) may appear to be the only contributing factors, there are other site-specific factors independent of the treatment to be considered. In Watershed B, the section now designated “thinned” appeared to be wetter and generally swampier than the upper unthinned section before the harvest; and it is more so after harvesting. In addition, despite the deep, confined channel in the downstream section of Watershed C, there is a large area on the terrace that appears to be wetter since the harvest and is unique to that section of the stream. Also, because much of the unthinned section of Watershed C contains meandering and braided channels, often separated by 10 m or more, the overall width of that section may make it less susceptible to damaging winds. More investigation needs to be done on this subject.

### CONCLUSIONS

Preliminary results indicate the changes in hydrology due to harvesting on these headwater streams are similar to those previously studied. Overall stream flow appears to have increased while peakflow increase is not statistically significant, leaving the source of the increased flow to likely be increase summer baseflows. While suspended sediment data has not yet been analyzed, the results from the SMZ breakthrough surveys indicate that very little sediment is moving

Windthrow - basal area

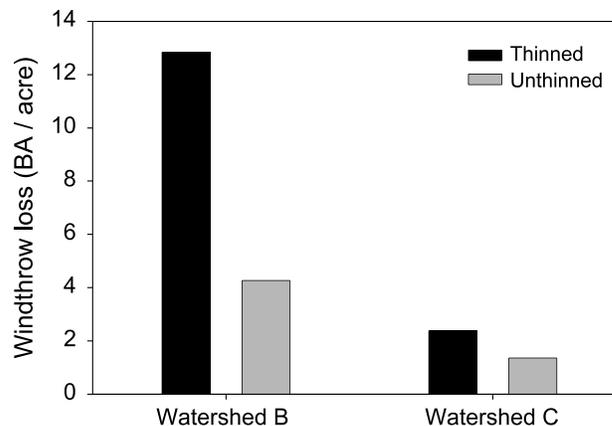


Figure 5—Basal area loss from windthrow per acre of SMZ. Data reflects 9 months after the harvest.

Windthrow - tree loss

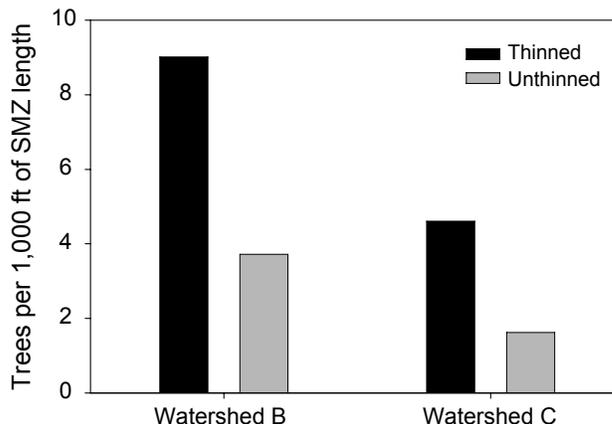


Figure 6—Tree loss from windthrow per 1,000 feet of SMZ boundary. Data reflects 9 months after the harvest.

from the harvested areas into the stream. Two observations from the surveys that should be of concern to managers are: (1) the toe-slope seeps and their ability to link upland forest practices to the stream and (2) the potential for many trees to be lost to windthrow in the thinned SMZs, especially those with near surface water tables.

### ACKNOWLEDGMENTS

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### LITERATURE CITED

Aust, W.M.; Schaffer, R.M.; Burger, J.A. 1996. Benefits and costs of forestry best management practices in Virginia. *Southern Journal of Applied Forestry*. 20(1): 23-29.

Cooper, J.R.; Gillingham, J.W.; Daniels, R.B.; Robarge, W.P. 1987. Riparian areas as filters for agricultural sediment. *Soil Science Society of American Journal*. 51: 416-420.

- Georgia Forestry Commission. 1999. Georgia's best management practices for forestry. [Place of publication unknown]: Georgia Forestry Commission. 70 p.
- Hewlett, J.D. 1982. Principles of forest hydrology. Athens, Ga: University of Georgia Press. 183 p.
- Neary, D.G.; Swank, W.T.; Riekerk, H. 1988. An overview of non-point source pollution in the Southern United States. Symposium proceedings of the forested wetlands of the Southern United States. Gen. Tech. Rep. SE-50. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 1-7.
- Phillips, J.D. 1989. An evaluation of the factors determining the effectiveness of water quality buffer zones. *Journal of Hydrology*. 107: 133-145.
- Rivenbark, B.L.; Jackson, C.R. 2004. Concentrated flow breakthroughs moving through silvicultural streamside management zones: southeastern Piedmont, USA. *Journal of the American Water Resources Association*. 40(4): 1043-1052.
- Ward, J.M.; Jackson, C.R. 2004. Sediment trapping within streamside management zones: Georgia Piedmont, USA. *Journal of the American Water Resources Association*. 40(6): 1421-1431.
- Waters, T.F. 1995. Sediment in streams: sources, biological effect and control. Monograph 7. Bethesda, MD: American Fisheries Society. 251 p.

# DRY CREEK LONG-TERM WATERSHED STUDY: ASSESSMENT OF IMMEDIATE RESPONSE OF AQUATIC MACROINVERTEBRATES TO WATERSHED LEVEL HARVESTING AND THINNING OF STREAMSIDE MANAGEMENT ZONES

M.W. Griswold, R.T. Winn, T.L. Crisman, and W.R. White<sup>1</sup>

**Abstract**—Streamside Management Zones (SMZs) are meant to protect riparian habitat and the stream ecosystem. Benthic macroinvertebrates are recognized bioindicators of water quality in streams, typically occupying multiple trophic levels in these systems and providing food for vertebrates. Thus, it is important to understand the effects of harvest within and adjacent to the SMZ on macroinvertebrate assemblages. Benthic macroinvertebrates were sampled pre- and post-harvest from four first-order streams draining the Dry Creek watershed in southwestern Georgia. A multi-habitat sampling procedure was used. Macroinvertebrates were identified and compared using biotic indices. Comparisons were made between streams within the pre-harvest period and between the pre- and post-harvest periods to determine the effects of harvest. Differences in community structure were seen between pre- and post-harvest periods. These may have been influenced by environmental factors including, but not limited to, stream flow, water chemistry, and canopy cover.

## INTRODUCTION

Riparian zones are important ecotones for aquatic systems, providing food for aquatic (e.g., organic matter and terrestrial insects) and terrestrial organisms (e.g., emerging aquatic adults), shade, temperature regulation, and woody debris (Nakano and others 1999). These factors determine stream community structure (Kiffney and others 2003) and produce heterotrophic systems dependent on allochthonous detritus. Furthermore, small headwater streams are closely linked to their terrestrial surroundings since they are relatively narrow and are usually shaded by the forest canopy (Cummins 1974, Hynes 1975, Vannote and others 1980). Headwater streams can account for 70 to 80 percent of total stream length and provide downstream areas with organic matter (OM), sediments, and nutrients (Kiffney and others 2003). Thus, it is important to understand how forest management strategies influence stream biota.

Forest harvest and removal of vegetation in the riparian zone reduce detrital input to streams. The extent of this reduction is influenced by the remaining canopy cover within the riparian buffer zones. Decreased canopy cover leads to increased light availability for stream biota and may increase primary productivity, thus changing typically heterotrophic forested streams into autotrophic ones (Fuchs and others 2003, Hartman and Scrivener 1990) dominated by macrophytes and periphyton (Kedzierski and Smock 2001, Noel and others 1986). This results in increased density, biomass and diversity of macroinvertebrates and can shift macroinvertebrate trophic structure from shredders to grazers (Fuchs and others 2003, Jackson and others 2001, Kedzierski and Smock 2001). The shift in habitat structure will result in changed patch quality as the availability of leaf packs decreases and cover in the form of macrophytes increases. Noel and others (1986) found that 50 percent of logged streams were covered by macrophytes, while unlogged reference streams only had 10 percent macrophyte cover. Instream habitat cover depends greatly on inputs and

cover provided by the riparian zone. Thus, subtle changes in the composition and amount of riparian cover will influence available habitat for invertebrates. The objective of the study was to determine the immediate impacts of upland and streamside management zone (SMZ) harvest on aquatic macroinvertebrates and their basal resource.

## MATERIALS AND METHODS

### Site Description

The site is located in southwestern Georgia on International Paper's Southlands Forest within the Dry Creek watershed, which discharges to the Flint River. The study streams are first order, groundwater-influenced, low to medium gradient, and have sand-dominated substrate. In-stream habitat includes coarse woody debris, undercut banks, leaf packs, fine roots, and macrophytes. The four study watersheds (A-D) average 39 ha, 1.5 L/s average annual discharge, and 457 m channel length (Summer and others 2003). Watersheds A and B have gentle slopes and broader, meandering/braided channels, whereas C and D have steeper slopes with well-defined stream channels.

### Study Design

The overall Dry Creek Study design includes elements of before versus after, control versus impacted (treatment), and upstream versus downstream comparisons. Watersheds A and D were designated controls and were left undisturbed throughout the study. Watersheds B and C were designated treatment watersheds, each receiving two silvicultural treatments. Treatment watersheds were harvested during fall 2003, leaving a SMZ. The SMZ along the upstream portion was left intact, while the downstream SMZ was partially harvested to reduce canopy cover by 50 percent. All harvesting followed Georgia BMPs (Georgia Environmental Protection Division 1999).

<sup>1</sup> Graduate Student, Howard T. Odum Center for Wetlands, University of Florida, Gainesville, FL, 32611; Partnerships Coordinator, International Paper, Memphis, TN, 38115; and Director and Graduate Student, respectively, Howard T. Odum Center for Wetlands, University of Florida, Gainesville, FL 32611.

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### Habitat Measurements

Eight 30-m fixed-distance sample stream reaches, two per watershed, were established. Three transects were established perpendicular to the stream within each reach for physical measurements including channel cross-sections, canopy cover, and percent cover of in-stream habitat. These habitat characterization data are not discussed in this paper but will be used in the later analysis.

### Biological Measurements

Within each stream reach, 10 randomly selected locations were sampled for periphyton and macrophytes from June, 2001, to December, 2004, using a 0.25 m<sup>2</sup> quadrat. Following the method of Tett and others (1978), two petri dishes (17.34 cm<sup>2</sup>) were inserted into the sediment at each sampling location. Chlorophyll a concentrations of periphyton in the sediment sample were measured using an ethanol extraction procedure (Sartory and Grobbelaar 1984) followed by spectrophotometric analysis. The contents of the second petri dish were dried at 60 °C, weighed, ashed at 500 °C, and reweighed for ash-free dry weight determination of instream organic matter. Macrophytes were sampled by cutting all vegetation at the sediment surface within a 0.25 m<sup>2</sup> quadrat. Macrophyte samples were rinsed and dried at 60 °C (Kedierski and Smock 2001) to determine dry weight.

Benthic macroinvertebrates were collected within sample reaches using a 500-µm-mesh D-frame net (0.3 m wide) every December and February from 2001 to 2005. A multi-habitat sampling procedure was used (Barbour and others 1999). Winter was selected because this is prior to the emergence of most species, and larvae are generally easier to identify because of their larger size. Within each reach, 20 sampling sweeps (i.e., disturbing habitat for 0.5 m, approximately 3.1 m<sup>2</sup>) were made through major habitat types including sand, woody debris, fine roots, macrophytes, and leaf packs. The duration of sampling in each reach was timed to maintain a consistent sampling effort for all reaches. Samples were stored in 90 percent ethanol and transported to the laboratory where they were processed by washing organic debris (leaves and woody debris) with water into a 500-µm-mesh sieve. Invertebrates were sorted and identified, typically to genus, although *Chironomidae* were separated into *Tanypodinae* (predators) and non-*Tanypodinae* (collectors) for functional feeding group analysis.

### RESULTS AND DISCUSSION

It is accepted that harvest will decrease leaf litter input to streams (Webster and Waide 1982) and will decrease canopy cover. However, there may be delayed reduction of leaf litter in the stream due to initial runoff from harvest and retention within the substrate. In this study, instream particulate organic matter remained similar between treatment and control watersheds for up to 1 year post harvest. A peak occurred the following autumn in the control but not in the treatment watersheds (fig. 1), confirming a reduction in detrital input. Furthermore, the open canopy allowed more light to reach the stream, resulting in increased primary productivity. Both macrophyte and periphyton biomass increased in the treatment watersheds after the harvest (fig. 2). Periphyton biomass only increased in the downstream portions of the watersheds where partial harvest had occurred. This suggests that more light is reaching the stream in the partial harvest SMZs. As noted elsewhere,

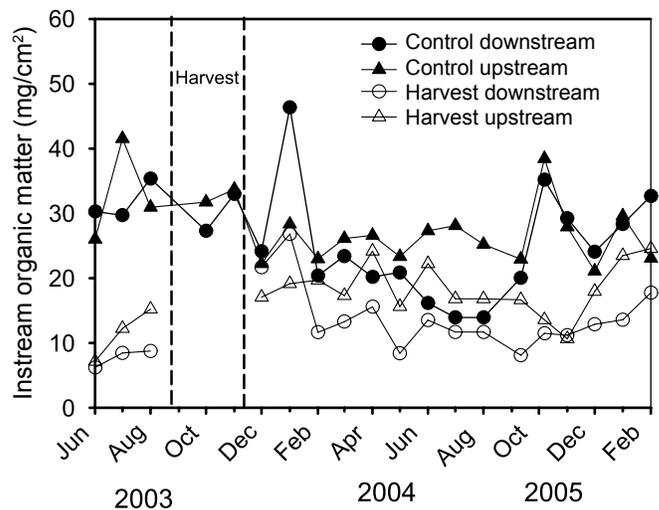


Figure 1—Average instream particulate organic matter (AFDW) before and after harvest. In harvested watersheds, the upstream SMZ was left intact and partial harvest occurred downstream.

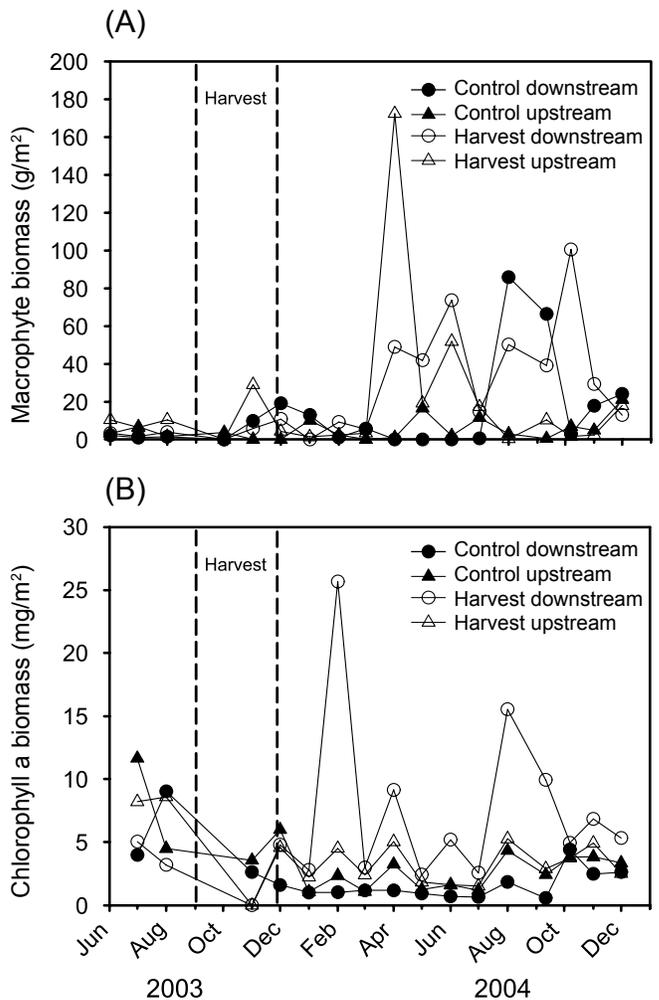


Figure 2—Average biomass of macrophytes (A) and periphyton (B) before and after harvest.

harvest is progressively shifting the stream from a heterotrophic to an autotrophic system (Fuchs and others 2003) even in the presence of the prescribed SMZ width.

The response of macroinvertebrates to harvest was more subtle and may lag behind the shift from a heterotrophic to autotrophic stream. Relative abundance and total taxa all increased in both the control and treatment sites postharvest (fig. 3). Such increases possibly reflect a recovery from drought in the region, as rainfall increased during the study period. However, Kreutzweiser and others (2005) found that removing 29 or 42 percent basal area from the riparian zone did not result in differences in macroinvertebrate abundance or richness immediately after harvest when compared to a reference site. Sedimentation may eliminate sensitive taxa; however, taxa richness may not change immediately after harvest if sedimentation is controlled. Stone and Wallace (1998) suggested that taxa richness may only be a useful metric for detecting disturbances such as organic pollution rather than shifts in relative abundance. Furthermore, any changes in richness may need to be examined on a longer time scale, as colonization by new species may not occur until the following spring and summer.

The most obvious change following harvest was the increased percentage of scraper insects in the treatment watersheds (fig. 4). Opening of the canopy and possible input of nutrients and/or detritus immediately following harvest created conditions for increased productivity. As elsewhere (Gurtz and Wallace 1984, Hawkins and others 1982, Wallace and Gurtz 1986), mayflies were the principal group displaying a response immediately after harvest. The mayflies encountered in this study (*Habrophlebiodes* spp.) feed primarily on periphyton (e.g., diatoms) and responded to increased levels of this resource. Wallace and Gurtz (1986) attributed such an increase to short generation time and high fecundity. However, samples in the current study were collected shortly after harvest (2 to 4 months), and increased abundance may have been due to resource tracking by this species. Benstead and Pringle (2004) found that mayflies are one of the few macroinvertebrate groups able to switch diets from terrestrial to algal carbon sources following forest harvesting.

Although shredders were expected to decrease with harvest, there were no differences between the treatment and reference sites (11 versus 9 percent,  $P > 0.05$ ). Shredders may not be a good bioindicator in low-gradient sandy streams as their abundance is relatively low (Kedzierski and Smock 2001). They comprised at most 13 percent of total invertebrates in any stream in this study. Furthermore, instream particulate organic matter did not decline immediately following harvest. Leaf litter was retained within the substrate and may have been trapped in debris dams, providing habitat and food for shredders. However, many stream invertebrates may have relatively rigid diets (Benstead and Pringle 2004), limiting their distribution with decreased input of terrestrial carbon sources. Thus, as streams become more autotrophic, species diversity of specialists depending on allochthonous material, including collectors, is expected to decrease.

Riparian cover is an important factor affecting stream communities. It is expected that changes in cover and amount of vegetation will have profound effects on community structure. This study reports results from the first 2 to 4 months after

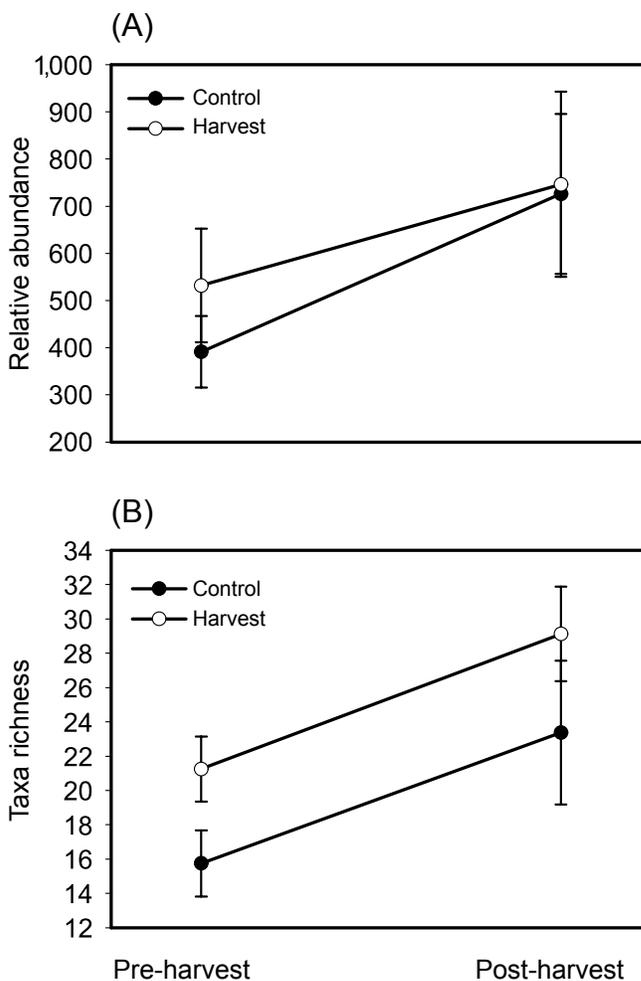


Figure 3—Mean relative abundance (per 20 dipnet samples) (A) and taxa richness (number of taxa) (B) pre- and post-harvest. Bars are  $\pm 1$  standard error. Data were combined for all dates before and after harvest.

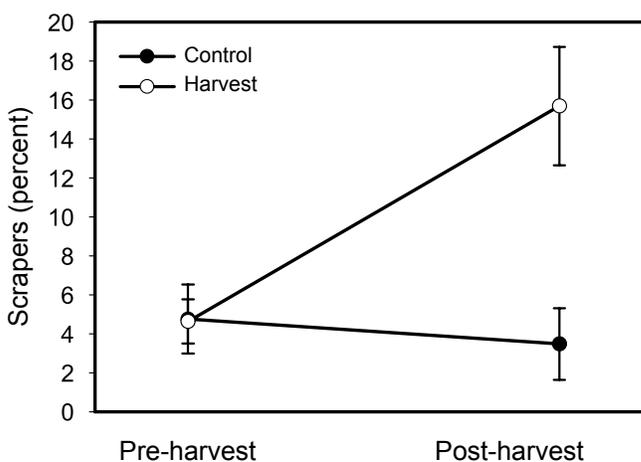


Figure 4—Mean percent of scrapers pre- and post-harvest. Bars are  $\pm 1$  standard error. Data were combined for all dates before and after harvest.

harvest, when community structure of invertebrates and the resource base are likely still in flux. Although there were no differences in intact and partially harvested SMZs, the abiotic and biotic structure of the stream are changing. Increased macrophytes in harvested watersheds are continuing and are expected to lead to changes in the macroinvertebrate community, further dividing the intact SMZ from the SMZ that was partially harvested.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Barbour, M.T.; Gerritsen, J.; Snyder, B.D.; Stribling, J.B. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. 2<sup>d</sup> ed. EPA 841-B-99-002. Washington, DC: U.S. Environmental Protection Agency, Office of Water. 339 p.
- Benstead, J.P.; Pringle, C.M. 2004. Deforestation alters the resource base and biomass of endemic stream insects in eastern Madagascar. *Freshwater Biology*. 49: 490–501.
- Cummins, K.W. 1974. Structure and function of stream ecosystems. *Bioscience*. 24: 631-641.
- Fuchs, S.A.; Hinch, S.G.; Mellina, E. 2003. Effects of streamside logging on stream macroinvertebrate communities and habitat in sub-boreal forests in British Columbia, Canada. *Canadian Journal of Forest Research*. 33: 1408-1415.
- Georgia Environmental Protection Division. 1999. Georgia's best management practices for forestry. 71 p.
- Gurtz, M.E.; Wallace, J.B. 1984. Substrate-mediated response of stream invertebrates to disturbance. *Ecology*. 65: 1556-1569.
- Hartman, G.F.; Scrivener, J.C. 1990. Impacts of forestry practices on a coastal stream ecosystem, Carnation Creek, British Columbia. *Canadian Bulletin of Fisheries and Aquatic Sciences*. 223: 1-148.
- Hawkins, C.P.; Murphy, M.L.; Anderson, N.H. 1982. Effect of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon. *Ecology*. 63: 1840-1856.
- Hynes, H.B.N. 1975. The stream and its valley. *Verhandlungen. Internationale Vereinigung fuer Theoretische und Angewandte Limnologie*. 19: 1-15.
- Jackson, C.R.; Sturm, C.A.; Ward, J.M. 2001. Timber harvest impacts on small headwater stream channels in the coast ranges of Washington. *Journal of the American Water Resources Association*. 37: 1533-1549.
- Kedzierski, W.M.; Smock, L.A. 2001. Effects of logging on macroinvertebrate production in a sand-bottomed, low-gradient stream. *Freshwater Biology*. 46: 821-833.
- Kiffney, P.M.; Richardson, J.S.; Bull, J.P. 2003. Responses of periphyton and insects to experimental manipulation of riparian buffer width along forest streams. *Journal of Applied Ecology*. 40: 1060-1076.
- Kreutzweiser, D.P.; Capell, S.S.; Good, K.P. 2005. Effects of fine sediment inputs from a logging road on stream insect communities: a large-scale experimental approach in a Canadian headwater stream. *Aquatic Ecology*. 39: 55-66.
- Nakano, S.; Miyasaka, H.; Kuhara, N. 1999. Terrestrial-aquatic linkages: riparian arthropod inputs alter trophic cascades in a stream food web. *Ecology*. 80: 2435-2441.
- Noel, D.S.; Martin, C.W.; Federer, C.A. 1986. Effects of forest clearcutting in New-England on stream macroinvertebrates and Periphyton. *Environmental Management*. 10: 661-670.
- Sartory, D.P.; Grobbelaar, J.U. 1984. Extraction of chlorophyll a from freshwater phytoplankton for spectrophotometric analysis. *Hydrobiologia*. 114: 177-187.
- Stone, M.K.; Wallace, J.B. 1998. Long-term recovery of a mountain stream from clearcut logging: the effects of forest succession on benthic invertebrate community structure. *Freshwater Biology*. 139: 151-169.
- Summer, W.B.; Jackson, C.R.; Jones, D.; Miwa, M. 2003. Characterization of hydrologic and sediment transport behavior of forested headwater streams in southwest Georgia. In: *Proceedings of the 2003 Georgia water resources conference*. Athens, GA: The University of Georgia, The Institute of Ecology. [Not paged].
- Tett, P.; Gallegos, C.; Kelly, M.G. [and others]. 1978. Relationships among substrate, flow, and benthic microalgal pigment density in Mechums River, Virginia. *Limnology and Oceanography*. 23: 785-797.
- Vannote, R.L.; Minshall, G.W.; Cummins, K.W. [and others]. 1980. River continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences*. 37: 130-137.
- Wallace, J.B.; Gurtz, M.E. 1986. Response of *Baetis* mayflies (Ephemeroptera) to catchment logging. *American Naturalist*. 115: 25-41.
- Webster, J.R.; Waide, J.B. 1982. Effects of forest clearcutting on leaf breakdown in a southern Appalachian stream. *Freshwater Biology*. 12: 331-344.

# DRY CREEK LONG-TERM WATERSHED STUDY: BUFFER ZONE PERFORMANCE AS VIABLE AMPHIBIAN HABITAT

Brooke L. Talley and Thomas L. Crisman<sup>1</sup>

**Abstract**—As bioindicators, amphibians typically require both terrestrial and aquatic habitats to complete their life cycles. Pre-timber-harvest monitoring (December 2002 through September 2003) of salamander and frog (*Hylidae*) populations was conducted in four watersheds of Decatur County, GA. Post-timber-harvest monitoring (December 2003 through September 2004) continued in the same watersheds (two reference and two treatment watersheds). Coverboards were used to monitor adult salamanders, larval salamanders were surveyed with dipnet sweeps, and frogs were monitored with vertical PVC pipes. Six salamander species (*Desmognathus apalachicola*, *Eurycea cirrigera*, *E. guttolineata*, *Notophthalmus viridescens*, *Plethodon grobmani*, and *Pseudotriton ruber*) and five frog species (*Hyla chrysoscelis*, *H. cinerea*, *H. femoralis*, *H. squirella*, and *Pseudacris crucifer*) were recorded. Pre- and post-harvest data were compared to assess changes in amphibian population structure. Larval salamanders were the only amphibian group to decline 1 year after timber-harvest. Further long-term examination of amphibian populations should be continued to assess potential delayed responses to site disturbance.

## INTRODUCTION

Timber- and partial-harvest in uplands and within Streamside Management Zones (SMZs) may cause significant aquatic and terrestrial habitat alteration. Alterations include, but are not limited to, stream hydrology and water quality. Physiological adaptations of many amphibians make them vulnerable to ecosystem stress following perturbation because of specific aquatic and terrestrial microhabitat requirements (Welsh and Ollivier 1998).

In previous studies, increased sedimentation from land management activities (including timber-harvest) led to reduced amphibian abundance (Welsh and Ollivier 1998). In the southern Appalachians, Petranka and others (1993) found that adult terrestrial salamander abundance declined in clear-cut plots compared to mature forest stands. In general, stream-dwelling organisms like macroinvertebrates and fishes have been more frequently studied for timber-harvest response compared to amphibians (Welsh and Ollivier 1998). Natural variation in magnitude and frequency for amphibian populations can make it difficult to identify fluctuation causes, including timber-harvest (Blaustein and others 1994, Pechmann and Wilbur 1994, Stebbins and Cohen 1995).

This study examines how interannual amphibian populations fluctuate in intact and harvested watersheds. As biological indicators of aquatic and terrestrial environments, salamander and frog (*Hylidae*) responses following timber harvest can provide valuable information on how Georgia Best Management Practices (BMPs) may affect biotic structure within these watersheds.

## Study Site

Southlands Experimental Forest of International Paper occurs within the Coastal Plain physiographic province, in Decatur County, GA (30°47'30" N and 84°37'30" W), approximately 16 km south of Bainbridge, GA (fig. 1). First-order perennial streams draining four neighboring watersheds (termed A, B, C, and D) were studied (fig. 1).

Located in the Dry Creek watershed, study streams flow into Dry Creek (a second-order stream) and eventually into the Flint River (upstream from the Apalachicola River). In-stream habitat composition included coarse woody debris, undercut banks, leaf packs, fine roots, and pools. Streams were ground-water-fed with sand-dominated substrates. Of deeper incision,

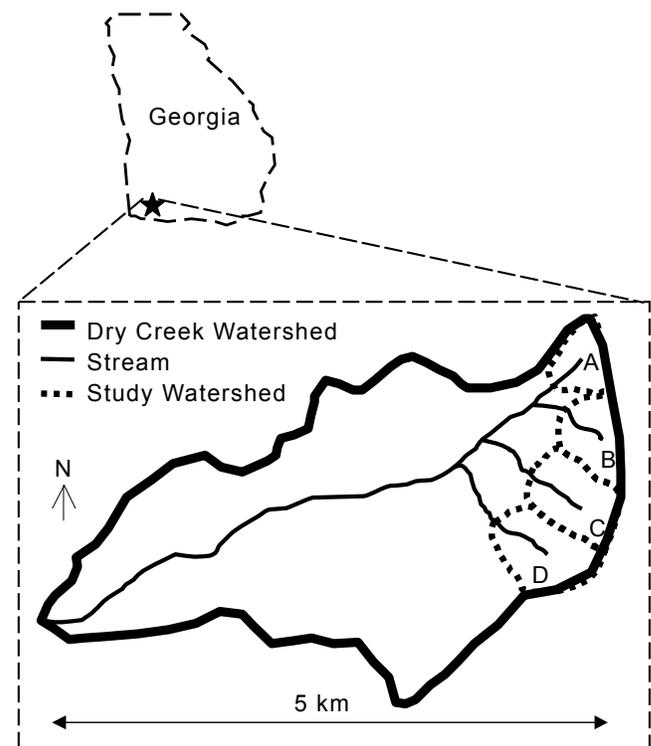


Figure 1—Dry Creek watershed location and experimental watershed layout (30° 47'30" N and 84°37'30" W). Watersheds A, B, C, and D are composed of headwater streams and mixed hardwood forests. Watersheds A and D were not harvested, while watersheds B and C were clearcut from September through November, 2003, according to Georgia Best Management Practices.

<sup>1</sup> Graduate Student and Professor, respectively, University of Florida, Department of Environmental Engineering Sciences, Howard T. Odum Center for Wetlands, Gainesville, FL 32611-7750.

streams C and D channels were adjacent to steeper slopes than streams A and B (Jones and others 2003, Sumner and others 2003) (fig. 1).

## METHODS

Two reaches per watershed were studied (1 = downstream reach, 2 = upstream reach), for a total of eight sample reaches (A1, A2, B1, B2, C1, C2, D1, and D2). Multi-year data were collected to examine amphibian seasonal differences (Pough and others 1998) and interannual differences in natural populations, with monitoring at monthly intervals. Pre-harvest sampling occurred over 10 months (December 2002 through September 2003) in all streams. Watersheds B and C were harvested following sampling in September, 2003, a process that lasted 3 months. Post-harvest data collection resumed in December, 2003, and continued through September, 2004. Sampling techniques employed to capture amphibians included dipnet sweeps (for larvae salamanders), coverboard shelter attractants (for adult salamanders), and vertical PVC pipe shelter attractants (for frogs).

To sample all potential microhabitats within the stream, the flat surface of a standard D-frame dipnet ( $V \cong 0.02 \text{ m}^3$ ; dimensions: 0.3-m opening, 0.5-m length, 1,000- $\mu\text{m}$  mesh) was swept along the bottom of the stream and under incised banks. For each sample reach, 20 dipnet sweeps were performed, each approximately 1-m long. Dipnet sampling occurred upstream from stationary hydrologic flumes. Captured larvae were counted, identified to species, and released into the stream reach where captured.

Coverboards were used as shelter attractants for terrestrial and semi-aquatic salamanders by mimicking conditions found under naturally occurring surface objects (Houze and Chandler 2002). In this study, coverboards were used to assess adult salamander species richness and dispersal distance into surrounding uplands. Coverboards, cut from 1.9 cm untreated plywood sheets into 60 by 60-cm squares, were placed along transects perpendicular to stream channels toward adjacent uplands. Eight coverboards were placed in designated habitat zones for a given sample reach (4 coverboards on either side of the stream, 256 total). The four habitat zones were designated as (1) streamside, (2) riparian, (3) midslope, and (4) upland, with increasing distance from the stream. Salamanders found under coverboards were identified to species and counted, noting specific coverboard position.

Vertical polyvinyl chloride (PVC) pipes (5.1-cm diameter and 60-cm height-above-ground) were used for frog monitoring. PVC pipes act as shelter attractants by shielding inhabitants from extreme wind and temperature, thereby providing moist refuge (Wyatt and Forsys 2004). One sampling pipe was installed at each coverboard location (256 total pipes). Frogs inhabiting the artificial habitat were identified to species, counted, and specific PVC pipe was noted.

Statistical analyses utilized Jandel SigmaStat 2.0<sup>®</sup>. Catch per Unit Effort (CPUE) data were analyzed with normality, equal variance, Mann-Whitney Rank Sum, and t-tests. All statistical analyses were considered significant with  $\alpha = 0.05$ .

## RESULTS AND DISCUSSION

Amphibian species richness data were collected monthly during pre- and post-harvest surveys. Although species richness varied between watersheds and years, this was not analyzed for any effect due to timber-harvest. Because capture data were not adjusted for detection probabilities, amphibian abundance could not be estimated (see Dodd and Dorazio 2004, Schmidt 2003, 2004). To make capture data comparable for pre- and post-harvest surveys, CPUE values were calculated based on the number of individuals captured per number of experimental units. Larval salamander CPUE values were calculated by dividing total capture by 1,600 (160 sweeps per month by 10 months), except for months when site conditions prohibited data collection. For adult salamander and frog surveys, CPUE values were determined by dividing capture values by 640 (64 coverboards/PVC pipes per habitat zone by 10 months). All amphibian Catch per Unit Effort (CPUE) data were tested for normal distribution using the normality test ( $\alpha = 0.05$ ) to determine further statistical analyses required.

### Larval Salamanders

Two larval salamander species were detected, *Eurycea cirrigera* and *Pseudotriton ruber*. When calculating CPUE values, larval species capture-data were combined to examine overall trends in population dynamics instead of specific species patterns.

CPUE distributions passed the normality test (reference streams:  $P = 0.129$ , treatment streams:  $P = 0.444$ ) and the test of equal variance for normally distributed populations in treatment streams ( $P = 0.246$ ) but not reference streams ( $P = 0.010$ ). Because CPUE distributions failed the test of equal variance for reference streams, Mann-Whitney Rank Sum Tests were performed. Statistical analyses showed no significant median value differences between pre- and post-harvest larval salamander populations in reference streams ( $P = 0.734$ ) (fig. 2a). Results of t-test statistical analyses for treatment streams showed significant differences between CPUE values for pre- and post-harvest larval salamanders ( $P = 0.032$ ) (fig. 2b).

Because larval salamander CPUE values in reference watersheds were not significantly different between sampled years, the differences detected in treatment watersheds were probably not due to natural variation. Instead of reflecting true timber-harvest effects, differences between CPUE values may be in response to other abiotic differences, such as temperature (Lucas and Reynolds 1967). Typically, early stages of amphibian development (i.e., larvae) are more sensitive to temperature changes than in later stages (Stebbins and Cohen 1995). Temperature change could have been caused by timber harvest (from tree canopy changes), but this was not examined in this study.

Although larval amphibian populations fluctuate between years and seasons, the resultant change in treatment watersheds was not apparent in reference watersheds. Because all four watersheds are in close proximity, abiotic factors that could potentially affect amphibian populations (e.g., temperature, rainfall) should be similar under natural conditions. Therefore, the difference detected after timber-harvest was likely a reflection of site-disturbance. Potential changes in abiotic factors of treatment watersheds should be examined further for their relationship to larval salamander populations.

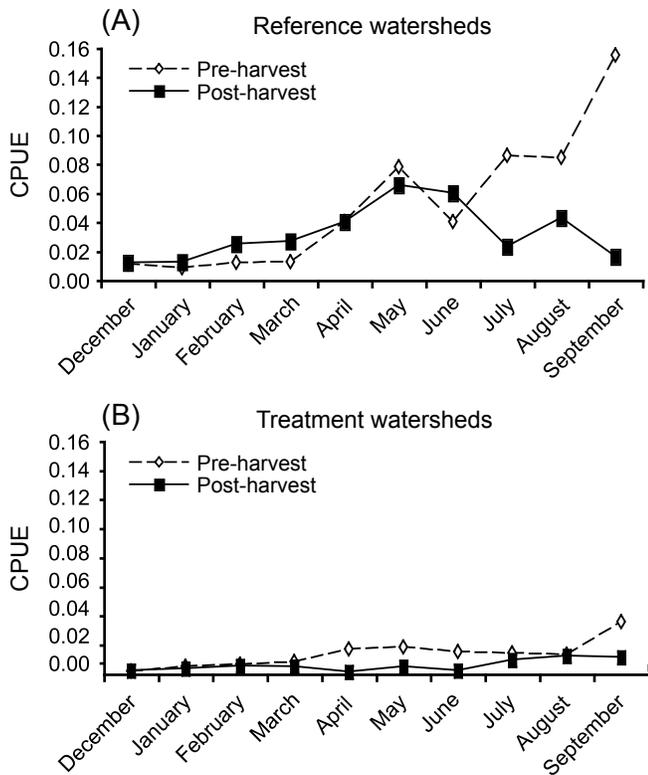


Figure 2—Larval salamander CPUE for (A) reference and (B) treatment watersheds. CPUE values are based on number of individuals captured with dipnet sweeps. Pre- (December 2002 through September 2003) and post-harvest (December 2003 through September 2004) CPUE values indicate differences in treatment watersheds. This statistical difference is not seen in reference watersheds. CPUE = catch per unit effort.

### Adult Salamanders

Adult salamander species richness was comprised of six species: *Desmognathus apalachicola*, *Eurycea cirrigera*, *E. guttolineata*, *Notophthalmus viridescens*, *Plethodon grobmani*, and *Pseudotriton ruber*. Both *E. cirrigera* and *Plethodon grobmani* were detected throughout all watersheds during pre- and post-harvest surveys. The presence of other salamanders varied between sampling years and watersheds. To further examine how adult salamander population dynamics responded to timber harvest, CPUE values combined capture data of all adult salamander species.

In reference and treatment watersheds, CPUE distributions passed the normality test (reference watersheds:  $P = 0.374$ , treatment streams:  $P = 0.551$ ) and the test of equal variance for normally distributed populations (reference:  $P = 0.882$ , treatment:  $P = 0.684$ ). Results of t-test statistical analyses showed no significant differences between CPUE values for pre- and post-harvest adult salamanders in all four watersheds (reference:  $P = 0.579$ , treatment:  $P = 0.931$ ) (fig. 3).

In both reference and treatment watersheds, adult salamander CPUE exhibited no significant change from the first year of sampling to the second. However, the population increased in reference watersheds from the first year of sampling to the second (fig. 3a); this was not detected in treatment watersheds (fig. 3b). Instead, the latter decreased in CPUE values from pre- to post-harvest surveys. In pre- and post-harvest surveys,

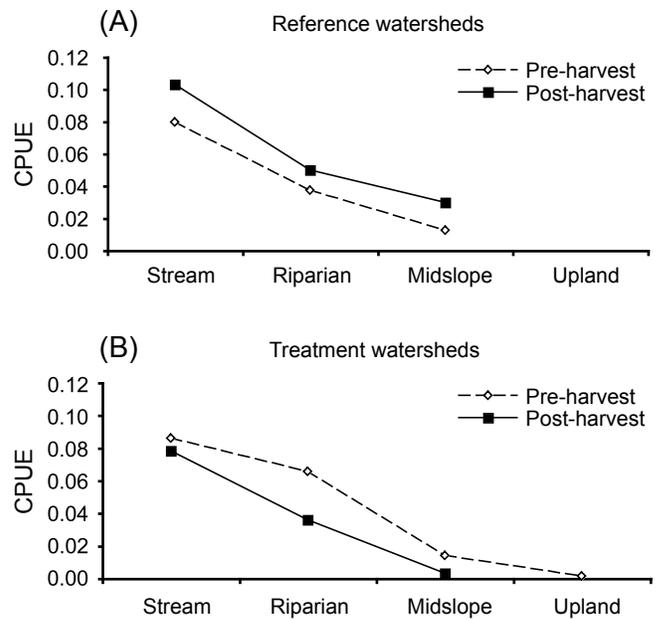


Figure 3—Adult salamander CPUE for (A) reference and (B) treatment watersheds. CPUE values are based on number of individuals captured beneath coverboards at each habitat zone. Pre- (December 2002 through September 2003) and post-harvest (December 2003 through September 2004) CPUE values are not statistically different. Treatment watershed CPUE values are lower after timber harvest, while experimental watershed CPUE values increase during the second survey year. CPUE = catch per unit effort.

salamanders preferred streamside habitat zones compared to those farther upland, regardless of timber-harvest treatment.

Because these watersheds are similar in morphology and located within the same larger watershed system (Jones and others 2003, Summer and others 2003), population dynamics would be comparable. Since CPUE trends differ between reference and treatment watersheds, overall interpretation should not be based only on statistical results. Adult salamanders can display delayed responses to site disturbance and other abiotic changes. Therefore, long-term examination in population structure should be continued.

### Frogs (*Hylidae*)

Five hylid frog species (*Hyla chrysoscelis*, *H. cinerea*, *H. femoralis*, *H. squirella*, *Pseudacris crucifer*) were detected. All frog capture values were used for CPUE determination to monitor changes in population dynamics.

For both reference and treatment watersheds, CPUE distributions were normal (reference watersheds:  $P = 0.652$ , treatment watersheds:  $P = 0.725$ ) but failed the test of equal variance (reference:  $P = 0.002$ , treatment:  $P = 0.04$ ). Because of this failure, Mann-Whitney Rank Sum Tests were performed and showed no significant median value differences between pre- and post-harvest frog populations in reference and treatment watersheds (reference:  $P = 0.114$ , treatment:  $P = 0.886$ ) (fig. 4).

Evaluating frog population dynamics through CPUE values indicated no differences between pre- and post-harvest surveys. In general, CPUE values showed a dramatic increase in reference watersheds for all habitat zones (fig. 4a). Although CPUE values increased in treatment watershed stream and

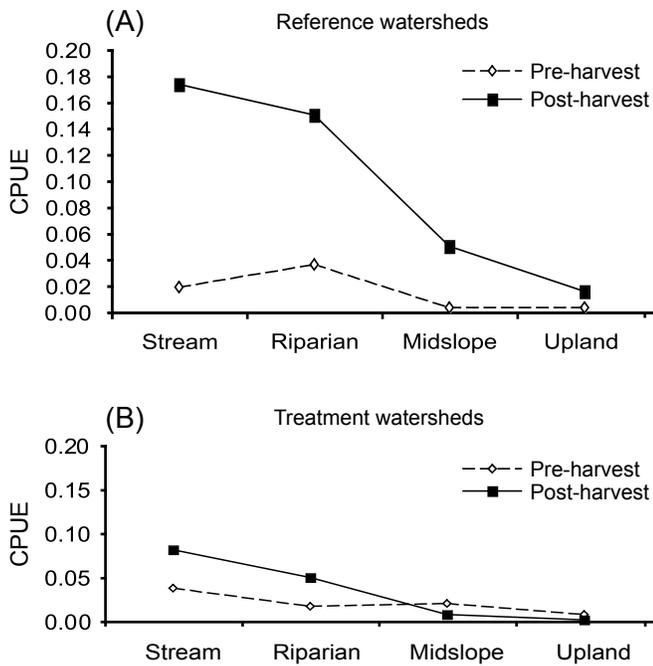


Figure 4—Frog CPUE for (A) reference and (B) treatment watersheds. CPUE values are based on number of individuals found within vertical PVC pipes. Pre- (December 2002 through September 2003) and post-harvest (December 2003 through September 2004) CPUE values showed no significant difference between survey years in reference and treatment watersheds. CPUE = catch per unit effort.

riparian habitat zones during post-harvest surveys, overall frog CPUE did not respond with the degree of change seen in reference watersheds.

Frog activity and PVC pipe inhabitation changes seasonally (Zacharow and others 2003). Because PVC pipe sampling techniques are a relatively new sampling device, changes in frog CPUE values could be influenced by sampling technique effectiveness. Therefore, data interpretation should be conservatively analyzed regarding population dynamics.

## CONCLUSIONS

Larval salamanders in treatment streams displayed the only amphibian population change after timber-harvest. The effect of timber-harvest was likely reflected in larval salamander populations because they live within streams, where site-disturbance changes are likely to occur quickly. Although adult salamander and frog populations did not change significantly after timber-harvest, overall changes in populations may not respond to site disturbance with as much immediacy as larval salamander populations. Therefore, future studies should examine long-term effects of timber-harvest on amphibian populations, information which could help predict degree of viability remaining in harvested habitat.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Blaustein, A.R.; Wake, D.B.; Sousa, W.P. 1994. Amphibian declines: judging stability, persistence, and susceptibility of populations to local and global extinctions. *Conservation Biology*. 8: 60-71.
- Dodd, C.K., Jr.; Dorazio, R.M. 2004. Using counts to simultaneously estimate abundance and detection probabilities in a salamander community. *Herpetologica*. 60: 468-478.
- Houze, C.M.; Chandler, C.R. 2002. Evaluation of coverboards for sampling terrestrial salamanders in South Georgia. *Journal of Herpetology*. 36: 75-81.
- Jones, D.G.; Summer, W.B.; Miwa, M.; Jackson, C.R. 2003. Baseline characterization of forested headwater stream hydrology and water chemistry in southwest Georgia. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silviculture research conference. Gen. Tech. Rep. SE-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 161-165.
- Lucas, E.A.; Reynolds, W.A. 1967. Temperature selection of amphibian larvae. *Physiological Zoology*. 40: 159-171.
- Pechmann, J.H.K.; Wilbur, H.M. 1994. Putting declining amphibian populations in perspective: natural fluctuations and human impacts. *Herpetologica*. 50: 65-84.
- Petranka, J.W.; Eldridge, M.E.; Haley, K.E. 1993. Effects of timber harvesting on southern Appalachian salamanders. *Conservation Biology*. 7: 363-370.
- Pough, F.H.; Andrews, R.M.; Cadle, J.E. [and others]. 1998. *Herpetology*. Upper Saddle River, NJ: Prentice-Hall. 612 p.
- Schmidt, B.R. 2003. Count data, detection probabilities, and the demography, dynamics, distribution, and decline of amphibians. *Comptes Rendus Biologies*. 326: S119-S124.
- Schmidt, B.R. 2004. Declining amphibian populations: the pitfalls of count data in the study of diversity, distributions, dynamics, and demography. *Herpetological Journal*. 14: 167-174.
- Stebbins, R.C.; Cohen, N.W. 1995. *A natural history of amphibians*. Princeton, NJ: Princeton University Press. 316 p.
- Summer, W.B.; Jackson, C.R.; Jones, D.G.; Miwa, M. 2003. Characterization of hydrologic and sediment transport behavior of forested headwater streams in southwest Georgia. In: Proceedings of the 2003 Georgia water resources conference. Athens, GA: The University of Georgia, The Institute of Ecology: 157-160.
- Welsh, H., Jr.; Ollivier, L.M. 1998. Stream amphibians as indicators of ecosystem stress: a case study from California's redwoods. *Ecological Applications*. 8: 1118-1132.
- Wyatt, J.L.; Forys, E.A. 2004. Conservation implications of predation by Cuban treefrogs (*Osteopilus septentrionalis*) on native hylids in Florida. *Southeastern Naturalist*. 3: 695-700.
- Zacharow, M.; Barichivich, W.J.; Dodd, C.K. 2003. Using ground-placed PVC pipes to monitor hylid treefrogs: Capture biases. *Southeastern Naturalist*. 2: 575-590.

# SOIL EROSION FROM HARVESTED SITES VERSUS STREAMSIDE MANAGEMENT ZONE SEDIMENT DEPOSITION IN THE PIEDMONT OF VIRGINIA

William A. Lakel III, W. Michael Aust, C. Andrew Dolloff, and Amy W. Easterbrook<sup>1</sup>

**Abstract**—Forestry best management practices were primarily developed to address two major issues related to soil erosion: water quality and site productivity. Sixteen watersheds managed as loblolly pine plantations in the piedmont region were monitored for soil erosion and water quality prior to treatment. Subsequently, all watersheds were harvested with clear-cutting, ground-based skidding, prescribed burning, and installation of fire lines. Four blocks were established on the basis of geology, soils, topography, vegetation, and management. Within each block, 5 SMZ treatments (25-foot-wide, 50-foot-wide with and without partial harvest, and 100-foot-wide with and without partial harvest) were installed. On-site erosion was estimated for the watershed and within each major disturbance category (harvest, skid trails, fire lines) and contrasted with the quantity of sediment trapped by the various SMZ treatments.

## INTRODUCTION

Streamside management zones (SMZs) are widely recommended for the protection of water quality during and after forest harvesting (Blinn and Kilgore 2001, VDOF 2002). Research has indicated that SMZs can be important for collecting and filtering runoff from harvested sites as well as reducing thermal pollution from direct sunlight (Kochenderfer and Edwards 1990, VDOF 2002). It is also widely accepted that these riparian buffers have significant value as wildlife habitat. Numerous studies have shown the positive impacts of SMZs (Castelle and others 1994), but few have investigated the efficacy of various widths and harvest levels.

It was hypothesized that the SMZs might collect measurable sediment moving downslope from cutover areas and firelines. It was also expected that different SMZ widths and harvest levels might impact the amount of sediment eroded or deposited.

## EXPERIMENTAL DESIGN AND SITE CHARACTERISTICS

This study includes 16 watersheds in the Piedmont Plateau in Buckingham County, VA. The study is an incomplete block design with four blocks and four treatments. The SMZ treatments are (1) 25 feet wide, (2) 50 feet wide with no thin, (3) 50 feet wide thinned, and (4) 100 feet wide with no thin. Pre-harvest data was collected and analyzed in 2002 (Easterbrook 2005). The watersheds were clear-cut in summer and fall 2003, and erosion measurements were re-taken in February 2005. SAS® software (SAS Institute, Cary NC) was used to determine significant differences between treatment means by the Tukey-Kramer procedure for all comparisons.

The Piedmont plateau of Virginia is typical of the Piedmont in the Southeast in general. Elevations range from 200 feet above sea level to the east and 1,200 feet above sea level to the west. Local slopes occasionally exceed 30 percent. Extensive agriculture since the 1700s has led to severe soil erosion and loss of significant site productivity (USDA 2002). The

watersheds are dominated by old field sites that were abandoned after the Civil War and reclaimed by native shortleaf pine (*Pinus echinata* Mill.) and Virginia pine (*Pinus virginiana* Mill.) as well as a mix of hardwood species such as white oak (*Quercus alba* L.), scarlet oak (*Quercus coccinea* Muenchh.) hickory (*Carya spp.*), red maple (*Acer rubrum* L.), and black gum (*Nyssa sylvatica* Marsh.). Non-native loblolly pine (*Pinus taeda* L.) plantations were initially planted in the 1970s (Gembroys 1974, Schultz 1997, USDA 2002, Van Lear and others 2004).

## RESULTS AND DISCUSSION

### Pre-harvest Erosion

Pre-harvest erosion in the SMZs using steel rebar erosion rod transects—The re-bar was pounded into the ground in three transects per SMZ and measured periodically to determine sediment aggradation or degradation across each SMZ. Pre-harvest erosion was estimated in the upland sections of each watershed using the USLE method described by Dissmeyer and Foster (1984). Figure 1 demonstrates the results of the

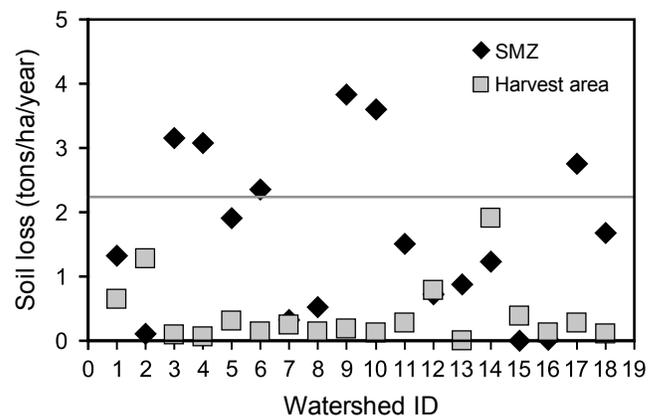


Figure 1—Pre-harvest soil loss for the SMZs in tons/ha/year.

<sup>1</sup> Instructor and Professor, respectively, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061; Project Leader, Coldwater Fisheries Unit, USDA Forest Service, Southern Research Station, Blacksburg, VA 24061; and Graduate Research Assistant, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

erosion rod method in each SMZ. The erosion for the upland section of the watersheds was very minor as expected for mature forest stands. The SMZ erosion was somewhat higher, probably because of steeper slopes and residual soil instability from past agricultural erosion (Easterbrook 2005).

### Post-harvest Erosion

Post-harvest erosion was measured exactly as above with the same three re-bar transects in each SMZ. USLE was again used as described by Dissmeyer and Foster (1984) for the cutover upland areas. Weighted average USLE erosion estimates for roads, skid trails, fire lines, and cutover area were used to determine overall erosion from the clear-cut. Table 1 shows that there are no significant differences between treatments for the USLE estimates in clear-cut areas at the  $\alpha=0.10$  level. It is evident that sediment movement within the SMZs was significantly different for the narrow 25 foot SMZ than for all other SMZ types. These narrow, highly disturbed SMZs showed a significant sediment deposition of 56 tons per acre per year 1.5 years after harvest. All other SMZ types showed substantial sediment losses (table 1).

Pre-harvest data indicates a significant level of soil instability within the SMZs even in the absence of harvesting operations (fig. 1). It is likely that the extensive agricultural history and the rolling topography of this area contribute greatly to the ongoing soil instability. Preliminary post-harvest data indicates that forest harvesting did not greatly increase soil erosion estimates in upland clear-cuts but likely exacerbated the soil instability problem in the SMZs. It is common for harvesting activities to increase surface water runoff for up to 5 years until plant and tree regeneration advances adequately to reduce overland and base flow by raising evapotranspiration (Aust and Blinn 2004, Kochenderfer and Edwards 1990, Kochenderfer and Wendel 1983). This runoff could be responsible for the highly elevated soil erosion experienced in most of the SMZs.

**Table 1—Post-harvest soil erosion (-) or deposition (+) by SMZ type within the SMZ (sediment rods) and in the upland clear-cut area (USLE) in tons per acre per year. Statistical significance ( $\alpha = 0.10$ ) is noted with lower case letters**

SMZ type	In clear-cut	In SMZ
	- - - tons/acre/year - - -	
25 feet	-1.3 a	+56 a
50 feet	-2.8 a	-57 b
50 feet thin	-3.7 a	-35 b
100 feet	-5.1 a	-53 b

The narrowest SMZs were 25 feet in width and had significant understory growth not common in the wider SMZs, perhaps because of increased sunlight in the narrower buffers. This increase in vegetation may have had a beneficial soil protective and evapotranspiration function which could have helped prevent the soil erosion evident in the wider buffers (table 1). No current vegetation data is available to allow an in depth discussion of that possibility. The data also does not currently indicate that this “narrow buffer effect” is due to the lower landscape position with less local slope in which the narrow buffers naturally occur.

### LITERATURE CITED

Aust, W.M.; Blinn, C.R. 2004. Forestry best management practices for timber harvesting and site preparation in the Eastern United States: an overview of water quality and productivity research during the past 20 years. *Water, Air, and Soil Pollution: Focus*. 4: 5-36.

Blinn, C.R.; Kilgore, M.A. 2001. Riparian management practices, a summary of state guidelines. *Journal of Forestry*. 99(8): 11-17.

Castelle, A.J.; Johnson, A.W.; Conolly, C. 1994. Wetland and stream buffer size requirements - a review. *Journal of Environmental Quality*. 23: 878-882.

Dissmeyer, G.E.; Foster, G.R. 1984. A guide for predicting sheet and rill erosion on forest land. Gen. Tech. Publ. R8-TP 6. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region. 40 p.

Easterbrook, A.W. 2005. Unpublished masters thesis data. Blacksburg, VA: Virginia Polytechnic Institute and State University, Department of Forestry.

Gembroys, S.R. 1974. The structure of hardwood forest ecosystems of Prince Edward County, Virginia. *Ecology*. 55: 614-621.

Kochenderfer, J.N.; Edwards, P.J. 1990. Effectiveness of three streamside management practices in the central Appalachians. In: Coleman, S.S.; Neary, D.G., comp. eds. Proceedings of the sixth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 688-700.

Kochenderfer, J.N.; Wendel, G.W. 1983. Plant succession and hydrologic recovery on a deforested and herbicided watershed. *Forest Science*. 29(3): 545-558.

Schultz, R.P. 1997. The ecology and culture of loblolly pine (*Pinus taeda* L.). Agric. Handb. 713. Washington, DC: United States Department of Agriculture, Forest Service. 1-1 to 12-28 p.

United States Department of Agriculture (USDA). 2002. Soil survey of Appomattox County, Virginia. Natural Resources Conservation Service. [Not paged].

VanLear, D.H.; Harper, R.A.; Kapeluck, P.R.; Carroll, W.D. 2004. History of piedmont forests: implications for current pine management. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 127-131.

Virginia Department of Forestry (VDof). 2002. Virginia's forestry best management practices for water quality. Fourth edition. Charlottesville, VA: Virginia Department of Forestry. 216 p.

# IMPACTS OF MULTIPLE APPLICATIONS OF FERTILIZER ON STREAM CHEMISTRY IN THE OUACHITA MOUNTAINS

Hal O. Liechty, Jami Nettles, and Stacy Wilson<sup>1</sup>

**Abstract**—We have previously reported changes in stream chemistry following a late winter application of urea and diammonium phosphate to a loblolly pine (*Pinus taeda* L.) plantation located in a 176-ha subwatershed in the Ouachita Mountains. This stand was again fertilized with 437 kg/ha of urea in March of 2001. Water chemistry prior to, during, and after fertilization was monitored downstream of the stand at the outlet of the subwatershed. Current Best Management Practices prohibit fertilizer entry in streamside management zones (SMZs) by either direct application or aerial drift. Fertilizer traps were located in a SMZ and within unprotected stream channels to document improper entry of fertilizer into the SMZ and quantify rates of applications in the unprotected stream channels. Nitrogen (N) concentrations at the subwatershed outlet increased immediately during application, and a number of the traps within the SMZ collected significant amounts of fertilizer. Application of urea upstream from the SMZ had only minor immediate impacts on stream chemistry. N concentrations increased dramatically during the first storm following fertilization. This increase indicated that the urea, which fell in unprotected stream channels or surrounding upland areas, was washed downstream to the main channel. In May, almost 3 months after application, NO<sub>3</sub><sup>-</sup>-N concentrations peaked at 15.4 mg/l during a small storm event. Concentrations of NO<sub>3</sub><sup>-</sup>-N remained elevated for at least 2 years after application. Concentrations of NO<sub>3</sub><sup>-</sup>-N were also greater than those observed following the first application of fertilizer, suggesting that repeated application of fertilizer could have a cumulative impact on N levels in water draining from intensively managed forests.

## INTRODUCTION

Fertilizer is commonly used to increase production in intensively managed loblolly pine forests. Recent estimates indicate that more than 1.3 million acres of southern pine are fertilized annually (NCSFNC 2002). Frequently multiple applications of fertilizer are made to intensively managed loblolly pine stands. Fertilization can occur at or near the time of planting, canopy closure, following the first thinning, and on a 3- to 5-year interval thereafter (Dickens and others 2003). Generally, the impacts of forest fertilization on water quality are considered to be minimal. Binkley and others (1999) performed a literature review and indicated that even without the use of Best Management Practices (BMPs) there were only short-lived increases of nitrogen (N) and phosphorous in waters draining forests following applications of fertilizer. In addition, increases are not large enough to degrade water or exceed state water quality standards (Binkley and Brown 1993, Binkley and others 1999). We previously reported that N levels in a stream draining a 176-ha subwatershed in the Glazypeau River watershed near Hot Springs Village, AR, were dramatically increased during and following an operational fertilization of a loblolly pine plantation in the subwatershed (Liechty and others 1999). We hypothesized that a portion of the fertilizer may have been applied in a streamside management zone (SMZ) and transported downstream during a severe storm following the urea application, causing increased levels of N in the stream. This manuscript reports the long-term changes in concentrations related to this initial fertilization application as well as the impact of a second operational application of urea to this subwatershed during March of 2001. Our objectives are: (1) to quantify long-term impacts of urea fertilization on NO<sub>3</sub><sup>-</sup>-N from multiple applications of urea and (2) to quantify inputs of urea to a SMZ and unprotected channels in the treated subwatershed.

## METHODS

### Study Site

The research site was in the Little Glazypeau watershed located approximately 20 km from Hot Springs, AR (fig. 1). The watershed encompasses 2,273 ha, has an elevation between 209 and 381 m, is located on a southwest aspect, and contains 32 km of perennial or intermittent streams. A 176-ha subwatershed (FSW) in the larger watershed (fig. 1) was instrumented, and a portion of this subwatershed received multiple fertilization applications. This FSW is dominated by the Bismark-Carnasaw soil complex on slopes of 8 to 20 percent and 20 to 40 percent. These soils are well- to excessively well-drained. The soils are also relatively shallow with depth to bedrock of 25 to 50 cm in the Bismark soils and 100 to 150 cm in the Carnasaw series. A 138-ha mid-rotation pine plantation in the FSW was the targeted area for fertilizer application (fig. 2). This stand had previously been fertilized with 437 kg ha<sup>-1</sup> of urea on February 9, 1998, and 140 kg ha<sup>-1</sup> of diammonium phosphate on April 27, 1998, prior to the second application of fertilizer. A total of 8.7 ha in the FSW bordering the stand was delineated as a SMZ and was not to be included in the area to be fertilized. A reference subwatershed (RSW) is located in the northwestern portion of the basin (fig. 1). The RSW contains 104 ha of loblolly pine plantations. Mixed hardwoods, natural pine stands, and shrub/bush vegetation dominate the remaining 221 ha. A total of 76 ha of pine plantations in the RSW had been fertilized in 1997. No other fertilization has occurred in this subwatershed since 1997. Monitoring stations were established at the outlet of each subwatershed as well as the outlet of the Little Glazypeau Watershed (LGW). The monitoring station on LGW is approximately 6.5 km below the FSW station.

<sup>1</sup> Associate Professor, University Arkansas at Monticello, Monticello, AR 71656; Research Hydrologist, Southern Forest Research Center, Weyerhaeuser Co., Columbus, MS 39704; and Program Technician, University Arkansas at Monticello, Monticello, AR 71656, respectively.

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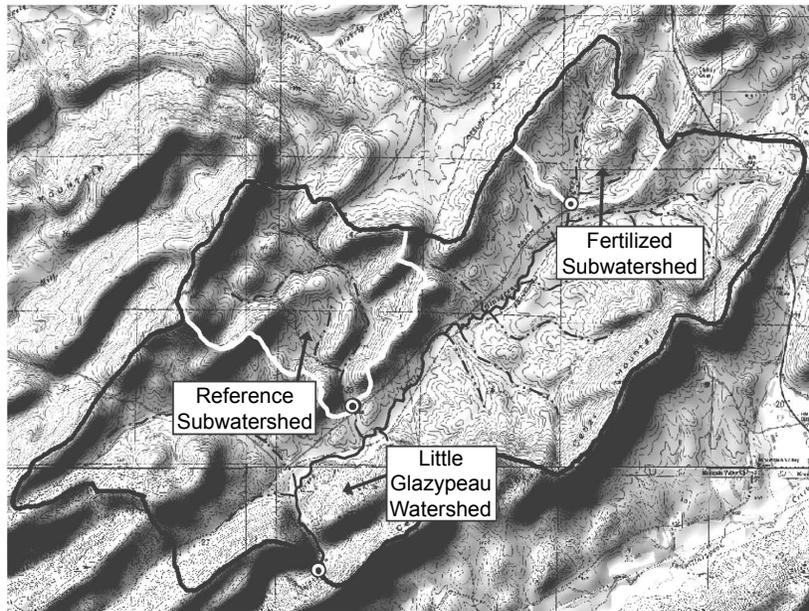


Figure 1—Study watersheds and outlet monitoring stations.

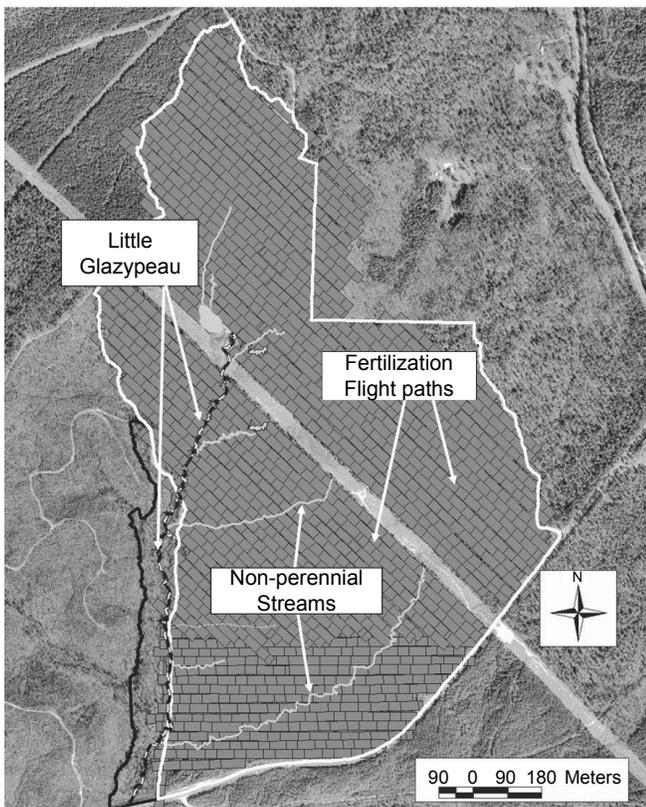


Figure 2—Fertilizer application area in the FSW.

### Fertilization Application

A total of 437 kg/ha urea was applied to the FSW during the second application of fertilizer, a 3-day period from March 9 to 11, 2001. Application of the fertilizer was by a fixed-winged aircraft and occurred during a 3-day period due to aircraft mechanical problems and adverse visual conditions. Fertilizer

was applied to approximately 33 percent of the pine plantation during a 2-hour period on March 9 (fig. 2). On March 10, approximately 50 percent of the plantation was fertilized over a 3-hour time period. Finally on March 11, the remaining portion of the plantation in the FSW was fertilized during an approximate 1-hour time period. Perennial stream channels and the SMZ surrounding this portion of the stream channel were avoided during application. However, non-perennial channels and the associated surrounding riparian areas did receive the same application rate as the upland portions of the watershed. Prior to fertilizer application, we deployed 38 1-m<sup>2</sup> traps along 5 transects that traversed the boundary of the SMZ, within unprotected ephemeral or intermittent drainages, and along sensitive water bodies such as ponds. A total of 10 traps were installed in the SMZ. A total of 20 traps were installed within unprotected ephemeral or intermittent drains in the stand. The traps were retrieved, the fertilizer collected from a trap, and then estimates of the amount of fertilizer collected on an area basis were determined.

### Sample Collection and Stream Measurements

Stream stage was measured in stilling wells using FW1 10-turn potentiometers at each station. Rainfall amounts were measured using tipping bucket rain gages, and stream water samples were collected using ISCO 3700 wastewater samplers. A Campbell CR10X Datalogger recorded the potentiometer stage and precipitation at 10-minute intervals. These measurements were then used to initiate, control, and record water sample collection by the ISCO 3700 samplers. A critical stage initiated hourly sampling, and incremental changes between consecutive 10-minute stage readings initiated additional sampling during rain events. Samples were collected on an hourly basis just prior, during, and following urea application in 2001. Baseflow sampling continued on a daily basis for several weeks after fertilization and then sporadically thereafter. Samples from storm events were taken for a 24 month period after urea application.

## Sample Analysis

Concentrations of  $\text{NO}_3^-$ -N and  $\text{NH}_4^+$ -N were determined for each water sample, but Total Kjeldahl N (TKN) concentrations were only determined for every other sample. Concentrations of  $\text{NO}_3^-$ -N were determined using ion chromatography. Concentrations of  $\text{NH}_4^+$ -N were determined colorimetrically using a Lachat 2000 flow injection system. TKN was determined in the same manner after digestion with sulfuric acid. All concentrations were determined after filtration using a 2.0 $\mu$  filter.

## RESULTS AND DISCUSSION

Concentrations of TKN began to increase almost immediately after urea application (fig. 3) and reached their highest levels during the first day of application (when application was nearest to the outlet of the FSW; fig. 2). TKN concentration, which includes N as  $\text{CO}(\text{NH}_2)_2$ , reached 60.3 mg/l at 13:00 EST on March 9. The maximum TKN concentration on March 10 was 18.1 mg/l, just following the second day of urea application. TKN concentrations then decreased and did not increase during the application on March 11. The flight lines on March 11 were in the upper northeastern section of the subwatershed, away from the SMZ. The lack of changes in stream N concentrations on March 11 further suggests the increased concentrations of N in the 2 previous days were related to the application of urea within or near the SMZ where water was flowing in the primary stream channel.

In addition to the increase in N concentrations, flight lines were found to frequently cross the eastern SMZ boundary, and 9 of the 10 traps within the SMZ received some amount of urea. A total of 7 of the traps within the SMZ had collected significant amounts of urea ranging between 93 and 833 kg/ha. Although amounts of urea collected in the traps near the eastern SMZ boundary were greater than those located nearest the stream channels in the interior of the SMZ, it seems likely that urea was applied directly to portions of the stream channel, which was as near as 5 to 10 m of the eastern boundary.

As in the first application of urea in 1998 (Liechty and others 1999), there was a dramatic increase of  $\text{NH}_4^+$ -N concentration in the first rainstorm following the 2001 application of urea (fig. 4). The maximum  $\text{NH}_4^+$ -N concentration at the FSW station was 3.36 mg/l. This concentration occurred during the peak discharge of a storm event that took place approximately 24 hours after the last urea application. During the storm event, concentrations in the RSW were < 0.04 mg/l. We attributed the high concentration of  $\text{NH}_4^+$ -N during the 1998 application of urea to runoff generated by a 60 to 80 year storm that occurred a few hours following the urea application. However, the storm that occurred in 2001 following the second application was much less intense than the 1998 storm (peak stage was 0.25 compared to 1.04 m) and occurred at least 24 hours following urea application. It seems likely that, given the relatively low amounts of surface runoff generated by the 2001

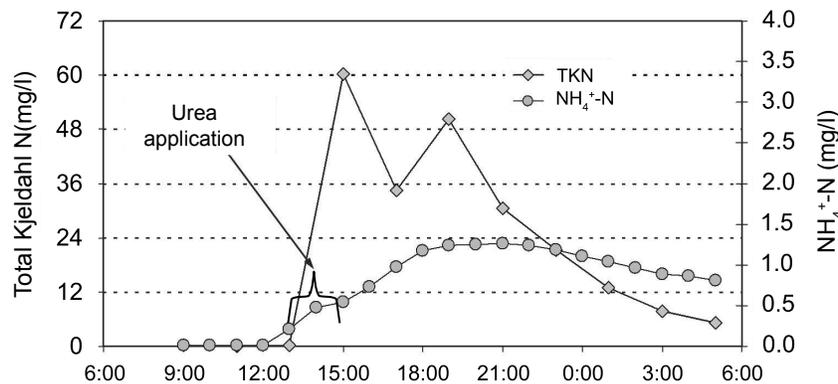


Figure 3—TKN and  $\text{NH}_4^+$ -N concentrations of water draining the FSB just prior, during, and for 15 hours following urea application on March 9, 2001.

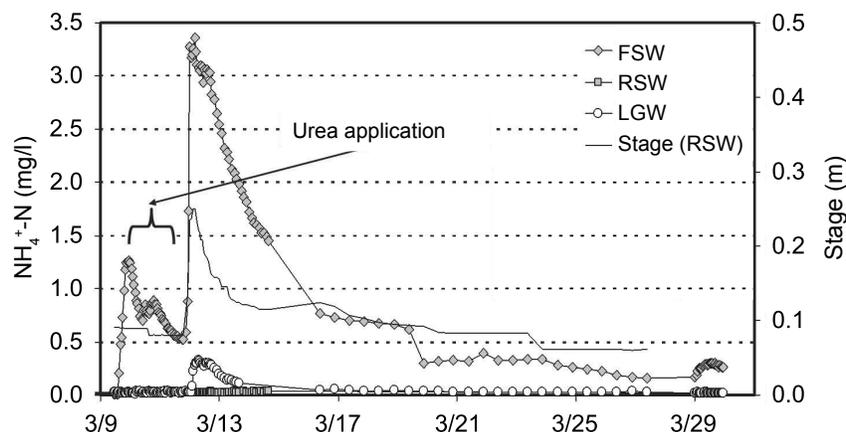


Figure 4— $\text{NH}_4^+$ -N concentrations at the three monitoring stations and the stream stage at the FSW during the first rainstorm following urea application.

storm, the source of much of the  $\text{NH}_4^+\text{-N}$  was the urea applied to unprotected ephemeral and intermittent channels. Similar to the first application of urea in 1998, increases in  $\text{NH}_4^+\text{-N}$  concentrations were observed at the outlet of the LGW during peak concentrations in the FSW (fig. 4).

To evaluate the amount of urea that was applied to these unprotected channels, we placed 22 traps within ephemeral and intermittent channels outside the SMZ prior to application. The average amount of urea collected in a trap was  $545 \pm 129$  kg/ha. This amount was approximately 117 kg more than the application rate. This may suggest that these channels receive higher loads of urea than a typical upland area. This increase would potentially be due to differences in structure and vegetation composition within these riparian areas compared to other portions of the pine plantation. Although differences between the amounts of urea collected in the traps located within the channels were not significantly different ( $p=0.125$ ) than the 437 kg/ha application rate, further quantification of delivery rates and loadings to unprotected channels appears warranted.

$\text{NO}_3^-\text{-N}$  concentrations in the FSB slowly increased following urea application (fig. 5). Maximum concentrations occurred 2

to 3 months following application. The maximum  $\text{NO}_3^-\text{-N}$  concentration following the second fertilization was 15.4 mg/l and occurred on May 31, 2001. When sampling following the last of these two rainfall events had ended, concentrations were still above 15.0 mg/l. Although our primary concern related to the increased concentrations of N in the stream is its impact on aquatic life, the  $\text{NO}_3^-\text{-N}$  concentrations did exceed the EPA drinking water standards of 10 mg/l  $\text{NO}_3^-\text{-N}$ . Similar elevated levels of  $\text{NO}_3^-\text{-N}$  were reported by Helvey and others (1989) and Edwards and others (1991) following fertilizer application to hardwoods in West Virginia.

$\text{NO}_3^-\text{-N}$  concentrations following the second fertilizations were much greater than those following the initial application of urea in 1998. There were a greater number and intensity of storms following the first application of urea than the second (fig. 5). The greater number of storms and storm water may have diluted concentrations during this time period and contributed to the lower concentrations in 1998. However, long-term monitoring of the FSB indicated that concentrations of  $\text{NO}_3^-\text{-N}$  continued to be elevated as much as 1 to 2 years after application (fig. 6). Again, the long-term elevation of  $\text{NO}_3^-\text{-N}$  concentrations were similar in duration to those observed during a 3-year time period by Edwards and others (1991) and Helvey and others (1989).

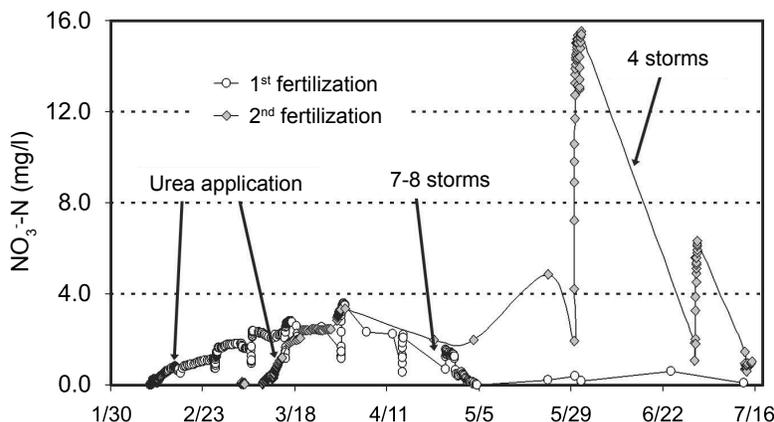


Figure 5—Stream  $\text{NO}_3^-\text{-N}$  concentrations in the FSB shortly following the initial (1998) and second (2001) application of urea.

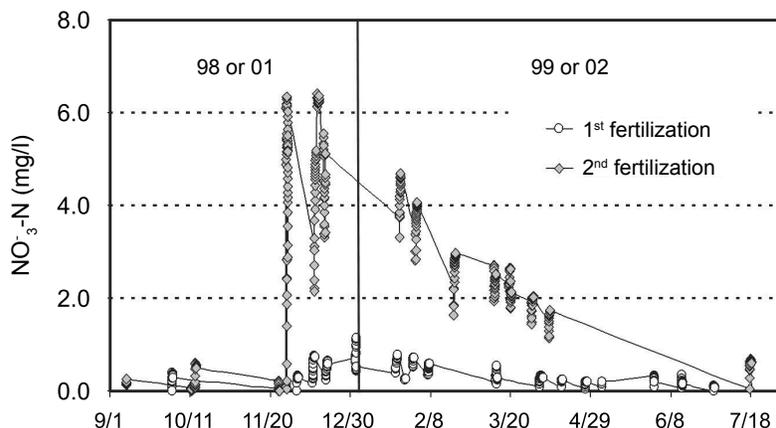


Figure 6—Stream  $\text{NO}_3^-\text{-N}$  concentrations in the FSB 6 to 18 months following the initial (1998) and second (2001) application of urea.

Average maximum storm event  $\text{NO}_3^-$ -N concentrations 8 to 18 months after application (September to August) were significantly ( $p < 0.001$ ) higher following the second urea application (3.14 mg/l from 9/01 to 8/02) than they were following the first application (0.45 mg/l from 9/98 to 8/99). Average maximum concentrations were also still significantly greater ( $p = 0.01$ ) 18 to 30 months following the second application (0.45 mg/l) than the first application (0.17 mg/l). Increased levels of  $\text{NO}_3^-$ -N in the soils or soil nitrification rates of the FSW following the second fertilization would likely contribute to these long-term increases in N concentrations. Soils in this watershed are shallow, and accordingly, discharge from the FSW responds rapidly to precipitation events. Thus, repeated application of fertilizer may have less long-term impacts on water quality in watersheds with deeper soils or that are hydrologically less responsive than the FSW.

## SUMMARY

We have documented increased levels of N following two separate applications of urea in a subwatershed located in the Ouachita Mountains. An increase in N during application of the urea was in part attributed to direct application of fertilizer in a SMZ. Initial storm events following application elevated levels of  $\text{NH}_4^+$ -N. We hypothesize that application of fertilizer over unprotected ephemeral or intermittent stream channels may have contributed to the amounts of N in stream water during these events.  $\text{NO}_3^-$ -N concentrations exceeded drinking water standards during two storm events following the second application of urea. Concentrations of  $\text{NO}_3^-$ -N in stream water during storm events following the second application of urea were consistently greater than those following the first application of urea. It seems likely that repeated application of urea to the subwatershed has increased nitrification rates and/or the levels of N within the soils of the subwatershed.

Based on these results, the Weyerhaeuser Company in this region has modified their fertilization practices to prevent aerial drift of fertilizer into SMZs. New Arkansas BMPs instituted after this study also require more intermittent stream protection. While these changes will greatly reduce fertilizer delivery to the streams, upstream ephemeral areas may continue to contribute nutrients to protected reaches of stream systems. These contributions need to be further quantified.

## LITERATURE CITED

- Binkley, D.; Brown, T.C. 1993. Forest practices as nonpoint sources of pollution in North America. *Water Resources Bulletin*. 29(5): 729-740.
- Binkley, D.; Burnham, D.H.; Allen, H.L. 1999. Water quality impacts of forest fertilization with nitrogen and phosphorus. *Forest Ecology and Management*. 121: 191-213.
- Dickens, E.D.; Moorhead, D.J.; McElvany, B. 2003. Pine plantation fertilization. *Better Crops*. 87: 12-15.
- Edwards, P.J.; Kochenderfer, J.N.; Seegrift, D.W. 1991. Effects of forest fertilization on stream water chemistry in the Appalachians. *Water Research Bulletin*. 27: 265-274.
- Helvey, J.D.; Kochenderfer, J.N.; Edwards, P.J. 1989. Effects of forest fertilization on selected ion concentrations in Central Appalachian streams. In: *Proceedings of the seventh central hardwood conference*. GTR NC-132. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experimental Station: 278-282.
- Liechty, H.O.; Nettles, J.; Marion, D.A.; Turton, D.J. 1999. Stream chemistry after an operational fertilizer application in the Ouachita Mountains. In: Haywood, J.D., ed. *Proceedings of the 10<sup>th</sup> biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 265-270.
- NCSFNC. 2002. North Carolina State forest nutrition cooperative: 31<sup>st</sup> annual report. Raleigh, NC: North Carolina State University, College of Natural Resources, Department of Forestry. 21 p.

# COMMERCIAL TIMBER VALUE OF STREAMSIDE MANAGEMENT ZONES IN MANAGED PINE AND HARDWOOD STANDS

William A. Lakel III, W. Michael Aust, C. Andrew Dolloff, and Elizabeth P. Sharp<sup>1</sup>

**Abstract**—Streamside management zones (SMZs) are widely recommended for protection of water quality, but the costs associated with maintaining SMZs are not well documented. This project documented the commercial timber values of 16 watersheds in the Piedmont region and 16 watersheds in the Allegheny Plateau region before and after SMZs were established. Four blocks were established in each region, and 5 combinations of SMZ width (25, 50, and 100 feet) and harvest level (none versus 50 percent in the 50 and 100 feet SMZ widths) were installed in each block. The average value of the residual timber was greater in the Allegheny Plateau region (high value sawtimber species) than in the Piedmont (pine plantations with low grade hardwoods near streams). Overall, the partial harvests may be more sustainable in the Allegheny region due to the presence of desirable shade tolerant species, in contrast to the Piedmont where partial harvests favor lower-value species.

## INTRODUCTION

Streamside management zones (SMZs) are widely recommended for the protection of water quality during and after forest harvesting (Blinn and Kilgore 2001, VDOF 2002). Research has indicated that SMZs can be important for collecting and filtering runoff from harvested sites as well as reducing thermal pollution from direct sunlight (Castelle and others 1994). It is also widely accepted that these riparian buffers have significant value as wildlife habitat. However, SMZ maintenance is a cost burden for landowners who leave them (Shaffer and others 1998). The timber volume in the SMZ remains unharvested and is often left susceptible to storm and insect damage, and SMZ acreage is generally lost to future production.

Most state BMP manuals recommend a variety of SMZ widths as well as partial harvests within SMZs (Blinn and Kilgore 2001). Few studies have examined the impact of varying SMZ widths and harvest levels on commercial timber values realized by landowners who harvest timber. Active management of SMZs could offer landowners opportunities to realize additional income from current and future harvests.

## EXPERIMENTAL DESIGN AND SITE CHARACTERISTICS

This study includes a set of 32 total watersheds with 16 in the Allegheny Plateau in Randolph County, WV, and 16 in the Piedmont Plateau in Buckingham County, VA. Each area is treated as a separate incomplete block design with four blocks and four treatments. The SMZ treatments are (1) 25-foot-wide, (2) 50-foot-wide with no thin, (3) 50-foot-wide thinned, and (4) 100-foot-wide with no thin. SAS<sup>®</sup> software (SAS Institute, Cary, NC) was used to determine significant differences between treatment means by the Tukey procedure.

The Piedmont plateau of Virginia is typical of the Piedmont in the southeast in general. Elevations range from 200 feet above sea level to the east and 1,200 feet above sea level to the west. Local slopes occasionally exceed 30 percent. Extensive agriculture since the 1700s has led to severe soil erosion and

loss of significant site productivity. The watersheds are dominated by old field sites that were abandoned after the Civil War and reclaimed by native shortleaf pine (*Pinus echinata* Mill.) and Virginia pine (*Pinus virginiana* Mill.) as well as a mix of hardwood species such as white oak (*Quercus alba* L.), scarlet oak (*Quercus coccinea* Muenchh.), hickory (*Carya* spp.), red maple (*Acer rubrum* L.), and black gum (*Nyssa Sylvatica* Marsh.) (table 1). Non-native loblolly pine (*Pinus taeda* L.) plantations were initially planted in the 1970s (Gembroys 1974, Schultz 1997, USDA 2002, VanLear and others 2004).

The Allegheny Plateau of West Virginia has very little agricultural history, but the stands have been selectively harvested in the past century. Earlier logging methods involved animal power and narrow gauge railroads for transportation, but more recent harvesting activities have utilized bladed skid trails on steep slopes and rubber-tired skidding equipment. These bladed skid trail networks often lead to severe local erosion and stream sedimentation. Elevations range from 2,000 feet above sea level in the valleys to 3,000 feet above sea level on the ridge tops. Local slopes often exceed 60 percent. Dominant tree species are sugar maple (*Acer saccharum* Marshall), northern red oak (*Quercus rubra* L.), yellow poplar (*Liriodendron tulipifera* L.), and American beech (*Fagus grandifolia* Ehrh.) (table 1; Sharp 2003).

**Table 1—The five most important commercial timber species found in SMZs by physiographic region**

Rank	Region	
	Allegheny Plateau	Piedmont Plateau
1	Sugar maple	Red maple
2	Yellow poplar	Blackgum
3	American beech	White oak
4	Basswood ( <i>Tilia</i> spp.)	Scarlett oak
5	Yellow birch ( <i>Betula lutea</i> )	Loblolly pine

<sup>1</sup> Instructor and Professor, respectively, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061; Project Leader, Coldwater Fisheries Unit, USDA Forest Service, Southern Research Station, Blacksburg, VA 24061; and Graduate Research Assistant, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

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## RESULTS AND DISCUSSION

There were no significant differences between different SMZ widths for residual dollar value per acre in the Allegheny Plateau. The average residual value across all un-thinned treatments was \$1,457.00 per acre. The thinned SMZ treatments had significantly less residual value (\$160.27 per acre) due to the 50 percent canopy removal during thinning. It is clear that a landowner can minimize residual SMZ value by leaving as little acreage as needed to protect water quality and selectively thinning SMZs where possible with the intent to remove the most valuable 50 percent of the canopy. Thinned SMZs still function with regard to water quality and wildlife habitat (Kochenderfer and Edwards 1990, VDOF 2002), and the less-dense canopy cover after thinning will likely encourage natural regeneration (Governo and others 2004). This subsequent regeneration may further enhance the filtering capacity, wildlife value, and future commercial value of the SMZ.

These sites demonstrate that there are significant opportunities for landowners to manage and harvest value from SMZs while adhering to BMPs in the Allegheny Plateau of West Virginia (table 2). These riparian zones will likely continue to produce higher value sawtimber on a continuous basis which can be selectively harvested again at the next rotation. The dominance of sugar maple, a shade tolerant species with high monetary value, is and will be a very important component in these SMZs. Future management options and timber values within SMZs will be largely dependent upon the commercial market for sugar maple (Sharp 2003).

The commercial value of residual timber across all SMZs was \$891.00 per acre in the Piedmont Plateau. These SMZs are dominated by low-value species like red maple, blackgum, and yellow poplar (Easterbrook 2005). The low overall value of these species made it difficult to thin significant amounts of timber revenue from the SMZs. In most cases, loggers would not thin SMZs even when required to do so. Logger reluctance

was due to a combination of environmental, production efficiency, and low timber value concerns. The site productivity in these areas tends to be higher than surrounding uplands, but lack of active management and desirable shade tolerant species composition also make future revenue from these SMZs marginal. Shorter rotations of the loblolly pine plantations on the surrounding uplands make it unlikely that slower-growing hardwoods in the SMZs will be available for selection at the next harvest.

These sites demonstrate that there are less significant opportunities for landowners to manage and harvest value from SMZs while adhering to BMPs in the piedmont of Virginia (table 2). These riparian zones will likely continue to produce lower-value red maple and blackgum without active management. Future harvest opportunities will largely be dependent upon the commercial market for hardwood pulpwood and small diameter hardwood logs.

## LITERATURE CITED

- Blinn, C.R.; Kilgore, M.A. 2001. Riparian management practices, a summary of state guidelines. *Journal of Forestry*. 99(8): 11-17.
- Castelle, A.J.; Johnson, A.W.; Conolly, C. 1994. Wetland and stream buffer size requirements - a review. *Journal of Environmental Quality*. 23: 878-882.
- Easterbrook, A.W. 2005. Unpublished masters thesis data. Blacksburg, VA: Virginia Polytechnic Institute and State University, Department of Forestry.
- Gembroys, S.R. 1974. The structure of hardwood forest ecosystems of Prince Edward County, Virginia. *Ecology*. 55: 614-621.
- Governo, R.; Lockaby, B.G.; Rummer, B.; Colson, C. 2004. Silvicultural management within streamside management zones of intermittent streams: effects on decomposition, productivity, nutrient cycling, and channel vegetation. *Southern Journal of Applied Forestry*. 28(4): 211-224.
- Kochenderfer, J.N.; Edwards, P.J. 1990. Effectiveness of three streamside management practices in the central Appalachians. In: Coleman, S.S.; Neary, D.G., comp. eds. *Proceedings of the sixth biennial southern silvicultural research conference*. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 688-700.
- Schultz, R.P. 1997. The ecology and culture of loblolly pine (*Pinus taeda* L.). *Agric. Handb.* 713. Washington, DC: United States Department of Agriculture, Forest Service. 1-1 to 12-28 p.
- Shaffer, R.M.; Haney, H.L., Jr.; Worrell, E.G.; Aust, W.M. 1998. Forestry BMP implementation costs for Virginia. *Forest Products Journal*. 48(9): 27-29.
- Sharp, E.P. 2003. Watershed and streamside management zone characterization in the Allegheny plateau of West Virginia. Blacksburg, VA: Virginia Polytechnic Institute and State University, Department of Forestry. 194 p. Masters thesis.
- United States Department of Agriculture (USDA). 2002. Soil survey of Appomattox County Virginia. Natural Resources Conservation Service. [Not paged].
- Van Lear, D.H.; Harper, R.A.; Kapeluck, P.R.; Carroll, W.D. 2004. History of piedmont forests: implications for current pine management. In: Connor, K.F., ed. *Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 127-131.
- Virginia Department of Forestry (VDOF). 2002. Virginia's forestry best management practices for water quality. Fourth edition. 216 p.

**Table 2—Mean production acreage and dollar value of merchantable timber lost per linear mile of SMZ for the Allegheny and Piedmont Plateau sites**

Site	SMZ type	Acreage per linear mile	Value lost per linear mile
			---- \$ ----
Allegheny Plateau	25 feet	3.03	4,414.27
	50 feet	6.06	8,829.42
	50 foot thin	6.06	971.24
Piedmont Plateau	100 feet	12.12	17,658.84
	25 feet	3.03	2,699.73
	50 feet	6.06	5,399.46
	50 foot thin	6.06	5,399.46
	100 feet	12.12	10,798.92

# CHARACTERISTICS OF A BOTTOMLAND HARDWOOD FOREST UNDER GREENTREE RESERVOIR MANAGEMENT IN EAST CENTRAL ARKANSAS

Michael R. Guttery and Andrew W. Ezell<sup>1</sup>

**Abstract**—Greentree reservoirs are a viable option for creating habitat and hunting opportunities for migrating waterfowl. Unfortunately, the prolonged annual flooding often associated with greentree reservoir management can be highly detrimental to many of the desirable tree species in these stands. In the summer of 2004, a total of 327 plot centers were established in a greentree reservoir under an annual flooding regime. At each plot center, a nested plot design was used to establish a 1/5-acre overstory plot, a 1/40-acre midstory plot, and a 1/100-acre understory plot. Our objective was to characterize the vegetative composition and abundance in a bottomland hardwood stand which had been under an annual flooding regime for over 50 years. Results indicate that overcup oak is dominant in all three vertical layers while the more desirable willow oak is common only in the overstory.

## INTRODUCTION

Bottomland hardwood forests of the Southeast historically provided ample habitat for numerous wildlife species. As the region was settled, millions of acres of bottomland hardwood forests were cleared for timber and agriculture. Karr and others (1990) reported a loss of 20,000 acres of bottomland hardwood forest per year as late as 1960 through 1975. In the 1930s, as the loss of bottomland hardwood forests became more obvious and waterfowl hunting increased in popularity, landowners around Stuttgart, AR, initiated the creation of greentree reservoirs by constructing a system of levees around and through a bottomland hardwood stand so that water could be impounded (Young and others 1995). Since that time, the typical management practice applied to most greentree reservoirs has consisted of flooding the stand every year. Flooding usually begins mid- to late fall and ends after the close of waterfowl hunting season. While this practice may be beneficial to waterfowl, prolonged annual flooding can be detrimental to many of the tree species considered desirable for both timber production and waterfowl management. In our study area, the primary desirable species was willow oak. Wigley and Filer (1989) stated that the two most common problems reported by greentree reservoir managers are the lack of desirable regeneration and the loss of mature trees.

## STUDY SITE

The study site is located in Arkansas County approximately 5 miles south of Stuttgart, AR. This particular greentree reservoir is approximately 650 acres in size and is part of the Monsanto Farm and Wildlife Management Center. The stand was converted to greentree reservoir use around 1950 and has been managed to provide opportunities for hunting migrating waterfowl. Annual flooding of the entire stand is typical of greentree reservoir management in this area. Flooding begins each year around the middle of October, but the exact date varies from year to year depending on climatic factors. During years of excessive rain, flooding can be delayed. However, flooding may be initiated earlier during dry years because it takes longer to saturate the soil. It should be noted that most trees in the study area have not gone dormant when flooding is started. Water gates are typically opened to release flood waters 2 to 3 weeks after the end of waterfowl hunting season,

usually around the middle of February. However, with late winter and early spring typically being the wettest time of the year in this area, the site can remain flooded well into the beginning of the growing season.

## MATERIALS AND METHODS

During the summer of 2004, a total of 327 plot centers were established on a 4 by 5 chain grid system. All plot centers were marked with a Magellan® global positioning system. At each plot center, a nested plot design was used to establish three circular plots: a 1/5-acre overstory plot, a 1/40-acre midstory plot, and a 1/100-acre regeneration plot. In each overstory plot, all overstory trees were identified to species, and diameter at breast height (d.b.h.) was measured and recorded. In the midstory plots, all midstory trees were identified to species. D.b.h. and total height, in 10-foot height classes, were also recorded for all midstory trees. Midstory vegetation was defined as all woody stems > 5 feet tall to the base of the overstory canopy. In each regeneration plot, all woody stems < 5 feet tall were tallied by species and height class. Regeneration height classes were: < 1 foot, 1 to 3 feet, and 3 to 5 feet.

## RESULTS

### Overstory Vegetation

A total of 20 tree species were recorded in the overstory. Table 1 contains a list of species codes and their corresponding common and scientific names. Overcup oak (*Quercus lyrata* Walt.) and willow oak (*Quercus phellos* L.) were the most common species and comprised 40 percent and 33 percent, respectively, of the total overstory stems per acre. Basal area calculations for each species again show that overcup oak and willow oak are the dominant species in the stand. However, in terms of basal area, their positions reverse, with willow oak comprising 39.47 square feet of basal area per acre while overcup oak comprised 33.08 square feet of basal area per acre.

Table 2 shows the average number of trees per acre and average basal area per acre for the eight most common species. Trees per acre and basal area for the remaining species are not reported because they occur infrequently throughout the stand.

<sup>1</sup> Graduate Research Assistant and Professor, respectively, Department of Forestry, Mississippi State University, Mississippi State, MS 39762.

**Table 1—Species codes with common and scientific names**

Code	Common name	Scientific name
CBO	Cherrybark oak	<i>Quercus pagoda</i> Raf.
DSH	Deciduous holly	<i>Ilex decidua</i> Walt.
GRA	Green ash	<i>Fraxinus pennsylvanica</i> Marsh.
HNL	Honey locust	<i>Gleditsia triacanthos</i> L.
NTO	Nuttall oak	<i>Quercus nuttallii</i> Palmer
OCO	Overcup oak	<i>Quercus lyrata</i> Walt.
PER	Persimmon	<i>Diospyros virginiana</i> L.
POO	Post oak	<i>Quercus stellata</i> Wang.
REM	Red maple	<i>Acer rubrum</i> L.
WAE	Water elm	<i>Planera aquatica</i> J. F. Gmel.
WAH	Water hickory	<i>Carya aquatica</i> Michx. f.
WLO	Willow oak	<i>Quercus phellos</i> L.

**Table 2—Overstory trees per acre and basal area per acre**

Species	Trees/acre	Basal area/acre
OCO	19.22	33.08
WLO	16.27	39.47
GRA	4.39	40.16
NTO	2.65	5.95
WAH	2.11	2.36
POO	0.86	1.22
REM	0.86	1.41
CBO	0.46	1.13

### Midstory Vegetation

A total of 20 species were recorded in the midstory. Overcup oak was the most common midstory species, with an average of 67.77 stems per acre. The majority of overcup oak stems occurred in the 10- and 20-foot height classes. Four other species had > 50 stems per acre. However, willow oak averaged only 6.73 trees per acre, with most stems in the 40-foot height class. Average number of stems per acre by height class for the eight most common midstory species is found in table 3. Trees per acre for the remaining species are not reported because they occur infrequently throughout the stand.

### Woody Regeneration

Twenty-two species were recorded in the regeneration layer. With an average of 3,341 stems per acre, overcup oak was the most common woody species in this layer. The majority of these stems (1,564.53 per acre) were < 1 foot tall. However, overcup oak was dominant in all three regeneration height classes. Willow oak averaged 152 stems per acre with most stems in the < 1 and 1 to 3 foot classes. There were virtually no willow oaks in the 3 to 5 foot height class. Average number of stems per acre by height class for each of the eight most common understory species is found in table 4. Trees per acre for the remaining species are not reported because they occur infrequently throughout the stand.

**Table 3—Midstory trees per acre by height class**

Species	Height class			
	10 foot	20 foot	30 foot	40 foot
OCO	42.2	12.97	6.97	5.63
DSH	57.37	0.73	0.12	0
GRA	23.24	18.96	11.5	3.67
PER	41.71	11.13	1.83	0
WAH	42.81	6.85	1.96	1.71
REM	18.35	15.9	5.5	1.22
WAE	10.89	10.03	4.04	1.71
WLO	1.22	1.22	1.59	2.69

**Table 4—Regeneration trees per acre by height class**

Species	Height class		
	< 1 foot	1 - 3 feet	3 - 5 feet
OCO	1,564.53	1,302.75	473.7
WAE	1,242.2	125.38	8.56
REM	228.44	40.67	6.73
PER	92.36	143.43	27.52
HNL	66.06	125.38	25.69
GRA	60.25	106.73	25.69
WAH	33.03	84.1	42.51
WLO	81.96	62.39	7.65

## DISCUSSION AND CONCLUSIONS

Overcup oak is a relatively flood- and shade-tolerant oak species. Due to its typically undesirable form, overcup oak is not considered a good timber producing species. The large encased acorns are of little value to waterfowl. Willow oak is far less tolerant of both flooding and shade (McKnight and others 1980). However, it is generally considered a good timber-producing species, and the acorns are preferred food for waterfowl (Allen 1980, Barras and others 1996). Tables 2, 3, and 4 demonstrate that overcup oak is abundant in all vertical layers in this greentree reservoir, but willow oak is abundant only in the overstory. The fact the willow oak has fewer stems per acre on average but more basal area per acre implies that the willow oaks in the overstory are considerably larger than the overcup oaks. The smaller diameters of the overcup oaks lead us to theorize that although overcup oaks have a slower growth rate, many of these trees may be younger trees that have only recently achieved a position in the overstory. This theory is supported by the fact that overcup oak is relatively common in all four midstory height classes. Willow oak, although it occurs in all four midstory height classes, occurs much less frequently. This indicates that very few willow oaks are progressing from the regeneration layer to the midstory and later into the overstory. Overcup oak is regenerating profusely and is extremely abundant in all three regeneration height classes (table 4). This same table shows that while willow oak is regenerating, very few trees are surviving to reach the upper height classes. All these facts imply that overcup oak is able to successfully regenerate in annually flooded greentree reservoirs, grow into the midstory, and eventually claim a place in the overstory. Conversely, willow oak was part of the overstory when greentree reservoir management was initiated, but it is now regenerating at a far lower rate with

very few trees surviving long enough to move into the midstory. The lack of smaller willow oaks in the overstory shows that very few are ever achieving this crown position. Data from all layers indicate that prolonged annual flooding practices (flooding before the onset of dormancy, and inadvertently allowing the stand to remain flooded into the next growing season) is shifting the species composition toward a more flood tolerant and less desirable species association. In order to maintain the willow oak currently in this stand and promote successful regeneration of willow oak, it may be necessary to alter the flooding regime of this stand.

#### **LITERATURE CITED**

- Allen, C. 1980. Feeding habits of ducks in a green-tree reservoir in eastern Texas. *Journal of Wildlife Management*. 44(1): 232-236.
- Barras, C.B.; Kaminski, R.M.; Brennan, L.A. 1996. Acorn selection by female wood ducks. *Journal of Wildlife Management*. 60(3): 592-602.
- Karr, B.L.; Young, G.L.; Hodges, J.D. [and others]. 1990. Effects of flooding on greentree reservoirs. Water Resources Research Institute, Technical Completion Report. Project Number G1571-03. Mississippi State, MS: Mississippi State University. 34 p.
- McKnight, J.S.; Hook, D.D.; Langdon, O.G.; Johnson, R.L. 1980. Flood tolerance and related characteristics of trees of the bottomland forests of the Southern United States. In: *Wetlands of bottomland hardwood forests. Proceedings of a workshop on bottomland hardwood forest wetlands of the Southeast United States*. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 29-69.
- Wigley, T.B.; Filer, T.H. 1989. Characteristics of greentree reservoirs: a survey of managers. *Wildlife Society Bulletin*. 17: 136-142.
- Young, G.L.; Karr, B.L.; Leopold, B.D.; Hodges, J.D. 1995. Effects of greentree reservoir management on Mississippi bottomland hardwoods. *Wildlife Society Bulletin*. 23(3): 525-531.



## **Forest Health**

*Moderator:*

**NOLAND HESS**  
USDA Forest Service  
Forest Health Protection



# GROUND TRUTH ASSESSMENTS OF FORESTS AFFECTED BY OAK DECLINE AND RED OAK BORER IN THE INTERIOR HIGHLANDS OF ARKANSAS, OKLAHOMA, AND MISSOURI: PRELIMINARY RESULTS FROM OVERSTORY ANALYSIS

James M. Guldin, Edward A. Poole, Eric Heitzman,  
John M. Kabrick, and Rose-Marie Muzika<sup>1</sup>

**Abstract**—Forests of the Interior Highlands of Arkansas, Oklahoma, and Missouri are being affected by oak decline and an unprecedented outbreak of a native beetle called the red oak borer. On average, Interior Highlands stands contained 236 trees per acre, of which 32 trees per acre (13.4 percent) were dead or dying. Stands averaged 97 square feet per acre of basal area, of which 14 square feet per acre (14.5 percent) was dead or dying. Red oak species had the greatest proportional damage. Red oak basal area in the region averaged 27.2 square feet per acre, of which 8.2 square feet per acre (30 percent) was affected. White oak basal area averaged 36.0 square feet per acre, of which 3.4 square feet per acre (9.4 percent) was dead or dying. White oak species showed evidence of decline in both the small and large diameter classes, whereas red oaks had some proportion of unhealthy trees across all diameter classes.

## INTRODUCTION

Forests of the Interior Highlands of Arkansas, Oklahoma, and Missouri are now being affected by oak decline and an unprecedented outbreak of a native cerambycid beetle, the red oak borer [*Enaphalodes rufulus* (Haldeman)] (Crook and others 2003, Heitzman 2003, Muzika and Guyette 2004, Starkey and others 2004). Data from the Ozark-Ouachita Highlands Assessment (Guldin and others 1999) show that the region has a total land area of 37.287 million acres of which 22.894 million acres, or 61 percent, is classified as timberland. One-third of this timberland area is composed of stands dominated by oaks (*Quercus* spp.) that are  $\geq 70$  years old and are potentially at risk. Roughly 13.8 billion board feet, or one-quarter of the total timber volume, is in the red oak group, (subgenus *Erythrobalanus*). Although the distribution of unhealthy forests on all public and private lands across the region is not yet known, if one-third of that red oak volume is lost, the potential loss exceeds \$1.1 billion. Our goal was to quantify the distribution, severity, and extent of oak decline and the red oak borer epidemic in the Interior Highlands.

## STUDY DESIGN

We used a risk-based sampling polygon approach that was developed to quantify regional trends in forest health (U.S. Department of Agriculture, Forest Service 2000). Polygons equal to the number of plots were identified on a map of the Interior Highlands which had been created using a geographic information system (GIS) (Heitzman and Guldin 2004).

We then applied an expert systems approach to classify sampling polygons based on risk, using published and unpublished literature and discussions with professional resource managers knowledgeable about oak decline. The system resulted in a classification of polygon plots into four categories based on site and red oak basal area factors:

1. High risk: stands with low site indices, e.g., ridgetop, south- or southwest-facing slopes having  $> 30$  square feet per acre of red oak species; or high red oak basal area ( $> 60$  square feet per acre) on high site indices;
2. Moderate risk: stands with  $> 60$  square feet per acre in red oak basal area but located on sites other than those specified in the high risk category;
3. Low risk: stands with moderate to high basal area (10 to 30 square feet per acre) in red oak species; and
4. No risk: stands with low basal area in red oak species ( $< 10$  square feet per acre)

## Plot Location Protocols

Within the geographic area represented by each sample polygon, a random point was identified as the location of the sample plot. During the summers of 2002 and 2003, 225 field plots were established in Arkansas, Missouri, and Oklahoma. Plots were excluded from this analysis if there were no oak species present in the overstory, if the plot fell in an agricultural area, if permission for access could not be obtained from the landowner, or if the plot had improper or questionable data records present. Thus, of the initial 225 plots, 181 plots contained some type of oak species within the overstory, and these were retained for data analysis.

## Field Procedure

Field crews used portable geographic positioning system (GPS) units to locate the center of each sample plot. At pre-determined coordinates, crew members visually assessed stand homogeneity and, if necessary, adjusted the location of the plot center within the immediate vicinity to ensure homogeneous stand conditions. This avoided situations where a sample plot fell adjacent to a road or in a stand transition area such as the border between forest and pasture. Plot attributes were recorded using the plot center as the

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<sup>1</sup> Supervisory Ecologist/Project Leader, USDA Forest Service, Southern Research Station, Hot Springs AR 71902; Graduate Research Assistant and Assistant Professor, respectively, School of Forest Resources, Arkansas Forestry Resources Center, University of Arkansas at Monticello, Monticello AR 71656; Research Forester, USDA Forest Service, North Central Research Station, Columbia MO 65211; and Associate Professor, School of Natural Resources, University of Missouri-Columbia, Columbia MO 65211.

locus of measurements. Geographic position was recorded using the portable GPS device to quantify latitude, longitude, and elevation, collected in UTM zone 15 and the NAD83 datum. Aspect was measured using a compass (declination set to 7° E.), and slope steepness was measured in percentage units using a clinometer.

Two plot sizes were used based on tree size. Trees with diameter at breast height (d.b.h.)  $\geq 3.6$  inches but  $\leq 9.5$  inches were sampled using a 0.1-acre fixed radius plot ( $r = 37.24$  feet). Trees with d.b.h.  $\geq 9.6$  inches were sampled using a 0.2-acre fixed radius plot ( $r = 52.66$  feet). Field crews determined the size, species composition, and condition of the woody vegetation on the plots. In addition, they estimated crown condition for each tree using an ordinal crown dieback rating from 0 to 3 as follows: 0 = no dieback, 1 = 1 to 33 percent dieback, 2 = 34 to 66 percent dieback, and 3 = 67 to 100 percent dieback.

## DATA ANALYSIS

We assumed tree health to be inversely related to crown dieback. Overstory trees with a dieback rating of 2 or 3 were classified as unhealthy—dead, dying, or strongly affected. Trees with a dieback rating of 0 or 1 were classified as healthy. Assessment of plot health was made by calculating the absolute value and the percent of healthy vs. unhealthy oak basal area and stem density. Calculations of healthy and unhealthy oak basal area, and respective oak basal area percentages, were made for each plot by species group. Dominant species in the white oak species group, *Leucobalanus*, were white oak (*Quercus alba* L.) and post oak (*Q. stellata* Wagenh.). Minor white oaks included bur oak (*Q. macrocarpa* Michx.), chinkapin oak (*Q. muehlenbergii* Engelm.), and chestnut oak (*Q. prinus* L.). The red oak species group primarily consisted of northern red oak (*Q. rubra* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), southern red oak (*Q. falcata* Michx. var. *falcata*), and blackjack oak (*Q. marilandica* Muenchh.). Minor and varying species included pin oak (*Q. palustris* Muenchh.), scrub oak (*Q. ilicifolia* Wagenh.), water oak (*Q. nigra* L.), willow oak (*Q. phellos* L.), and Shumard oak (*Q. shumardii* Buckl.). Conifers were primarily shortleaf pine (*Pinus echinata* Mill.), eastern redcedar (*Juniperus virginiana* L.), and rarely, loblolly pine (*P. taeda* L.). Hickories included all members of the *Carya* genus, and those most frequently recorded were mockernut hickory [*C. tomentosa* (Poir.) Nutt.], black hickory (*C. texana* Buckley), bitternut hickory [*C. cordiformis* (Wangenh.) K. Koch], shagbark hickory [*C. ovata* (Mill.) K. Koch], and pignut hickory (*C. glabra* Mill.). Other hardwoods included all other hardwoods not included in the oak or hickory groups.

We used inverse distance weighting (IDW) to map the extent of oak mortality in the Interior Highlands (Johnston and others 2001) and to evaluate the geographic pattern of incidence and severity. The estimate of oak decline at a given plot was calculated using a weighted distance score for oak decline at the nearest five plots to the given plot. We then used these coordinates and IDW calculations for each plot to generate a map representing the percentage of basal area affected by oak decline across the region.

## RESULTS

### Oak Decline Mapping

Across the Interior Highlands, 22 plots (12 percent of 181 plots) had unhealthy oak basal area  $> 29$  square feet per acre (fig. 1). The highest absolute levels of unhealthy oak basal area were in Missouri forests, along a crescent of counties from the south-central to central part of the State, including Howell, Shannon, Reynolds, Jefferson, Crawford, and Pulaski counties, the heart of the southeastern Missouri Ozark Highlands. Arkansas also had several plots with high levels of unhealthy oak basal area. Those plots were distributed in counties diagonally across the State: Randolph, Sharp, Marion, and Searcy counties in the north to Montgomery and Polk counties in the southwest. Oklahoma's damage was concentrated in McCurtain, LeFlore, and Latimer counties in the southeastern corner of that State.

The map created using IDW analysis shows the largest percentage of unhealthy oak basal area in a crescent encompassing Latimer and LeFlore Counties, OK, and Polk County, AR. Smaller hotspots appear in Marion County, AR, and Reynolds and Pulaski Counties, MO (fig. 2).

### General Trends in Overstory Health

Mean stem density for all sample plots across the Interior Highlands was 236 trees per acre, of which 32 trees per acre, or 13.4 percent, were unhealthy (table 1). Mean total basal area for all plots was 97.5 square feet per acre, of which slightly  $> 14$  square feet per acre (14.5 percent) was unhealthy.

The red oak group had the largest number of unhealthy trees of any species group: 33 percent of stem density and 30 percent of basal area. Of all trees classified as unhealthy, the red oaks constituted 52 percent of stem density and 59 percent of basal area.

The white oak group had the next highest number of unhealthy trees, but the percentage was only about one-third that of the red oaks. The only other group with a high percentage of dead or dying trees was the unknown group, and this is partially attributable to the difficulty in identifying species of dead and deteriorating stems.

Hickory, miscellaneous hardwoods, and conifers groups all had much lower absolute and relative levels of unhealthy trees. Collectively, these three groups accounted for roughly 43 percent of the total stem density but only 15 percent of unhealthy stems. Similarly, these species groups total 34 percent of the total basal area but only 15 percent of unhealthy basal area across the region.

### Diameter Distributions

We compared the diameter distributions for both healthy and unhealthy red oak and white oak species groups in the region (fig. 3). These data support anecdotal observations that the current outbreak has less severely affected white oaks, although they are more numerous. Unhealthy white oaks tended to be within the smaller size classes, although some larger trees also showed decline symptoms. In the 4-inch to the 8-inch d.b.h. classes, at least one tree per acre was classified as unhealthy. While the absolute number of white oaks per acre declined with increasing size, the percentage of

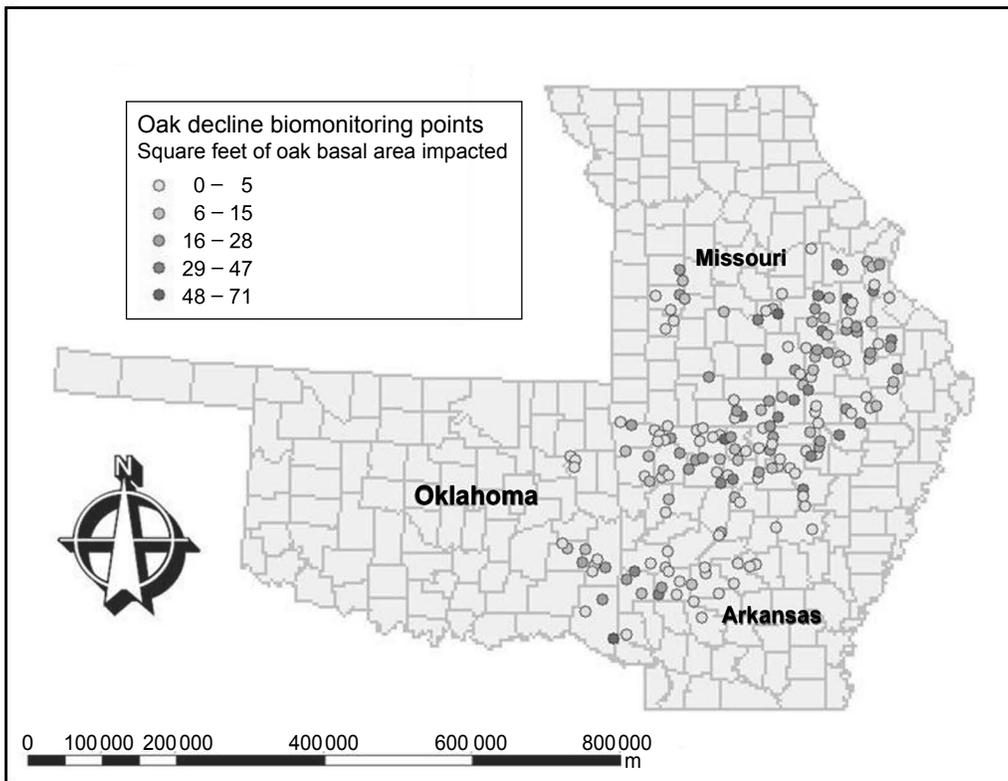


Figure 1—Absolute impacts on oak basal area (square feet per acre) by the oak decline/red oak borer event.

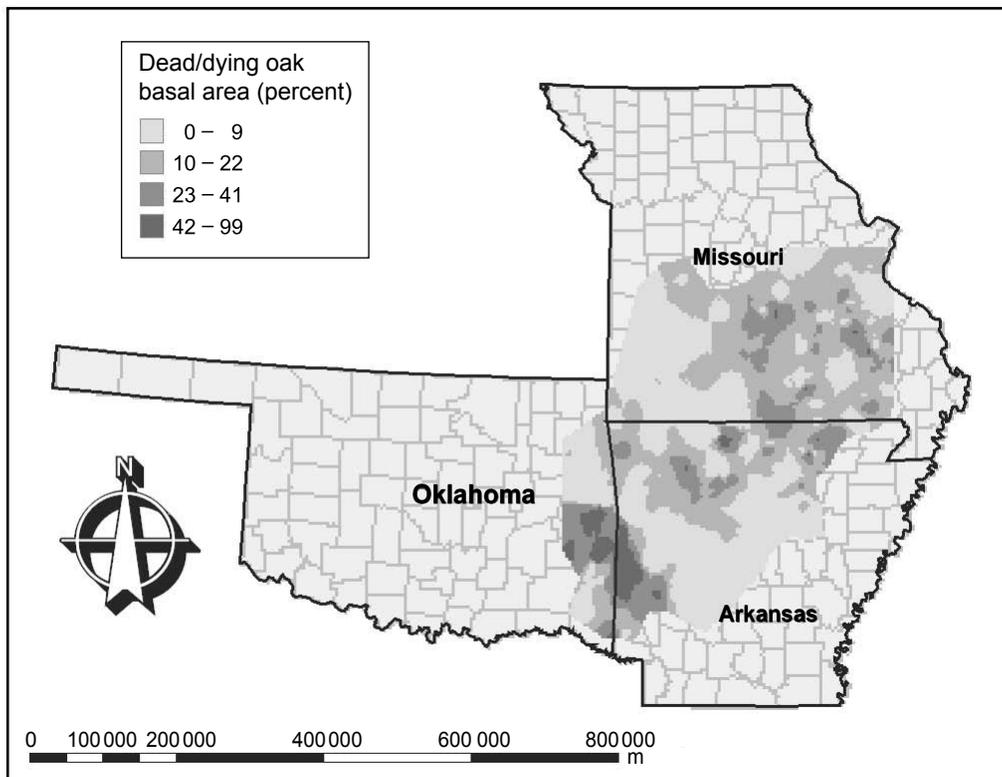


Figure 2—Predicted impact of the oak decline/red oak borer event in terms of percent of basal area of oak affected, using inverse distance weighting methodology.

**Table 1—Stem density and basal area of healthy and dead or dying trees by species group across all plots in the Interior Highlands**

Species group <sup>a</sup>	Stem density			Basal area		
	Healthy	Dead or dying		Healthy	Dead or dying	
	----- trees/ac -----	percent		----- ft <sup>2</sup> /ac -----	percent	
Red oak	33.65	16.44	32.82	19.05	8.17	30.02
White oak	72.15	9.14	11.25	32.64	3.37	9.35
Hickory	34.20	0.44	1.28	9.49	0.65	6.37
Miscellaneous hardwoods	33.51	2.29	6.40	8.70	0.80	8.44
Conifers	29.25	2.07	6.61	13.00	0.77	5.57
Unknown	1.60	1.19	42.57	0.56	0.36	38.86
<b>Total</b>	<b>204.36</b>	<b>31.57</b>	<b>13.38</b>	<b>83.43</b>	<b>14.11</b>	<b>14.47</b>

<sup>a</sup> Red oak group: northern red oak (*Quercus rubra* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), southern red oak (*Q. falcata* Michx.), and blackjack oak (*Q. marilandica* Muenchh.); minor and varying species reported included pin oak (*Q. palustris* Muenchh.), scrub oak (*Q. ilicifolia* Wagenh.), water oak (*Q. nigra* L.), willow oak (*Q. phellos* L.), and Shumard oak (*Q. shumardii* Buckl.). White oak group: white oak (*Q. alba* L.) and post oak (*Q. stellata* Wagenh.); minor white oaks reported included bur oak (*Q. macrocarpa* Michx.), chinkapin oak (*Q. muehlenbergii* Engelm.), and chestnut oak (*Q. prinus* L.). Hickories: all species in the genus *Carya*. Miscellaneous hardwoods: identifiable hardwoods not in the oak or hickory groups. Conifers: shortleaf pine (*Pinus echinata* Mill.) and eastern redcedar (*Juniperus virginiana* L.), and also loblolly pine (*P. taeda* L.). Unknown: species that could not be identified in the field.

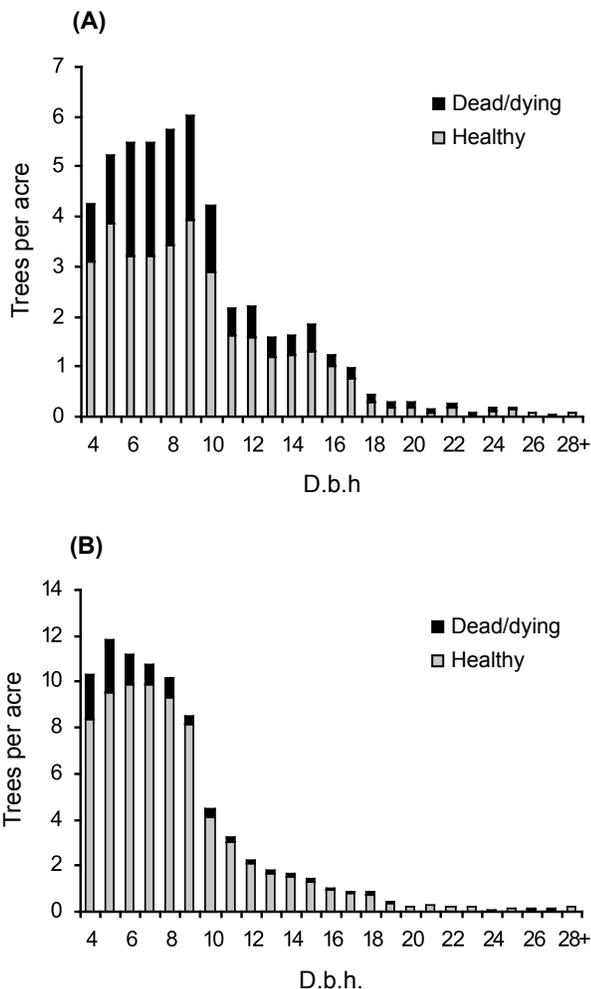


Figure 3—Diameter distributions of healthy and unhealthy trees in the Interior Highlands. (A) red oak group; (B) white oak group.

unhealthy trees remained relatively small until the largest size classes, which show a higher percentage of unhealthy trees.

Compared to white oak, red oak species in the region comprised more stems per acre and also had a higher percentage of unhealthy trees. Where white oak exhibited a larger percentage of unhealthy trees in small and large d.b.h. classes, red oak had a relatively constant percentage of unhealthy trees among all size classes. In red oaks in the 4- to 15-inch d.b.h. classes, an average of two trees per acre were classified as unhealthy, and nearly one-half of the trees in the 6- to 8-inch d.b.h. classes were unhealthy.

## DISCUSSION

The current oak decline/red oak borer event is widespread and appears to be distributed relatively uniformly across the Interior Highlands. Unhealthy red oaks are found in roughly similar proportions in each of the three States, comprising 22 to 36 percent of stem density and 24 to 31 percent of basal area of the red oak group. White oaks have also been affected but at levels roughly one-third that of red oaks in each State. Unhealthy white oaks constitute 8 to 13 percent of white oak stem density and 7 to 19 percent of white oak basal area. GIS-based IDW analysis found hotspots in the southwestern and northern parts of the Interior Highlands, which had not been identified as more adversely affected than stands in northwest Arkansas, where the tree mortality was first reported.

In addition to the roughly threefold difference in damage between the red oak and white oak groups, there appear to be differences in impacts on different size classes. Unhealthy white oaks occurred disproportionately in the smaller diameter classes (the 4- to 9-inch classes) or in trees with d.b.h.  $\geq$  18 inches. Conversely, unhealthy red oaks were relatively uniformly

distributed in roughly equal proportions across the diameter distribution. This might be explained by differences in vigor and senescence as related to size of red oaks vs. white oaks. For example, one might hypothesize that the unhealthy small oaks of either species group are adversely affected because of a lack of vigor. But in the white oak group, a lack of vigor and resulting increase in susceptibility to decline and borer attack might not be seen until the trees are quite advanced in age and size. Both of the two major white oaks in the study, white oak and post oak, reach advanced age (300 years and older) and are capable of growing to large size. Conversely, some of the red oak species, such as scarlet oak, often reach maturity and senescence in about 100 years and in relatively unremarkable sizes. Thus, in the red oak group, the presence of unhealthy trees across the diameter distribution might be related to the particular species of red oak in the group, which collectively reach maturity at different age and size across the region. While a hypothesis developed along these lines might explain the observed differences in tree health between the species groups across the diameter distribution, other hypotheses do as well. Additional research is needed on this or other datasets to develop an acceptable hypothesis that explains the observations.

#### **ACKNOWLEDGMENTS**

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#### **LITERATURE CITED**

- Crook, D.; Stephen, F.; Fierke, M. [and others]. 2004. Biology and sampling of red oak borer populations in the Ozark Mountains of Arkansas. In: Spetich, M.A., ed. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 223-228.
- Guldin, J.M.; Thompson, F.R.; Richards, L.L.; Harper, K.C. 1999. Status and trends of vegetation. In: Ozark-Ouachita Highlands assessment: terrestrial vegetation and wildlife. Rep. 5. Gen. Tech. Rep. SRS-35. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 21-72. Chapter 3.
- Heitzman, E. 2003. Changes in forest structure caused by red oak decline and red oak borer: a case study from northern Arkansas. *Southern Journal of Applied Forestry*. 27(4): 264-268.
- Heitzman, E.; Guldin, J.M. 2004. Impacts of oak decline on forest structure in Arkansas and Oklahoma: preliminary results. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 142-146.
- Johnston, K.; Ver Hoef, J.M.; Krivoruchko, K.; Leis, N. 2001. Using ArcGis geostatistical analyst. Redlands, CA: Environmental System Research Institute. 300 p.
- Muzika, R.; Guyette, R.P. 2004. A dendrochronological analysis of red oak borer abundance. In: Spetich, M.A., ed. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 102-105.
- Starkey, D.A.; Oliveria, F.; Mangini, A.; Mielke, M. 2004. Oak decline and red oak borer in the Interior Highlands of Arkansas and Missouri: natural phenomena, severe occurrences. In: Spetich, M.A., ed. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 217-222.
- U.S. Department of Agriculture, Forest Service. 2000. Forest Inventory and Analysis, national core field guide. Field data collection procedures for phase 2 & 3 plots, section 9. Ozone bioindicator plants. New Town Square, PA: Northeast Forest Experiment Station; Portland, OR: Pacific Northwest Research Station. [Not paged]. Vol. 1.

# IMPACT OF HERBIVORY BY COTTONWOOD LEAF BEETLE ON THREE SELECTED COTTONWOOD CLONES: YEAR 2 RESULTS

T. Evan Nebeker, W. Doug Stone, and T. Keith Beatty<sup>1</sup>

**Abstract**—Defoliation by herbivores, especially the cottonwood leaf beetle (CLB) (*Chrysomela scripta* F.), is a concern in the management of eastern cottonwood. In 2003, an 8-year study was initiated to determine the impact of herbivores on three selected eastern cottonwood clones. The plantation is located near Hayti, MO, on property managed by MeadWestvaco. Each clone was planted in 100 tree plots in each of 8 blocks for a total of 2,400 trees in the study. Four of the 8 blocks (1,200 trees) were not protected from defoliation, and the remaining 4 were treated with an insecticide to control CLB and other incidental herbivores. The 8-year objective is to determine the overall losses and/or gains associated with controlling and not-controlling defoliation primarily by the CLB. During the 2003 and 2004 growing seasons, monthly height, ground-line diameter (gld) (2003), diameter at breast height (d.b.h.) (2004), and degree of defoliation were recorded and statistically analyzed. Comparisons of the results of the first 2 years of this 8-year study are presented.

## INTRODUCTION

Eastern cottonwood (*Populus deltoides* Marshall) has received increased interest over the past 2 decades as a short rotation species (Fang and Hart 2000). The relatively short rotation periods of 6 to 12 years make it a desirable species for fiber production, biomass energy, and carbon sequestration. With the advent of short rotation (intensive culture systems for growing tree crops), a concern has arisen over the potential of serious growth losses due to insect damage (Bassman and others 1982, Fang and others 2002). The primary insect pest of *Populus* species is the cottonwood leaf beetle (*Chrysomela scripta* F.) (fig. 1). The objective of this study is to determine the impact that CLB defoliation has on height, diameter, and mortality of cottonwood throughout a rotation.

## STUDY SITE

A MeadWestvaco plantation, located just north of Hayti, Pemiscot County, MO, was chosen, and three clones (WV-90, WV-98, and WV-99) were selected and planted. There was a total of 8 blocks separated by 19 rows of trees. Each block contained all three clones. Each clone was planted in 100 (10 x 10) tree plots. Four of the eight blocks were not protected from defoliation (untreated), and the remaining four (treated) were treated with Sevin (carbaryl 80S at 0.6 pounds of active ingredient per acre) to control CLB feeding. In 2003, a total of six spray treatments were applied.

## METHODS

### Year One

The area was planted in June of 2003, following a late May flood. Monthly study plots were established using the inner 16 (4 x 4) trees of each plot. In July, a paint pen was used to mark the point at which the ground-line diameter (gld) was to be taken. This point was 10 inches from soil level. Gld was measured monthly using digital calipers. Height was also taken monthly using a measuring stick and/or a height pole. The annual study plots, consisting of the inner 36 (6 x 6) trees, were measured in January, 2004. Monthly damage ratings were completed on the inner 16 trees and were recorded in

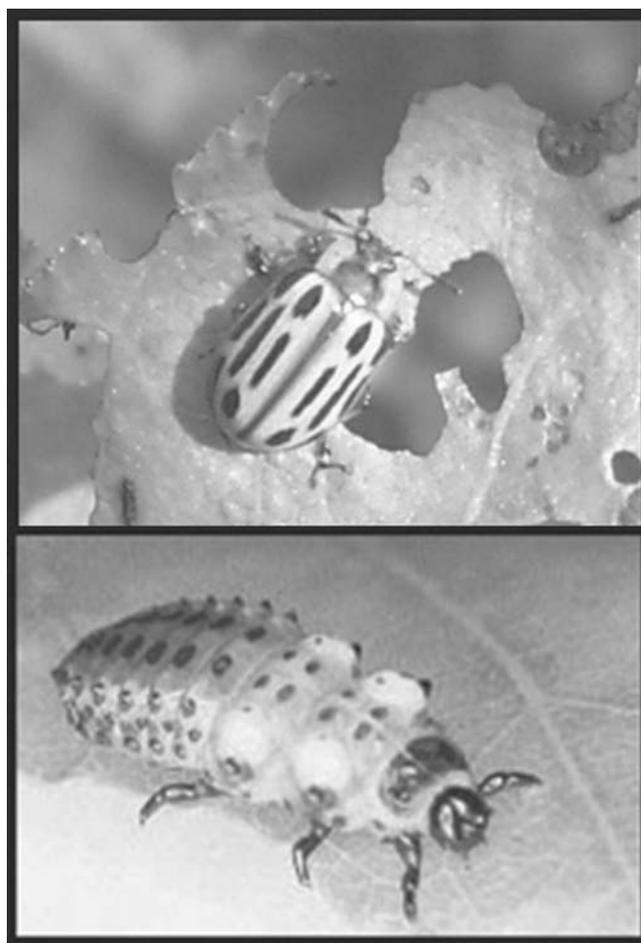


Figure 1—Mature adult and larva of the cottonwood leaf beetle.

August, September, and October 2003, to assess the amount of defoliation. The damage rating system followed that described by Larson and Isebrands (1971) and Fang and Hart (2000). A value of 0 was assigned to trees with no feeding on

<sup>1</sup> Professor and Research Associate, respectively, Mississippi State University, Department of Entomology and Plant Pathology, Mississippi State, MS 39762; and Hancock County Forester, 16195 Highway 603-43, Kiln, MS 39556.

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LPI (Leaf Plastochron Index) 1 to 8 leaves. Trees with light feeding or sample feeding on LPI 1 to 8 leaves were assigned a value of 1. Trees with light to moderate feeding with < 50 percent of LPI 1 to 8 leaves missing were assigned a value of 2. Trees with moderate to heavy feeding with 50 percent of LPI 1 to 8 leaves missing and the main leader still intact were assigned a value of 3. Trees with heavy damage with > 50 percent of LPI 1 to 8 leaves missing and with the main leader and terminal buds heavily damaged or destroyed were assigned a value of 4.

The data was collected and stored in a spreadsheet on field computers, then transferred to a spreadsheet on a desktop computer prior to analysis. Data were analyzed using SAS<sup>®</sup> PROC ANOVA and Fisher's PLSD (SAS Institute 2000) at  $\alpha = 0.05$ . In January 2004, above ground volume index was calculated using the formula [Volume Index = height \* (gld<sup>2</sup>)].

### Year Two

Methods of data collection remained essentially the same as in 2003. Once trees had a measurable diameter at breast height (d.b.h.), gld measurements were not collected. D.b.h. was measured monthly using Haglof<sup>®</sup> Aluminum calipers, and height was measured using a height pole and/or Haglof<sup>®</sup> Vertex III hypsometer. Monthly damage ratings were recorded in May, June, July, August, September, and October 2004. Annual study plots were measured in January 2005. Annual data were used to calculate an index of the above ground volume using the formula [Volume Index = height \* (dbh<sup>2</sup>)].

## RESULTS

### Year One

Survival rate was not significantly different between treatments (untreated and treated blocks) at  $\alpha = 0.05$ . Survival rate across all clones was extremely high. Survival rate was 95.8 percent in the untreated blocks and 98.9 percent in the treated blocks. Damage ratings were significantly different among untreated and treated blocks. In treated blocks, feeding was minimal, while in untreated blocks, feeding was moderate to heavy (fig. 2). Damage ratings between untreated and treated blocks differed significantly each month. In August, 2003, the untreated blocks and treated blocks were signifi-

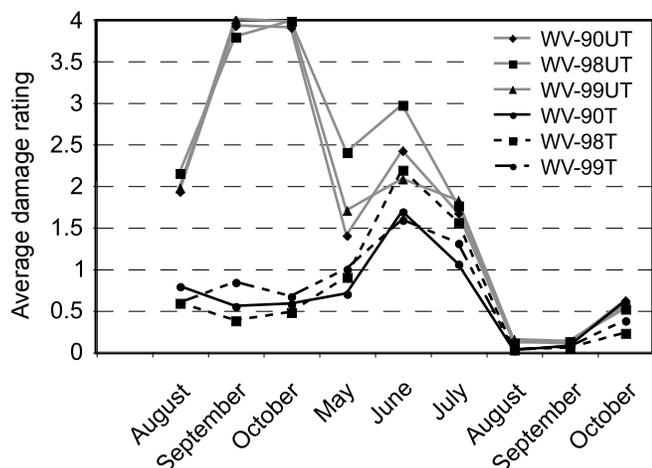


Figure 2—Average damage ratings of untreated and treated clones for the 2003 and 2004 growing season.

cantly different (fig. 2). However, no significant differences were found between clones within the untreated blocks or treated blocks. WV-98UT, WV-99UT, and WV-90UT had average damage ratings of  $2.15 \pm 0.13$ ,  $1.97 \pm 0.14$ , and  $1.92 \pm 0.14$ , respectively, while WV-90T, WV-98T, and WV-99T had average damage ratings of  $0.79 \pm 0.11$ ,  $0.59 \pm 0.08$ , and  $0.59 \pm 0.05$ , respectively (fig. 2). Untreated and treated blocks had significant differences in both height and gld measurements over the entire study period in all three clones (fig. 3 and fig. 4a).

### January 2004

Gld of clones WV-99UT and WV-90UT in the untreated blocks were found to have no significant difference, averaging  $0.84 \pm 0.03$  and  $0.80 \pm 0.02$  inches, respectively (fig. 4a). However, average gld of WV-98UT ( $1.08 \pm 0.03$  inches) was significantly different from WV-90UT and WV-99UT. Each of the clones in the treated blocks was significantly different, with average gld of  $1.75 \pm 0.03$ ,  $1.38 \pm 0.03$ , and  $1.19 \pm 0.02$  inches, respectively. Clone WV-98T had the largest gld, averaging  $1.75 \pm 0.03$  inches (fig. 4a).

Heights of clones WV-98T, WV-99T, WV-90T, WV-98UT, WV-99UT, and WV-90UT in untreated and treated blocks were all significantly different, averaging  $118.4 \pm 1.7$ ,  $112.9 \pm 1.3$ ,  $99.7 \pm 1.4$ ,  $73.4 \pm 1.8$ ,  $62.6 \pm 1.8$ , and  $57.8 \pm 1.4$  inches, respectively. WV-98T exhibited the largest height in both the untreated and treated blocks, averaging  $118.4 \pm 1.7$  inches (fig. 3).

Volume Index is an important tool in determining volume loss and/or gains when comparing two or more treatments. For the first year, the volume loss for WV-90, WV-98, and WV-99 was 71, 72, and 74 percent, respectively, when comparing the treated and untreated clones (table 1).

### Year Two

Survival rate among the clones within each treatment continued to be high. WV-99T and WV-98UT had the highest survival rates, 97.2 percent, while the lowest survival rate was 91.7 percent for WV-90UT. Damage ratings were not as high in 2004 as in 2003 (fig. 2). The highest damage rating was 3.0 for WV-98UT in June 2004. After June 2004, damage ratings for both untreated and treated blocks continued to

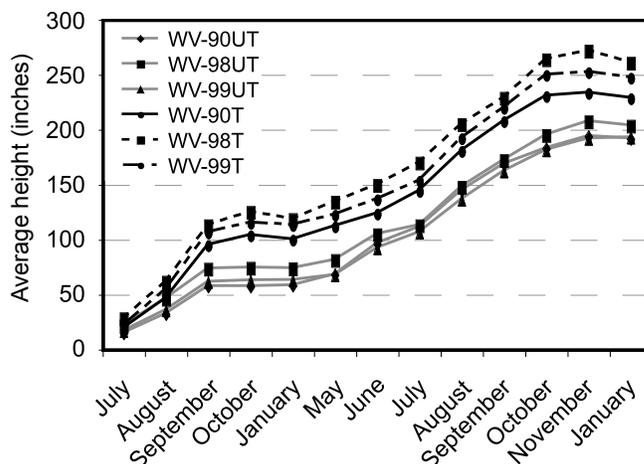


Figure 3—Average height of untreated and treated clones from July 2003 to January 2005.

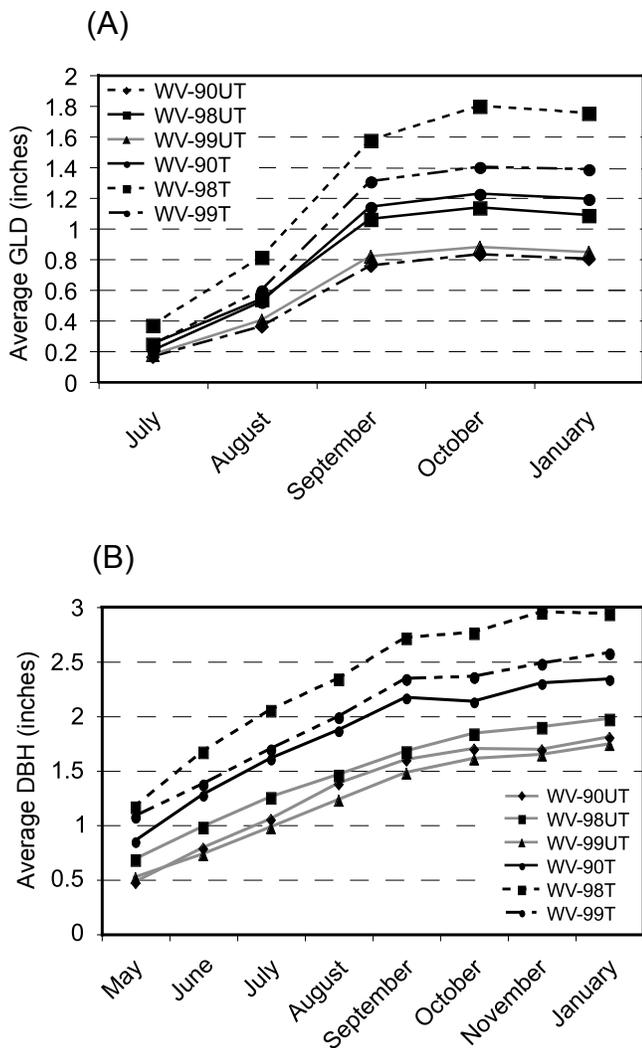


Figure 4—(A) Average ground-line diameter (gld) of untreated and treated clones from July 2003 to January 2004, (B) Average d.b.h. of untreated and treated clones from May 2004, to January 2005.

**Table 1—Volume Index<sup>a</sup> shows the total volume loss between treated and untreated blocks for all clonal lines in January 2004**

Clone	Treated	Untreated	Volume loss
	---- cubic inches ----		percent
WV-90	158	46	71
WV-98	401	111	72
WV-99	233	61	74

<sup>a</sup> Volume Index = height \* (gld)<sup>2</sup>.

decrease rapidly. For August, September, and October 2004, average damage ratings in each treatment were not greater than 0.62 (fig. 2).

### January 2005

Diameter of clones WV-98UT and WV-90UT in untreated blocks were found to have no significant differences, averaging  $1.92 \pm 0.07$  and  $1.88 \pm 0.05$  inches, respectively (fig. 4b). However, average diameter of  $1.72 \pm 0.05$  inches in WV-99UT was significantly less. Each of the clones (WV-98T, WV-99T, and WV-90T) in the treated blocks was significantly different, with average diameters of  $2.86 \pm 0.06$ ,  $2.54 \pm 0.04$ , and  $2.33 \pm 0.03$  inches, respectively. Clone WV-98T had the greatest diameter, averaging  $2.86 \pm 0.06$  inches (fig. 4b).

Heights of clones WV-98T, WV-99T, and WV-90T in treated blocks were all significantly different, averaging  $255.9 \pm 3.7$ ,  $244.9 \pm 1.8$ , and  $226.6 \pm 2.1$  inches, respectively. WV-98T exhibited the greatest height growth in both the untreated and treated blocks, with an average height of  $255.9 \pm 3.7$  inches (fig. 3). WV-98UT, WV-90UT, and WV-99UT were not significantly different with respect to mean tree heights, averaging  $197.3 \pm 3.9$ ,  $194.5 \pm 2.5$ , and  $192.2 \pm 2.7$  inches, respectively (fig. 3). The volume loss for WV-90, WV-98, and WV-99 was 39, 59, and 58 percent, respectively, when comparing the treated and untreated clones (table 2).

### DISCUSSION

Feeding by CLB caused reduction in gld, d.b.h., and height. All clones showed dramatic reduction in above-ground volume index when comparing untreated and treated blocks. In January, 2004, average volume index loss across the stand was 72 percent. This observation is similar to an earlier study, where reduction in above-ground volume was as much as 73 percent (Coyle and others 2002). In January, 2005, average volume index loss across the stand was 52 percent. The volume loss in the second year was less than the first year's volume index loss and attributed to minimal CLB feeding during the 2004 growing season (fig. 2). Damage ratings show that growth is significantly affected by increased feeding. Results indicate tree volume increases significantly in the first and second years if CLB feeding is controlled. As age of the plantation increases, CLB damage should lessen. However, other pests such as the poplar borer (*Saperda calcarata* Say) may present a problem. It appears that cottonwood continues to gain popularity as a short rotation crop; therefore the need for controlling herbivory will continue.

**Table 2—Volume Index<sup>a</sup> shows the total volume loss between treated and untreated blocks for all clonal lines in January, 2005**

Clone	Treated	Untreated	Volume loss
	---- cubic inches ----		percent
WV-90	1,298	795	39
WV-98	2,335	969	59
WV-99	1,655	694	58

<sup>a</sup> Volume Index = height \* (dbh)<sup>2</sup>.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Bassman, J.; Meyers, W.; Dickmann, D.; Wilson, L. 1982. Effects of simulated insect damage on early growth of nursery-grown hybrid poplars in Northern Wisconsin. *Canadian Journal of Forest Research*. 12: 1-8.
- Coyle, D.R.; McMillin, J.D.; Hall, R.B.; Hart, E.R. 2002. Cottonwood leaf beetle (Coleoptera: Chrysomelidae) defoliation impact on *Populus* growth and above-ground volume in a short-rotation woody crop. *Agricultural and Forest Entomology*. 4: 293-300.
- Fang, Y.; Hart, E.R. 2000. Effect of cottonwood leaf beetle (Coleoptera: Chrysomelidae) larval population levels on *Populus* terminal damage. *Environmental Entomology*. 29: 43-48.
- Fang, Y.; Pedigo, L.P.; Colletti, J.P.; Hart, E.R. 2002. Economic injury level for second generation cottonwood leaf beetle (Coleoptera: Chrysomelidae) in two-year-old *Populus*. *Journal of Economic Entomology*. 95: 313-316.
- Larson, P.R.; Isebrands, J.G. 1971. The plastochron index as applied to developmental studies of cottonwood. *Canadian Journal of Forest Research*. 1: 1-11.
- SAS Institute Inc. 2000 SAS OnlineDoc: SAS/STAT User's guide. Version 8.0. Cary, NC: SAS Institute Inc.

# EARLY CHANGES IN PHYSICAL TREE CHARACTERISTICS DURING AN OAK DECLINE EVENT IN THE OZARK HIGHLANDS

Martin A. Spetich<sup>1</sup>

**Abstract**—An oak decline event is severely affecting up to 120 000 ha in the Ozark National Forest of Arkansas. Results of early changes in physical tree characteristics during that event are presented. In the fall and winter of 1999 and 2000, we established research plots on a site that would become a center of severe oak decline. In August 2000, standing trees > 14 cm in diameter at breast height on twenty-four 0.3025-ha plots were inventoried. By late summer 2001, oak decline symptoms were evident. In November 2001, overstory trees on six plots were remeasured and changes in physical tree characteristics between the inventories were compared. Standing dead trees (all species < 35 cm in diameter at breast height) increased from 52 to 70 trees/ha ( $p = 0.049$ ). The number of northern red oak (*Quercus rubra* L.) trees exhibiting epicormic branching increased from 9 trees/ha in 2000 to 55 trees/ha in 2001 ( $p = 0.009$ ). Evidence of red oak borer damage on that portion of the main stem extending through the tree crown increased from 2 trees/ha in 2000 to 31 trees/ha in 2001 ( $p = 0.008$ ). The mean ratio of standing dead to live trees increased from 0.15 in 2000 to 0.25 by 2001. I term this ratio the “forest health quotient.” In 2000 the quotient was already above expected values, evidence of its potential utility in early detection of forest health issues.

## INTRODUCTION

Fifty-seven oak mortality events have been recorded in the Eastern United States between 1856 and 1986 (Millers and others 1989). This included one in 1959 in the Ozark Mountains of Arkansas (Toole 1960), one in 1980-81 in north-western Arkansas (Bassett and others 1982, Mistretta and others 1984), and one event in Missouri from 1980 to 1986 (Law and Gott 1987). The current oak decline event in Arkansas and Missouri has severely affected up to 120 000 ha in the Ozark National Forest of Arkansas alone (Starkey and others 2004).

In the Eastern United States, oak decline is considered a complex set of interactions involving many factors (Wargo and others 1983). Manion (1991) describes it as resulting from the interaction of three major groups of factors: predisposing factors, inciting factors, and contributing factors. Predisposing factors include physiologic age, tree density, soil conditions, and topography; inciting factors include drought and defoliating insects; and contributing factors include opportunistic insects such as some wood boring insects and diseases, e.g., *Hypoxylon* canker (*Hypoxylon atropunctatum*).

A 3-year drought occurred across the region from 1998 to 2000, an inciting factor of oak decline according to Manion (1991) and Starkey and others (2004). This, coupled with the fact that it occurred in a forest with high tree density and mature trees, made Arkansas's upland hardwood forests especially vulnerable to oak decline (Oak and others 2004). Those factors were present in both Arkansas and Missouri.

Such an oak decline event has the potential to significantly alter forest structure and species composition. Based on previous oak decline events (Oak and others 1988, Starkey and others 1989, Tainter and others 1984), it is likely that oaks will remain an important component of these forests at a regional scale. Within some stands, however, oaks may no longer be the dominant tree without active management to encourage oak regeneration and recruitment. On sites where oak reproduction is present, but competing species have an

advantage, active management will be necessary to establish and successfully grow a new cohort of oaks into the tree canopy. An understanding of physical tree characteristics that help lead to early detection of oak decline would aid our ability to address future oak decline events.

One potential early indicator of forest stress is the ratio of standing dead to live trees. I term this ratio the “forest health quotient.” The quotient averages 0.08 in Midwestern second-growth forests (Spetich and others 1999). For Arkansas forests, the quotient's mean value is 0.089 with a 95 percent confidence interval of  $\pm 0.009$  (Spetich and Guldin 1999). Forests with quotients above these values may indicate forest stress. Because small changes in the quotient are often not visually detectable on site, it may be useful as an early data-evident indicator of forest health issues, prompting further investigation when the quotient is determined to be high.

One year after measuring vegetation on permanent plots in the Boston Mountains of Arkansas, oak decline symptoms were evident (Spetich 2004). Although this meant the temporary loss of one replication of the original study, it provided a serendipitous and unprecedented opportunity to examine oak decline event dynamics using detailed early data to make comparisons.

My objective was to evaluate both visually evident and data-evident changes in physical tree characteristics 1 year after taking the first woody vegetation measurements. The study's long-term objective is to compare stand dynamics among areas treated with a growing season prescribed fire, a dormant season prescribed fire, and a control area.

## STUDY SITE

The study site is a 32-ha area in an upland oak-hickory stand that is approximately 73 years old. It is in the Boston Mountains of Arkansas, part of the southern lobe of the Central Hardwood Region (Merritt 1980). More specifically, it is in the northwestern corner of Pope County, approximately 3 km

<sup>1</sup> Research Forester, USDA Forest Service, Southern Research Station, Hot Springs, AR 71902.

southeast of Sand Gap, AR. The stand is dominated by oak (*Quercus* spp.) and hickory (*Carya* spp.) and has become the center of a local patch of oak decline. In August 2000, basal area for all standing trees was 25.9 m<sup>2</sup>/ha, and there were 417 standing trees/ha, of which 1.8 m<sup>2</sup>/ha of basal area and 53 trees/ha comprised standing dead trees. Stocking was 88 percent.

The Boston Mountains are the highest and most southern member of the Ozark Plateau Physiographic Province (Croneis 1930). They form a band 48 to 64 km wide and 320 km long from northcentral Arkansas westward into eastern Oklahoma. Elevations range from about 275 m in the valley bottoms to 760 m at the highest point. The plateau is sharply dissected. Most ridges are flat to gently rolling and generally are less than 0.8 km wide. Mountainsides are alternating steep simple slopes and gently sloping benches. Vegetation across the landscape is a forest matrix with nonforest inclusions.

## METHODS

The site was located in the fall of 1999. During the winter of 2000, twenty-four 55- by 55-m overstory plots (0.3025 ha) were established across the study area. In summer 2000, all trees > 14 cm diameter at breast height (d.b.h.) were measured to the nearest 0.1 cm at 1.37 m above ground level within each plot; each tree's azimuth and distances from plot center were recorded. Species, log grade, crown class, and multi-factor damage codes were also recorded for each tree using a Hewlett-Packard 200LX palmtop computer to record all data in the field.

In each of the twenty-four 55-m-square plots, four circular 0.01-ha plots were established to inventory midstory trees. Within each 0.01-ha plot, all trees from 5 cm to < 25 cm d.b.h. were measured in July 2000. Diameter at breast height was recorded to the nearest 0.1 cm.

Further, within each of the 0.01-ha plots, five circular 0.000539-ha plots (1.31-m radius) were established to inventory regeneration. Within each regeneration plot, all trees < 5 cm d.b.h. were measured in spring of 2000.

Initially, all 24 plots were intended to be part of 1 replication of a large, periodic, prescribed fire study, but by the summer of 2001, oak decline symptoms were clearly evident at the site. At that point, this site was designated for a long-term case study of oak decline forest dynamics. In November and December of 2001, the overstory on a quarter of the 24 plots was remeasured (only 6 plots were remeasured due to time constraints). This site is now the center of a local patch of severe oak decline covering hundreds of hectares in northwestern Pope County, AR. The data were analyzed using a paired t-test to compare 2000 plot values with 2001 plot values.

## RESULTS AND DISCUSSION

### Visually Evident Results

In 2000, most standing dead trees (all species) were < 35 cm d.b.h. at 52 trees/ha, while standing dead trees ≥ 35 cm d.b.h. averaged only 1 tree per ha. The small-diameter dead trees were not visually evident in 2000 because they were lost in a sea of small trees. By 2001, the number of both small- and large-diameter standing dead trees had increased. The number of < 35 cm d.b.h. trees had increased from 52 trees/ha in

2000 to 70 trees/ha in 2001. The difference was statistically significant ( $p = 0.049$ ). Although the mean value of large standing dead trees, those ≥ 35 cm d.b.h., had increased from 1 to 12 trees/ha from 2000 to 2001, the change was not statistically significant ( $p = 0.064$ ).

Of all tree species, northern red oak (*Q. rubra* L.) had the largest increase in the number of standing dead, and in 2001 that mortality was the most visually evident at the study site (fig. 1). Although the number of standing dead black oak (*Q. velutina* Lam.) doubled, the increase was only from 2 to 4 trees/ha, thus was not visually evident in the study area. By comparison, the number of standing dead northern red oak more than doubled from 23 to 51 trees/ha (Spetich 2004). Standing dead trees ≥ 35 cm constituted no northern red oak in 2000 but 11 trees/ha in 2001, although that change was not statistically significant ( $p = 0.061$ ). On the other hand, the change in standing dead northern red oak < 35 cm d.b.h. was statistically significant ( $p = 0.037$ ), increasing from 22 trees/ha in 2000 to 40 trees/ha in 2001. Nonetheless, large northern red oak were the most visually evident standing dead trees in 2001.

Because virtually all visually evident characteristics involved northern red oak, the rest of this section will focus on that species.

The most visually evident change in physical tree characteristics in this stand was the increase of epicormic branching on standing live northern red oak. In 2000, epicormic branching was observed on only nine northern red oak trees/ha. By 2001, the number had increased to 55 trees/ha (fig. 2). This increase was statistically significant ( $p = 0.009$ ). Most trees exhibiting epicormic branching were codominant. In 2000, 8 of the 9 trees with epicormic branching were codominant, while in 2001, 48 of the 55 trees with epicormic branching were codominant.

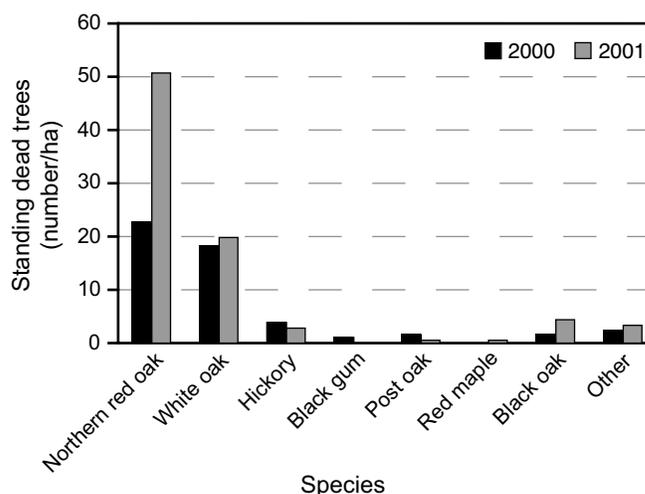


Figure 1—Number of standing dead trees/ha by species and year. "Other" includes black cherry (*Prunus serotina* Ehrh.), black walnut (*Juglans nigra* L.), elm (*Ulmus* spp.), black locust (*Robinia pseudo-acacia* L.), serviceberry (*Amelanchier* spp.), sassafras (*Sassafras albidum* Nutt.), and white ash (*Fraxinus americana* L.).

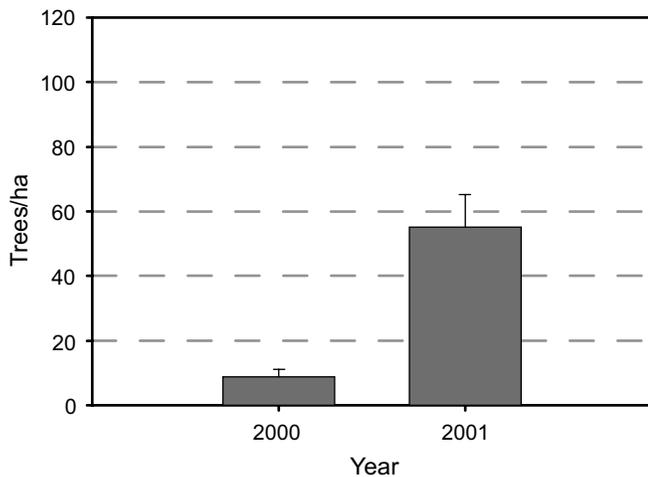


Figure 2—Number of trees/ha exhibiting epicormic branching in 2000 vs. 2001. Error bars represent one standard error.

### Data-Evident Results

**Dead-to-live ratio (forest health quotient)**—In 2000, the mean ratio of standing dead to live trees for all species combined was 0.15, a value greater than we would typically expect. For that reason we examined the site for forest health problems the next growing season. By 2001, the ratio of dead to live trees had increased to 0.25. In upland hardwood forests of Arkansas, Spetich and Guldin (1999) found the typical ratio was 0.09. Earlier in 1999, Spetich and others found the mean ratio of dead to live trees in Midwestern second-growth upland hardwood forests to be 0.08. They suggested using the 0.08 ratio as a baseline indicator of forest health, which if exceeded should prompt further investigation.

**Atypical infestation**—One unique characteristic of this region-wide event is the preponderance of red oak borers (*Enaphalodes rufulus* Haldemann). The insect was noticeable at the study site by the end of the first-year inventory, and trees with evidence of oak borer were noted. In 2000, the number of trees/ha with oak borer evidence in the main bole below the tree crown was 33, but in 2001 there were 26 trees/ha. This decrease was not statistically significant ( $p = 0.071$ ). In both years, the greatest number of trees/ha with oak borer evidence in this part of the bole was in the 30-cm or smaller diameter classes (fig. 3).

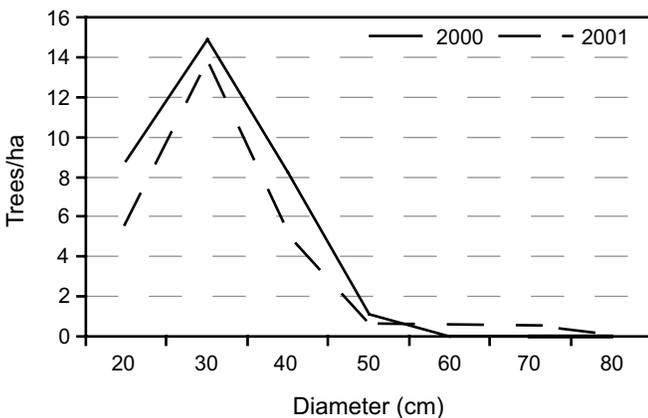


Figure 3—Number of northern red oak trees/ha by diameter class exhibiting oak borer damage in the main bole below the tree crown.

However, there was a significant increase in oak borer damage evident in the main stem portion within the crown area. In 2000, an average of only 2 trees/ha had oak borer damage in this portion of the main stem, but that number increased to 31 trees/ha in 2001. This increase was statistically significant at  $p = 0.008$ . It occurred in the 20- to 50-cm diameter class; no change was observed in the 60-cm diameter class (fig. 4).

Evidence of red oak borer damage on the main stem below the tree crown for trees  $\leq 40$  cm was likely an early indicator of small trees under additional competitive stress in the stand. However, these values included trees with scars from past oak borer damage; we did not discern between new and old damage, where old damage may have occurred up to 15 years earlier. The reduction in number of trees exhibiting damage was likely due to the number of small-diameter trees that died and fell to the ground prior to the second inventory. Small-diameter dead trees tend to fall sooner than large-diameter trees due to a more rapid loss of structural integrity.

### Characteristics with Potential Utility for Early Detection

Of the characteristics examined here, the one with the potential for earliest detection of oak decline is the dead to live ratio that I term the “forest health quotient.” The fact that the 2000 forest health quotient of 0.15 was much higher than usual (Spetich and Guldin 1999, Spetich and others 1999) and that it was determined prior to more visual evidence of oak decline is further evidence of the potential utility of the quotient. In forests with continuous forest inventory or other recent inventory data, this quotient can be quickly and easily calculated. Arkansas forests with quotients of  $> 0.09$  and Midwestern forests with quotients of  $> 0.08$  should prompt further investigation of potential forest health issues. The quotient also may be useful as a component of a more comprehensive, integrated forest health index.

Epicormic branching and standing dead trees were not extensive enough to be significant visual indicators until the second year. Oak borer damage was evident by the end of the first period of data collection. However, it was the epicormic branching and large dead trees that stood out visually during the second year.

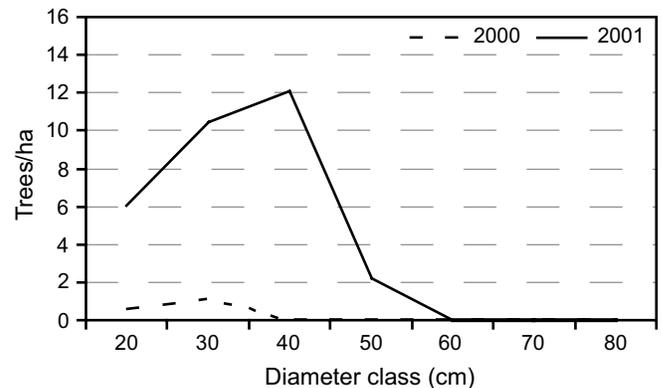


Figure 4—Number of northern red oak trees/ha by diameter class exhibiting oak borer damage in the main stem within the tree crown area.

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## LITERATURE CITED

- Bassett, E.N.; Fenn, P.; Mead, M.A. 1982. Drought-related oak mortality and incidence of hypoxylon canker. *Arkansas Farm Research*. 31: 8.
- Croneis, C. 1930. Geology of the Arkansas Paleozoic area. *Bulletin* 3. [Place of publication unknown]: Arkansas Geological Survey. 457 p.
- Law, J.R.; Gott, J.D. 1987. Oak mortality in the Missouri Ozarks. In: Hay, R.L.; Woods, F.W.; De Selm, H., eds. *Proceedings of the sixth central hardwood forest conference*. Knoxville, TN: University of Tennessee: 427-436.
- Manion, P.D. 1991. *Tree disease concepts*. 2d ed. Englewood Cliffs, NJ: Prentice-Hall. 402 p.
- Merritt, C. 1980. The central region. In: Barrett, J.W., ed. *Regional silviculture of the United States*. 2d ed. New York: John Wiley: 107-143.
- Millers, I.; Shriner, D.S.; Rizzo D. 1989. History of hardwood decline in the eastern United States. *Gen. Tech. Rep. NE-126*. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 79 p.
- Mistretta, P.A.; Anderson, R.L.; Lewis, R.; MacDonald, W.L. 1984. Annotated bibliography of oak wilt 1943-1980. *Gen. Tech. Rep. WO-45*. Washington, DC: U.S. Department of Agriculture, Forest Service. 132 p.
- Oak, S.W.; Starkey, D.A.; Dabney, J.M. 1988. Oak decline alters habitat in southern upland forests. In: *Proceedings of the annual conference of the southeast association of fish and wildlife agencies*. [Place of publication unknown]: Southeast Association of Fish and Wildlife Agencies. 42: 491-501.
- Oak, S.W.; Steinman, J.; Starkey, D.A.; Yockey, E.K. 2004. Assessing oak decline incidence, distribution, and severity in the southeastern U.S. using forest inventory and analysis data. In: Spetich, M.A., ed. *Proceedings of the upland oak ecology symposium: history, current conditions and sustainability*. *Gen. Tech. Rep. SRS-73*. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 236-242.
- Spetich, M.A. 2004. Forest dynamics at the epicenter of an oak decline event in the Boston Mountains, Arkansas, year one. In: Yaussy, D.A.; Hix, D.M.; Long, R.P.; Goebel, P.C., eds. *Proceedings of the 14th central hardwood forest conference*. *Gen. Tech. Rep. NE-316*. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 21-26.
- Spetich, M.A.; Guldin, J.M. 1999. The spatial distribution of dead trees across Arkansas timberlands. In: Haywood, J.D., ed. *Proceedings of the 10th biennial southern silvicultural research conference*. *Gen. Tech. Rep. SRS-30*. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 53-56.
- Spetich, M.A.; Shifley, S.R.; Parker, G.R. 1999. Regional distribution and dynamics of coarse woody debris in Midwestern old-growth forests. *Forest Science*. 45(2): 302-313.
- Starkey, D.A.; Oak, S.W.; Ryan, G.W. [and others]. 1989. Evaluation of oak decline areas in the South. *Protection Rep. R8-PR 17*. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region. 37 p.
- Starkey, D.A.; Oliveria, F.; Mangini, A.; Mielke, M. 2004. Oak decline and red oak borer in the interior highlands of Arkansas and Missouri: natural phenomena, severe occurrences. In: Spetich, M.A., ed. *Proceedings of the upland oak ecology symposium: history, current conditions and sustainability*. *Gen. Tech. Rep. SRS-73*. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 217-222.
- Tainter, F.H.; Fraedrich, S.W.; Benson, D.M. 1984. The effect of climate on growth, decline, and death of northern red oaks in the western North Carolina Nantahala Mountains. *Castanea*. 49(3): 127-137.
- Toole, E.R. 1960. Rootrot of white oak in Arkansas. *Plant Disease Reporter*. 44: 783.
- Wargo, P.M.; Houston, D.R.; LaMadeleine, L.A. 1983. Oak decline. *Forest Insect and Disease Leaflet* 165. Washington, DC: U.S. Department of Agriculture, Forest Service. 8 p.

# SITE FACTORS INFLUENCING OAK DECLINE IN THE INTERIOR HIGHLANDS OF ARKANSAS, MISSOURI, AND OKLAHOMA

Edward A. Poole, Eric Heitzman, and James M. Guldin<sup>1</sup>

**Abstract**—Oak decline is affecting the forests in the Interior Highlands of Arkansas, Missouri, and Oklahoma. In 2002 and 2003, field plots were established throughout the region to evaluate the influence of topographic position and aspect on oak decline. Density and basal area of dead and dying oaks did not significantly differ by either topographic position or aspect. Lack of differences by topographic position may be partially explained by the low number of sample plots on ridgetops. It is also likely that factors other than topography and aspect influenced oak decline severity.

## INTRODUCTION

Oak decline involves an interaction of predisposing, inciting, and contributing factors that results in the death of oaks in general and red oaks in particular (Starkey and Oak 1989, Starkey and others 2004). Since the late 1990s, oak decline has affected forests throughout the Interior Highlands of Arkansas, Missouri, and Oklahoma (Oak and others 2004, Rosson 2004). The predisposing factors in this decline include advanced tree age, shallow and rocky soils, and a high proportion of red oaks. The inciting factor was an acute regional drought from 1998 through 2000. Contributing factors include red oak borer (*Enaphalodes rufulus* Haldeman) (Crook and others 2004), *Armillaria* spp. root rot (Bruhn and others 2000), and hypoxylon canker (*Hypoxylon* spp). The spatial extent and severity of the current decline may be unprecedented. Approximately one-third of red oak density and basal area in the Interior Highlands is either dead or dying (Guldin and others 2006). Due to the monetary value of the sawtimber and pulpwood at risk, as well as the aesthetic and wildlife values of oak forests in the region, oak decline has become an important issue for foresters and land management agencies.

The area affected extends from the Ouachita Mountains in eastern Oklahoma and western Arkansas to the Ozark Mountains in northern Arkansas and southern Missouri. It is unclear whether particular topographic positions and aspects are more or less susceptible to this decline. During an oak decline in the 1980s that impacted forests from Arkansas to Virginia, Starkey and Oak (1989) found that field plots with the highest incidence of mortality were associated with stony, gravelly soils < 46 cm deep; were on ridgetops or upper slope positions; and had average or lower site indices (< 21 m at 50 years). Using data from the 1980s decline, Oak and others (1996) developed oak decline risk rating models for the Ozark Mountains and northern and southern Appalachian Mountains. Significant site variables for the Ozarks included high clay content of soil and low slope gradient (i.e., ridgetops).

In summer 2002 and 2003, field plots were established in forests throughout the Interior Highlands to quantify the distribution and severity of oak decline. Preliminary results were presented by Heitzman and Guldin (2004), and a summary was reported by Guldin and others (2006). In the current study, we used data from these field plots to explore

the relationship between site factors and oak decline. Specifically, we examined whether decline severity varied by topographic position and aspect.

## METHODS

In 2002, 500 polygons with a data collection point centrally located in each were delineated on a digital map of the Highlands. Prior to field sampling, the points were stratified by their presumed susceptibility to oak decline (Oak and others 1996, Starkey and Oak 1989). Risk categories were as follows:

1. Very high risk – red oak basal area > 6.9 m<sup>2</sup>/ha on ridgetops or south- to southwest-facing slopes
2. High risk – red oak basal area > 13.8 m<sup>2</sup>/ha but on sites other than ridgetops or south- to southwest-facing slopes
3. Moderate risk – red oak basal area between 2.3 to 6.9 m<sup>2</sup>/ha on ridgetops or south- to southwest-facing slopes, or 2.3 to 13.8 m<sup>2</sup>/ha on other topographic positions or aspects
4. Low risk – red oak basal area < 2.3 m<sup>2</sup>/ha regardless of topographic position or aspect.

Initially, the sampling objective was to visit all 500 field plots, the majority of which were in the very high and high risk categories. However, due to financial constraints, property access delays, and misinterpretation or misclassification of GIS data, only 225 field plots were sampled, most of which were in the moderate to low risk categories. The 225 field plots were established in Arkansas, Missouri, and Oklahoma during the summer of 2002 and 2003. Of these 225 plots, 181 contained at least 1 oak tree > 24.4 cm d.b.h. Data from these 181 plots (90 in Arkansas, 78 in Missouri, and 13 in Oklahoma) were analyzed for this study.

Plots consisted of one 0.08-ha overstory plot in which all living, dying, and dead trees > 24.4 cm d.b.h. were tallied by species, crown condition, and d.b.h. Crown condition was recorded as: alive and healthy (0 to 33 percent crown dieback), alive but dying (> 33 percent crown dieback), or dead within the past 3 years. Trees that had been dead for more than 3 years were not measured. In addition, living, dying, and dead trees 8.9 to 24.4 cm d.b.h. were tallied in a 0.04-ha midstory plot that was nested within the overstory plot. Midstory trees were recorded by species, crown condition, and d.b.h.

<sup>1</sup> Graduate Research Assistant and Assistant Professor, respectively, School of Forest Resources, University of Arkansas, Monticello, AR 71656; and Project Leader and Research Forest Ecologist, USDA Forest Service, Southern Research Station, Hot Springs, AR 71902.

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Various site attributes were assessed at each point. These included topographic position (ridgetop, upper-slope, mid-slope, lower-slope, or floodplain), which was visually estimated, and aspect (from 0 to 360° azimuth), which was measured by compass. We defined north aspects as ranging from 315 to 45°, east aspects as 46 to 134°, south aspects as 135 to 224°, and west aspects as 225 to 314°.

Basal area and density of dead/dying oaks (of any species) were calculated for each plot. These values were grouped by topographic position to determine if decline severity (expressed as mean dead/dying oak basal area/ha and trees/ha) varied by topography. After this, plots were grouped into different aspect categories to determine if decline severity, expressed as mean dead/dying oak basal area and density, varied by aspect.

A Shapiro-Wilks test indicated that none of the data analyzed were normally distributed, so oak mortality was compared using a Kruskal-Wallis test. Significance was accepted at  $P \leq 0.05$ . Data were analyzed in SAS (SAS Institute 1993).

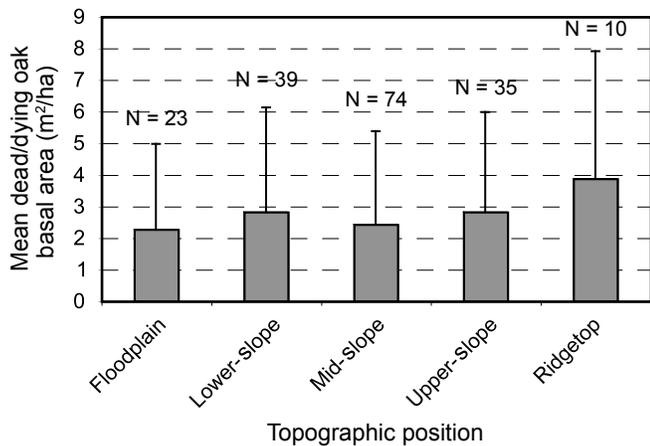


Figure 1—Mean dead/dying oak basal area by topographic position in the Interior Highlands. Bars are one standard deviation.

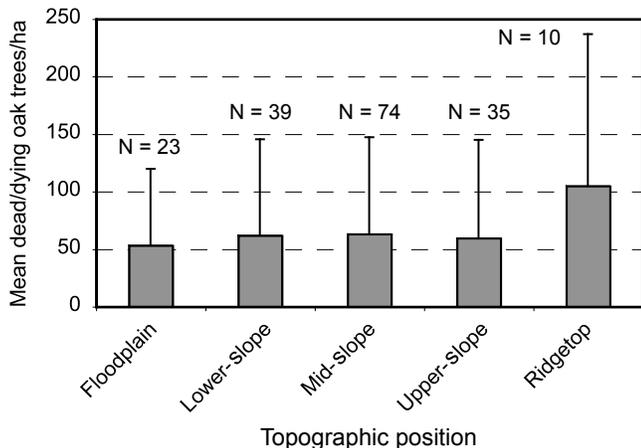


Figure 2—Mean dead/dying oak density by topographic position in the Interior Highlands. Bars are one standard deviation.

## RESULTS AND DISCUSSION

There was no significant difference ( $P=0.72$ ) between mean dead/dying oak basal area in different topographic positions (fig. 1). There was also no significant difference ( $P=0.59$ ) between the mean number of dead/dying oak trees/ha on different topographic positions (fig. 2). In general, higher topographic positions had a greater amount of decline, both in basal area and density. Oak mortality was greatest on ridgetops (4.0 m²/ha and 104 trees/ha) and least on floodplains (2.0 m²/ha and 54 trees/ha).

There was no significant difference ( $P=0.14$ ) between mean dead/dying oak basal area on different aspects (fig. 3). Oak mortality was greatest on south-facing (3.1 m²/ha) and west-facing (3.0 m²/ha) slopes and least on east-facing slopes (1.8 m²/ha). There was also no significant difference ( $P=0.50$ ) between the mean number of dead/dying oak trees/ha on different aspects (fig. 4). In general, south-facing slopes had the highest density (69 trees/ha) of oak mortality, followed by west-facing slopes (68 trees/ha). The lowest mortality (50 trees/ha) was on eastern slopes.

Previous studies have demonstrated that ridgetops had the greatest amount of oak decline (Oak and others 1996, Starkey and Oak 1989). However, we found no significant differences in oak decline by topographic position. This might be because the majority of field plots in this study were not on ridgetops.

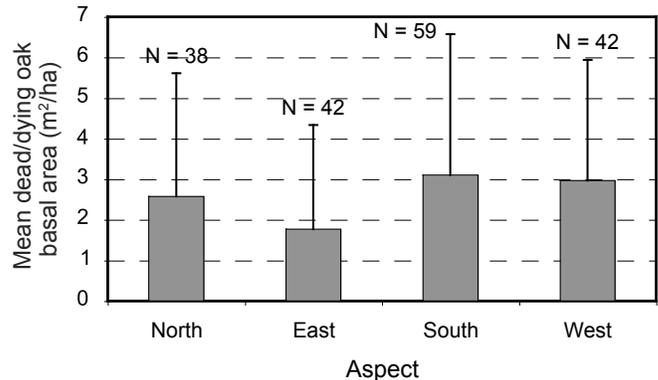


Figure 3—Mean dead/dying oak basal area by aspect in the Interior Highlands. Bars are one standard deviation.

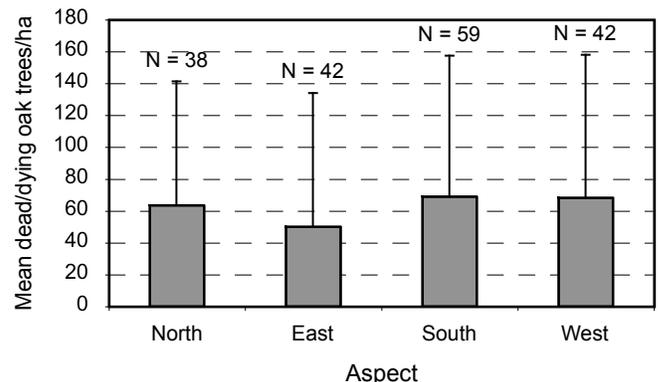


Figure 4—Mean dead/dying oak density by aspect in the Interior Highlands. Bars are one standard deviation.

Only 10 plots fell on ridgetop positions, whereas 35 plots were on upper-slopes, 74 on mid-slopes, 39 on lower-slopes, and 23 on floodplains. The low sample size on presumably susceptible sites may have contributed to the lack of significant differences. In addition, we found no statistical differences in oak decline on different aspects, although the field plots were more evenly distributed by aspect. Starkey and Oak (1989) did not detect significant differences in oak decline by aspect, although they reported that north and western aspects had the greatest mortality. Oak and others (1996) stated that aspect was not a significant variable in oak decline risk models developed for the Ozark and Appalachian Mountains.

Field observations in the Interior Highlands indicated that oak decline seemed to be most severe on ridgetops and xeric aspects, but not all forests on ridgetops and xeric aspects were in decline. Our results support this finding and suggest that factors other than (or perhaps in addition to) topography and aspect influenced the severity of oak decline in the Interior Highlands. Recent work by Kabrick and others (2004) in the Ozark Mountains of southern Missouri showed that oak species and crown class were more important than site factors in affecting oak mortality from 1992 to 2002. The mortality rate of red oaks was four times greater than for white oaks, and suppressed oaks were about three times more likely to die than upper canopy oaks. Also, mortality sharply increased for red and white oaks larger than the 33 to 38 cm d.b.h. class. Thus, severity of the current oak decline in the Interior Highlands is influenced by a combination of individual tree, stand, and site variables.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

Bruhn, J.N.; Wetteroff, J.J.; Mihail, J.D. [and others]. 2000. Distribution of *Armillaria* species in upland Ozark Mountain forests with respect to site, overstory species composition and oak decline. *European Journal of Forest Pathology*. 30: 43-60.

- Crook, D.; Stephen, F.; Fierke, M. [and others]. 2004. Biology and sampling of red oak borer populations in the Ozark Mountains of Arkansas. In: Spetich, M.A., ed. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 223-228.
- Guldin, J.M.; Poole, E.A.; Heitzman, E. [and others]. 2006. Ground truth assessments of forests affected by oak decline and red oak borer in the Interior Highlands of Arkansas, Oklahoma, and Missouri: preliminary results from overstory analysis. In: Connor, K.F., ed. Proceedings of the thirteenth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 415-419.
- Heitzman, E.; Guldin, J.M. 2004. Impacts of oak decline on forest structure in Arkansas and Oklahoma: preliminary results. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 142-146.
- Kabrick, J.M.; Shifley, S.R.; Jensen, R.G. [and others]. 2004. Factors associated with oak mortality in Missouri Ozark Forests. In: Yaussy, D.A.; Hix, D.M.; Long, R.P.; Goebel, P.C., eds. Proceedings of the 14<sup>th</sup> central hardwoods forest conference. Gen. Tech. Rep. NE-316. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 27-35.
- Oak, S.; Tainter, F.; Williams, J.; Starkey, D. 1996. Oak decline risk rating for the Southeastern United States. *Annales des Sciences Forestieres*. 53: 721-730.
- Oak, S.W.; Steinman, J.R.; Starkey, D.A. [and others]. 2004. Assessing oak decline incidence and distribution in the southern U.S. using Forest Inventory and Analysis data. In: Spetich, M.A., ed. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 236-242.
- Rosson, J.F. 2004. Oak mortality trends on the Interior Highlands of Arkansas. In: Spetich, M.A., ed. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 229-235.
- SAS Institute. 1993. SAS/ETS user's guide. Version 6, second ed. Cary, NC: SAS Institute, Inc. 1022 p.
- Starkey, D.A.; Oak, S.W. 1989. Site factors and stand conditions associated with oak decline in southern upland hardwood forests. In: Rink, G.; Budelsky, C.A., eds. Proceedings of the seventh central hardwood forest conference. Gen. Tech. Rep. NC-132. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 95-102.
- Starkey, D.A.; Oliveria, F.; Mangini, A. [and others]. 2004. Oak decline and red oak borer in the Interior Highlands of Arkansas and Missouri: natural phenomena, severe occurrences. In: Spetich, M.A., ed. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 217-222.

# GEOGRAPHIC ORIGIN OF COTTONWOOD FROM THE SOUTHEAST AFFECTS *MELAMPSORA* INFECTION IN 3-YEAR-OLD CLONAL TRIALS

Samuel B. Land, Jr. and Jonathan Paul Jeffreys<sup>1</sup>

**Abstract**—Open-pollinated seeds were collected separately by mother tree from several trees in each of 64 natural stands of eastern cottonwood (*Populus deltoides* J. Bartram ex Marsh. var. *deltoides*) in the Southeastern United States. Rooted cuttings from the seedlings were grown at four sites (North Carolina, Florida, Alabama, and Missouri). Measurements were taken during September-October in each of the first 3 years after planting for *Melampsora medusae* Thuem. f.sp. *deltoidae* leaf rust infection. Average severity of infection over the 3 years varied with latitude and longitude of the stand where the seeds were collected, with subregion of origin, and with individual stand of origin within subregion. However, differences among river-system groups or topographic positions (upland or bottomland) for stand origins within subregions were not significant. Some of the natural stands were comparable in resistance (less infection) to a set of 12 “check” clones in the trials that came from former tree improvement programs in the lower Mississippi River Valley and Texas.

## INTRODUCTION

The poplars (*Populus* genus) are important worldwide for pulp, lumber, and biofuel. That importance is based on their fast growth, but leaf rusts caused by *Melampsora* species can seriously reduce this growth. *Melampsora medusae* is native to eastern North America, and eastern cottonwood is a natural host. This rust can reduce growth by 20 to 35 percent as a result of premature defoliation during the growing season (Chastagner and Hudak 1999, Ostry and others 1988). Early defoliation also predisposes the tree to damage from other diseases and environmental stresses, and mortality has been observed in nursery stool beds from severe infections during the preceding fall (Newcombe and others 1994).

A major gene has been discovered by Newcombe and others (1996) for resistance to *Melampsora medusae*. However, there are different races of the pathogen, inheritance of resistance varies by race (suggesting that more than one gene may be involved), and environmental factors modify the degree of susceptibility (Prakash and Heather 1986). Those authors recommend that clones be tested over time and space to sample rust races and environmental factors, thereby ensuring “durability” of resistance.

Since eastern cottonwood is a natural host of *Melampsora medusae* and is also one of the parents in many of the poplar hybrids used throughout the world, information is needed for the species on how leaf rust resistance varies across the range of the natural population. That information will help in traditional breeding programs and in the search for additional resistance genes. A short-term nursery study at two sites in Mississippi suggested that southern sources were more resistant than northern sources in the Southern United States (Friend 1981). The present paper reports results from a more intensive sample of the natural population in the Southeast, and it provides assessment of resistance for 3 years over four widely distributed test sites in the region. The objective is to determine if specific geographic areas can be identified where the natural population has high resistance.

## PROCEDURES

Open-pollinated seeds were collected by Mississippi State University and industrial cooperators from up to 10 eastern cottonwood trees per stand in 72 natural stands throughout the southeastern United States (fig. 1) (Land and others 2001). This region was subdivided into three subregions: the Southeast Atlantic (SA) from North Carolina to eastern Georgia, the East Gulf (EG) from northwest Florida and west Georgia through the southern 80 percent of Alabama into eastern Mississippi, and the East Central (EC) from Tennessee and the northern 20 percent of Alabama to western Kentucky and southeast Missouri. Each stand's origin was identified by latitude, longitude, river, and either floodplain (bottomland) or terrace/upland (upland) topographic position. Seeds were

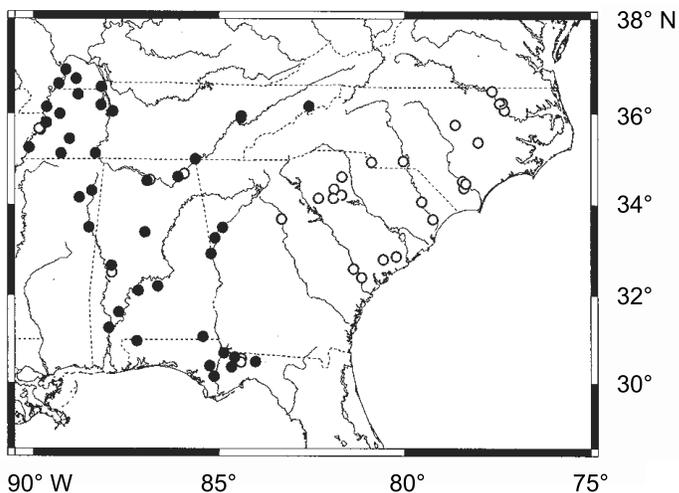


Figure 1—Map of 72 natural *Populus deltoides* stands from which seeds were collected to produce seedling cuttings for a southwide clonal trial. Stands in North Carolina, South Carolina, and east Georgia (open circles) represent the SA subregion; stands in west Georgia, southern 80 percent of Alabama, northwest Florida, and east Mississippi (filled and open circles) indicate the EG subregion; and stands in Tennessee, west Kentucky, and north 20 percent of Alabama (filled and open circles) depict the EC subregion.

<sup>1</sup> Professor and Graduate Student, respectively, Mississippi State University, Department of Forestry, Mississippi State, MS 39762.

germinated at the University of Florida, and container-grown rooted cuttings were produced from seedlings for 64 stands.

Cuttings from stool beds of 12 “check” clones were rooted in containers at the same time and place as the seedling cuttings. Eleven of these check clones came from former tree improvement research by the United States Forest Service at Stoneville, MS, and their origins were in the lower Mississippi River Valley from Memphis, TN, to Baton Rouge, LA. Clone identities from the delta of northwest Mississippi were 110226, 110531, 110804, ST-121, 111101, and ST-71; clones from southwest Mississippi were 111733, 112127, 112620, and 112830; and the clone from near Baton Rouge, LA was 3324. The other check clone (S7C1) came from the Brazos River bottom near College Station, TX, and was selected by the Western Gulf Tree Improvement Program.

The rooted cuttings from seedlings and checks were planted at four locations during the period from June 1999 to March 2000, and the trees were scored for severity of *Melampsora* leaf rust infection in both September and October of each of the 3 years 2000-2002. The four test locations were a drip-irrigated upland field in northwest Florida (FL1), a drip-irrigated field on a Mississippi River alluvial site in southeast Missouri (MO1), a recently-harvested hardwood plantation site on the Tombigbee River floodplain in southwest Alabama (AL1), and a recently-harvested hardwood plantation site on a terrace of the Roanoke River in northeast North Carolina (NC1). The field design at each test location was a randomized complete block with three replications. Seedling clones were arranged by origin in subregion split plots within each replication. The 12 checks were placed in each subregion split plot. Each clone (seedling clones and check clones) was represented by a single-tree plot in each replication. Severity of leaf rust infection was scored as follows: 1 = no rust (no yellow urediospores on any leaves); 2 = little rust (isolated

spores on a few leaves, but no “crinkled” leaves); 3 = medium rust (many spores, some coalesced necrotic spots, often has “crinkled” leaves and some defoliation in interior of crown); and 4 = heavy rust (most of crown defoliated, with only young leaves at branch tips). Mean score for the 3 years of observations was calculated for each tree, and stand plot means were used in analyses.

A data set with the checks excluded was used for (1) regression of leaf rust severity on latitude and longitude of stand origin and (2) analysis of variance for effects of subregions, differences between two river groups within subregions, and differences between the bottomland and upland origins within subregions on rust severity. PROC GLM in SAS (1999) provided the analyses. A mixed-effects model for the analysis of variance was assumed, with test locations, subregions, river groups, and topographic positions treated as fixed effects. A similar analysis of variance was conducted on a data set that included the checks, and the difference in “selection types” (checks versus wild stands) within subregions was treated as a fixed effect. Tukey-Kramer tests of ranked means were conducted to determine which fixed effects were significantly different.

## RESULTS AND DISCUSSION

### Effects of Latitude and Longitude of Stand Origin

Rust severity increased as origin of stand moved north and west within the southeast region, with latitude having the greatest influence (figs. 2 and 3). The latitude effect was significant at the Missouri, Alabama, and Florida locations, but the longitude effect was only significant at the Alabama location (table 1). These stand-origin effects were greatest at the Missouri site, where the rust severity was greatest. Friend (1981) also found an increase in susceptibility as latitude of stand origin increased in the south, but his study only involved

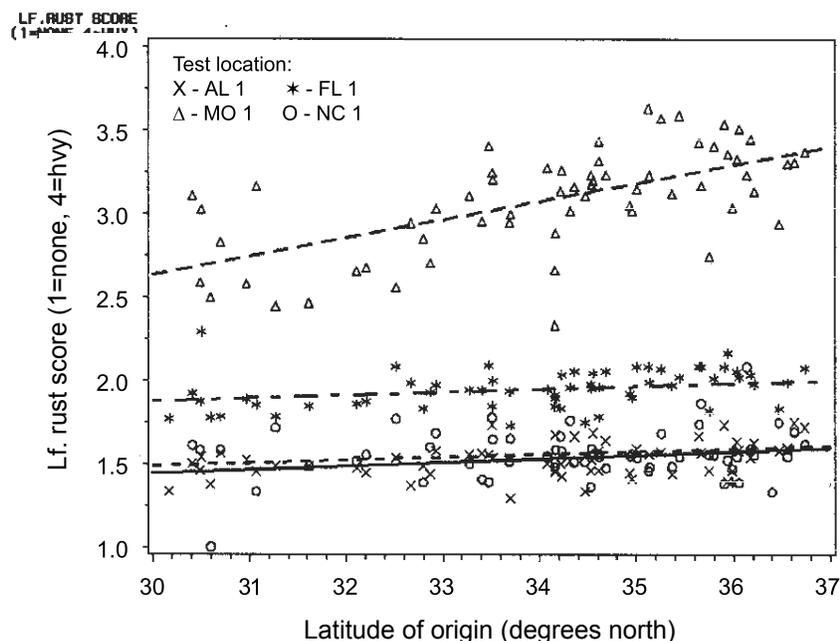


Figure 2—Effect of latitude of seed origin on *Melampsora* leaf rust infection in a 3-year-old southwide cottonwood clonal trial planted at four locations. Plotted points are stand averages at a location. A stand average is the mean of all clones derived from that stand. Higher leaf rust scores represent greater infection.

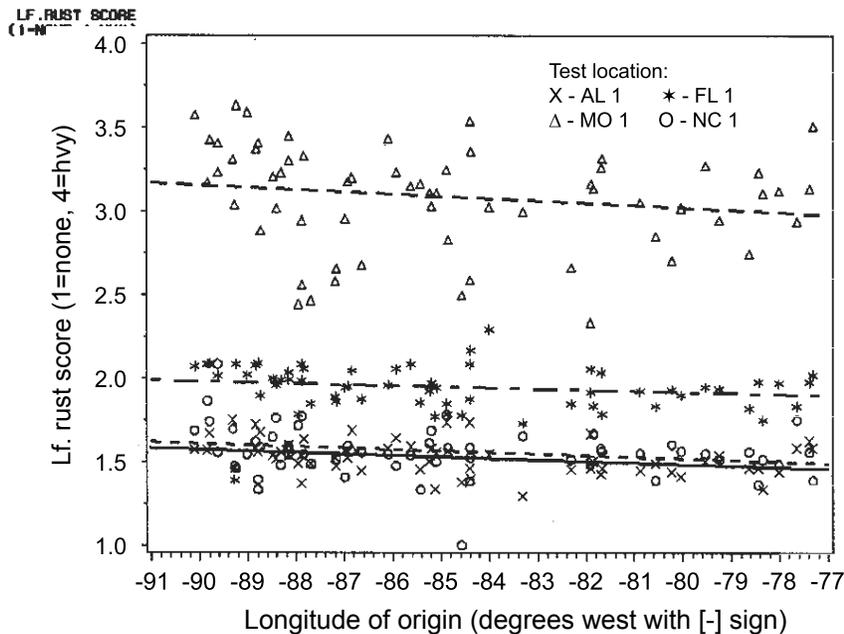


Figure 3—Effect of longitude of seed origin on *Melampsora* leaf rust infection in a 3-year-old southwide cottonwood clonal trial planted at four locations. Plotted points are stand averages at a location.

**Table 1—Regression of *Melampsora* leaf rust score on latitude and longitude of seed origin (stand) at each of four test locations in a 3-year-old southwide clonal trial of *Populus deltoides*; higher scores represent greater leaf rust infection; test locations are in Choctaw County, AL (AL1), Gadsden County, FL (FL1), Scott County, MO (MO1), and Bertie County, NC (NC1)**

Test location	Number of stands	Regression equation <sup>a</sup>	R-Square	Parameter	Pr> t  <sup>b</sup>
AL1	59	RUST = .7784 + .0221 LAT	0.154	LAT	0.002*
		RUST = .7732 + .0089 LONG	0.105	LONG	0.012*
		RUST = -.1284 + .0239 LAT + .0100 LONG	0.285	LAT & LONG	0.001**
FL1	61	RUST = 1.3308 + .0180 LAT	0.059	LAT	0.059
		RUST = 1.3911 + .0065 LONG	0.034	LONG	0.155
		RUST = .6921 + .0190 LAT + .0071 LONG	0.100	LAT & LONG	0.044*
MO1	62	RUST = -.6687 + .1100 LAT	0.395	LAT	0.001**
		RUST = 1.9269 + .0136 LONG	0.029	LONG	0.189
		RUST = -1.8972 + .1104 LAT + .0143 LONG	0.427	LAT & LONG	0.001**
NC1	60	RUST = .9676 + .0172 LAT	0.038	LAT	0.136
		RUST = .7857 + .0091 LONG	0.056	LONG	0.068
		RUST = .2325 + .0166 LAT + .0089 LONG	0.092	LAT & LONG	0.142

<sup>a</sup> RUST = average rust score for all clones from stand; LAT=latitude and LONG=longitude of stand.

<sup>b</sup> Asterisks denote level of significance: \* = 0.001 < Pr < 0.050, \*\* = Pr ≤ 0.001.

two planting sites in Mississippi. The combined results from Friend's study and the current study indicate that clones from more southerly origins have more rust resistance than clones from further north within this southeast region.

### Effects of Test Location

The Missouri location had the most severe leaf rust infection, followed by the Florida location (tables 2 and 3). The North Carolina and Alabama locations had the lowest incidence of

infection and were not significantly different from each other. The Missouri and Florida locations had drip irrigation, while the Alabama and North Carolina locations did not. Perhaps the *Melampsora* urediospores are hindered in germination and leaf infection by low humidity, dry leaf surfaces in the early morning, and semi-senescent leaves during late summer on the non-irrigated sites. The high frequency of cottonwood trees along the Mississippi River in the vicinity of the Missouri location (and not at the other locations) may also allow a buildup

**Table 2—Analysis of variance for effects<sup>a</sup> of test locations, subregions of origin, classification groups within subregions, and stands on 3-year average *Melampsora* rust score for a southwide trial of *Populus deltoids***

Source of variation	DF	Mean square #	F-test MS#/#	Classification groups					
				Rivers		Bottom-vs-upland		Check-vs-wild	
				MS	F-test <sup>b</sup>	MS	F-test	MS	F-test <sup>b</sup>
Locations [=L]	3	#9	9/5	75.949	1315.00**	77.452	1330.00**	83.617	751.00**
Reps in L [=R(L)]	8	#8	8/5	0.056	0.96ns	0.052	0.90ns	0.093	0.83ns
Subregions [=S]	2	#7	(7+1) / (5+3)	1.216	8.58**	1.437	9.96**	0.572	2.31ns
S x L	6	#6	6/5	0.448	7.75**	0.502	8.62**	0.249	2.24ns
S x R(L)	16	#5	5/1	0.058	1.97*	0.058	2.01*	0.111	2.93**
Classif.in S [=C(S)]	3	#4	4/3	0.045	0.51ns	0.094	1.06ns	0.818	5.35*
Stands in C in S	58	#3	3/1	0.087	2.99**	0.089	3.07**	0.153	4.03**
L x C(S)	9	#2	2/1	0.072	2.48*	0.088	3.03**	0.264	6.97**
Pool error	517	#1		0.029		0.029		0.038	

<sup>a</sup> A mixed-effects model is used, where “Stands” and “Reps” are random effects and “Locations”, “Subregions”, and “Classification Groups” are fixed effects.

<sup>b</sup> Asterisks denote level of significance: \* = 0.010 < Pr < 0.050, \*\* = Pr ≤ 0.010, and ns = not significant (Pr > 0.050).

**Table 3—Tests<sup>a</sup> of differences among locations of trials, subregions of origin, and location-by-subregion combinations for mean leaf rust scores of cottonwood cuttings in clonal trials in the southeastern United States**

Subregion of origin	Location of trial				Subregion differences
	AL1	NC1	FL1	MO1	
EC	1.59a	1.61a	2.01b	3.33d	2.14B
SA	1.48a	1.53a	1.92b	3.05c	2.00A
EG	1.52a	1.56a	1.91b	2.89c	1.97A
Location differences =	1.53X	1.57X	1.95Y	3.09Z	Overall = 2.08

<sup>a</sup> Tukey-Kramer tests were used. Means followed by the same letter and case were not significantly different at the 5 percent probability level.

of the rust population. If these hypotheses are correct, the greatest need for rust-resistant clones will be on irrigated sites in areas where cottonwood is prevalent in natural stands or other plantations. Conifers (pines, larches, or hemlocks) serve as alternate hosts for the disease and need to be nearby for rust infections to occur early in the year (Ostry and others 1988).

### Subregion and Location-by-Subregion Effects

Stands from the East Central (EC) subregion had significantly more infection than stands from the Southeast Atlantic (SA) and East Gulf (EG) subregions (tables 2 and 3). There was a significant location-by-subregion effect for the data that excluded check clones (“Rivers” and “Bottom vs Upland” classification groups in table 2). The interaction was caused by a change in scale rather than a change in rank. The subregion means had similar ranks at all locations, but the differences were significant only at the Missouri location. The differences among subregions only become important when rust incidence is high. The practical application of this result is to avoid use of clones from natural stands in the EC subregion for plantings anywhere in the southeast until those clones have been tested for *Melampsora* resistance at a high-hazard location.

### Effects of Rivers and Topographic Positions within Subregions

Stands from different river groups within subregions did not differ in rust susceptibility, nor did stands from different topographic positions within subregions (table 2). However, there were differences, primarily due to subregion effects, when the group-within-subregion mean rust scores for all subregions were compared (table 4). Combined results over all test locations indicated that the stands from rivers in the EG and southern half of the SA subregions had more resistance than stands from rivers in the EC subregion. River origins in the northern half of the SA subregion were not different from either the EG or EC rivers. Stands from the bottom topographic position in the EG subregion exhibited the greatest resistance, and stands from the bottom position in the EC subregion had the least.

There were significant location-by-group-within-subregion effects for both rivers and topographic positions (table 2). These interactions with locations were due to scale effects, because the differences were only significant at the Missouri location (table 4). Even then, they were only different between subregions (not within subregions). The origin with least rust at the Missouri location came from bottoms along the Tombigbee River in the EG subregion, and the origin with greatest rust at that location came from uplands along the central Mississippi River in the EC subregion.

### Selected Checks versus Natural Stands

Overall, the check clones from the lower Mississippi River Valley and east Texas differed significantly from unselected stands within subregions for *Melampsora* infection (table 2). Specifically, however, the checks had significantly less rust than only the unselected stands from the EC subregion (combined results over all four test locations in right column of table 4). Checks and unselected stands did not differ for the SA and EG subregions.

There was an interaction with test locations (tables 2 and 4). The checks had less leaf rust than the unselected EC stands at all but the North Carolina location. However, they were better than the SA stands at only the Missouri location, and they were not better than the EG stands at any location.

**Table 4—Tests<sup>a</sup> of differences among river origins, topographic origins, and selection types (selected checks vs. unselected wild types) for mean leaf rust scores of cottonwood cuttings in clonal trials at four locations in the southeastern United States**

Sub-region	Classification types within subregion	Location of trial				Class type differences
		AL1	NC1	FL1	MO1	
<i>River Groups</i>						
EC	Central MS River	1.60ab	1.68b	1.98c	3.35f	2.15B
	Tennessee River	1.57ab	1.55ab	2.04c	3.31f	2.12B
SA	NC & n.SC rivers	1.50ab	1.52ab	1.94c	3.11e	2.02AB
	s.SC&ne.GA rivers	1.46a	1.54ab	1.90c	3.00e	1.98A
EG	Chatahoochee River	1.51ab	1.53ab	1.90c	2.96de	1.97A
	Tombigbee River	1.52ab	1.58ab	1.93c	2.81d	1.96A
<i>Topographic Position</i>						
EC	Bottom (floodplain)	1.63g	1.65g	2.09i	3.31m	2.17I
	Upland	1.54g	1.57g	1.91hi	3.36m	2.11HI
SA	Bottom	1.50g	1.51g	1.93hi	3.13l	2.02GH
	Upland	1.46g	1.53g	1.91hi	2.99kl	1.97GH
EG	Bottom	1.50g	1.60g	1.90h	2.79j	1.95G
	Upland	1.53g	1.50g	1.93hi	2.94k	1.98GH
<i>Selection Type</i>						
EC	Selected LM checks	1.40n	1.65opq	1.77pqr	2.92tu	1.94N
	Unselected EC wild	1.59op	1.63opq	2.03s	3.34v	2.15O
SA	Selected LM checks	1.45no	1.62opq	1.86qrs	2.87t	1.95N
	Unselected SA wild	1.4 no	1.53nop	1.92rs	3.06u	1.99N
EG	Selected LM checks	1.45no	1.56nop	1.81pqrs	2.79t	1.90N
	Unselected EG wild	1.52no	1.55nop	1.91rs	2.87t	1.96N

<sup>a</sup> Tukey-Kramer tests were used. Means followed by same letter and case were not significantly different at the 5 percent probability level.

In summary, superiority of the check clones for *Melampsora* resistance appears to be a result of the latitude-of-origin effect more than any selection effect in the former tree improvement programs. Equally high resistance may be found in natural stands from the EG and southern SA subregions.

### Best Stands and Check Clones for Resistance

Variation among stands within river groups, within topographic positions, and within checks and wild stands was highly significant for leaf-rust severity (table 2). This result indicates that the most important gains in *Melampsora* resistance will come from clone selection within the checks and from stand selection (regardless of river group or topographic position) within the EG and southern SA subregions. Such selection can only be accomplished after clonal testing for rust resistance at multiple locations over multiple years.

The best nine clones or stands for *Melampsora* resistance in the present study included four check clones, two natural stands from the southern part of the EG subregion, and three natural stands from the southern part of the SA subregion (table 5). These were chosen because they performed very well at two or more test locations. Several general observations can be made: (1) No natural stands from the EC subregion were selected in the top nine, and none of the selections came from latitudes north of the southernmost EC stand. (2) The selected checks came from southwest Mississippi (south of the delta region in Mississippi) and from east Texas. (3) The first four stands or clones (ranks #1 through #4)

exhibited consistently high resistance over most locations. (4) The next three stands or clones (ranks #5 through #7) had high resistance at the two southern locations (AL1 and FL1), but only average resistance at the two northern locations (NC1 and MO1). (5) The last two stands (ranks #8 and #9) indicated high resistance at the northernmost location (MO1) and were in the top third at the other locations. (6) There was no pattern of many selected stands coming from one river system or topographic position within the EG and SA subregions, but the selections did come from the southern halves of those two subregions.

### SUMMARY AND CONCLUSIONS

*Melampsora medusae* leaf rust resistance declined as stand origin moved north and west in the southeastern region from the Atlantic coast to the Mississippi River. The greatest effect was latitude. This southeast region was subdivided into Southeast Atlantic (SA), East Gulf (EG), and East Central (EC) subregions, and a significantly greater resistance was observed for stands from the EG and SA subregions as a reflection of the latitude-of-origin effect. River groups and topographic positions (bottomland and upland) of stand origins within subregions did not exhibit significant differences in rust resistance. However, river-group-by-subregion and topographic-position-by-subregion means for leaf rust score were different across all subregions. Greatest resistance was observed for rivers in the EG and southern SA subregions. Bottomland stands from the EG subregion had the least rust, and bottomland stands from the EC subregion had the most.

**Table 5—Stands and check clones with highest *Melampsora* resistance (lowest leaf score) over all locations, based on average of ranks at each location**

Rank	Stand or clone <sup>a</sup>	Geographic origin			Topographic position	Test location	At-location	
		State	County	River			Rust score	Rank
#1	CK-112830	MS	Wilkinson	Lower Miss.	Bottom	AL1	1.32	3
						FL1	—	—
						MO1	2.33	1
						NC1	1.38	5
#2	CK-111733	MS	Warren	Lower Miss.	Bottom	AL1	1.38	10
						FL1	1.65	3
						MO1	2.49	7
						NC1	1.40	10
#3	EG-1U1	FL	Gadsden	Ochlockonee	Upland	AL1	1.38	11
						FL1	1.78	10
						MO1	2.50	8
						NC1	1.00	1
#4	CK-S7C1	TX	Brazos	Brazos	Bottom	AL1	1.31	2
						FL1	1.64	2
						MO1	2.43	3
						NC1	1.79	69
#5	SA-5U2	NC	Bladen	Cape Fear	Upland	AL1	1.33	5
						FL1	1.75	7
						MO1	3.11	37
						NC1	1.51	24
#6	CK-112127	MS	Claiborne	Lower Miss.	Bottom	AL1	1.35	7
						FL1	1.75	6
						MO1	2.83	18
						NC1	1.58	46
#7	SA-7B1	GA	Greene	Oconee	Bottom	AL1	1.29	1
						FL1	1.73	5
						MO1	3.00	26
						NC1	1.65	56
#8	SA-4B1	SC	Greenwood	Saluda	Bottom	AL1	1.46	23
						FL1	1.92	29
						MO1	2.33	2
						NC1	1.48	18
#9	EG-2U6	AL	Clarke	Tombigbee	Upland	AL1	1.49	32
						FL1	1.85	18
						MO1	2.47	5
						NC1	1.49	20

<sup>a</sup> First two letters = subregion (EG, SA) or check (CK).

The tests reported here were planted at four locations: North Carolina, Florida, Alabama, and Missouri. The Missouri location exhibited the greatest rust, and the Florida location was next. Both of these locations had drip irrigation, so greater moisture and humidity on irrigated sites may be important in rust incidence. The other two locations were not irrigated and had the lowest amount of rust. There were interactions between origins and test locations for degree of resistance, but these interactions were usually a result of scale changes (changes in range and significance of differences from one location to another) rather than changes in ranks of origins. The Missouri location with its highest rust incidence provided the greatest number of significant differences among origins. Differences were often not significant at other locations, but ranks of means were similar to the Missouri location.

The selected check clones from the lower Mississippi River Valley and east Texas had less rust than the unselected stands from the EC subregion, but these checks were not significantly different from the stands that came from the EG and southern SA subregions. Thus, the improved resistance of the checks is apparently a result of the more southerly latitude-of-origin effect than the effect of selection in the original tree improvement program.

Significant variation among stands within origin classifications and among clones within checks was obtained for rust score, so large gains in resistance can be obtained from selection in clonal tests. The best nine clones or stands in the present study consisted of four check clones, three stands from the southern half of the SA subregion, and two stands from the southern half of the EG subregion. The four checks came from the southwestern half of Mississippi and east Texas.

There was no pattern indicating a majority of the best stands came from one river or topographic position. Additional gains may be possible from clone selection within the best stands.

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### LITERATURE CITED

Chastagner, G.A.; Hudak, J.M. 1999. Crop profiles for hybrid poplars in Washington & Oregon. Publication number MISC0355E. Pullman, WA: Washington State University Cooperative Extension. 12 p.

- Friend, M.M. 1981. Genetic variation in juvenile traits of eastern cottonwood from the Southern United States. Mississippi State, MS: Mississippi State University. 117 p. MS thesis.
- Land, S.B., Jr.; Stine, M.; Ma, X. [and others]. 2001. A tree improvement program for eastern cottonwood in the Southeastern United States. In: Dean, J. F.D., ed. Proceedings of the 26<sup>th</sup> biennial southern forest tree improvement conference. Sponsored publication No. 28; Southern Forest Tree Improvement Committee. Athens, GA: University of Georgia, Center for Continuing Education: 84-93.
- Newcombe, G.; Bradshaw, H.D., Jr.; Chastagner, G.A. [and others]. 1996. A major gene for resistance to *Melampsora medusae* f.sp. *deltoidae* in a hybrid poplar pedigree. *Phytopathology*. 86: 87-94.
- Newcombe, G.; Chastagner, G.A.; Schuette, W. [and others]. 1994. Mortality among hybrid poplar clones in a stool bed following leaf rust caused by *Melampsora medusae* f.sp. *deltoidae*. *Canadian Journal of Forest Research*. 24: 1984-1987.
- Ostry, M.E.; Wilson, L.F.; McNabb, H.S., Jr. [and others]. 1988. A guide to insect, disease, and animal pests of poplars. Agric. Handb. 677. Washington, DC: U.S. Department of Agriculture, Forest Service. 118 p.
- Prakash, C.S.; Heather, W.A. 1986. Inheritance of resistance to races of *Melampsora medusae* in *Populus deltoides*. *Silvae Genetica*. 35: 74-77.
- SAS Institute Inc. 1999. SAS/STAT User's Guide, Version 8. Cary, NC: SAS Institute Inc. 3884 p.

# TIP MOTH CONTROL AND LOBLOLLY PINE GROWTH IN INTENSIVE PINE CULTURE: FOUR YEAR RESULTS

David L. Kulhavy, Jimmie L. Yeiser, and L. Allen Smith<sup>1</sup>

**Abstract**—Twenty-two treatments replicated four times were applied to planted loblolly pine, *Pinus taeda* L., on bedded industrial forest land in east Texas for measurement of growth impact of Nantucket pine tip moth (NPTM), *Rhyacionia frustrana* Comstock, and effects on pine growth over 2 years. Treatments were combinations of Velpar®, Oust®, Escort®, and Arsenal® herbicides; and diammonium phosphate (DAP) fertilizer with treatments in 2000, in 2001, or in both years. Ten of the treatments were treated with Mimic timed with pheromone traps to reduce NPTM infestations. NPTM was controlled with the Mimic, and there was a small but significant increase in the loblolly pine growth at the end of the second growing season. However, the increase was minimal by the end of the fourth growing season. The best growth of pines with the most intensive treatments was equal with and without NPTM control. NPTM control made a difference on intermediate treatments.

## INTRODUCTION

The Nantucket pine tip moth (NPTM), *Rhyacionia frustrana* (Comstock), is an important pine regeneration insect in the eastern and southern United States (Berisford 1987), with larval feeding causing significant damage particularly in areas of forest regeneration (Yates and others 1981). Southeastern industrial forestry, to maximize production of wood and fiber, currently emphasizes establishment of large, homogeneous pine plantations that may favor increased damage by NPTM following vegetation control treatments (Ross and Berisford 1990). NPTM infestation rates tended to increase as site preparation intensity increased and levels of competing vegetation and overstory decrease (Berisford and Kulman 1967, Hertel and Benjamin 1977, Hood and others 1988, Lantagne and Burger 1988, Nowak and Berisford 2000, White and others 1984, Zutter and others 1986). Intensive forest management practices that improve tree growth, such as weed control and fertilization, have been shown to exacerbate NPTM damage and decrease volume growth (Cade and Hedden 1987, Fettig and others 2000, Ross and Berisford 1990, Ross and others 1990, Sun and others 1999). However, McCravy and Berisford (2001) showed significantly lower NPTM damage in plots with vegetation control than in untreated plots; and Nowak and others (2003) found NPTM populations to be unstable following applications of fertilizers and herbicides. Miller and Stephen (1983) indicated competing herbaceous and woody vegetation provide food and shelter for NPTM predators and parasites.

Pritchert and Smith (1972) observed little change in NPTM infestation on trees fertilized with nitrogen. Application of phosphorus, however, resulted in a significant NPTM reduction, with potassium reducing NPTM even further. Tiarks and Haywood (1985), in a study measuring effects of fertilization and vegetation control on loblolly pine, observed uniform NPTM damage across all treatments, but NPTM infestation rates were not quantified. Meeker and Kulhavy (1992) found a negative correlation between NPTM levels in soil and foliage and NPTM infestation rates, with increasing levels of phosphorus associated with decreasing infestation rates.

Herbicides, including Sulfometuron methyl (Oust®) and Hexazinone (Velpar®-L), are commonly used to reduce competing

herbaceous vegetation in loblolly pine plantations (Cantrell and others 1985, Creighton and others 1986, Kulhavy and others 2004, Michael 1985, Yeiser and Boyd 1989, Yeiser and Rhodenbaugh 1994). Use of herbicides for vegetation management continues to increase (Dubois and others 1999) along with growth (Glover and others 1994); forest fertilization has increased, with 200,000 acres of southern pines fertilized at planting. The resulting population of NPTM following herbicide applications and fertilizers, especially addition of phosphorus, warrants additional investigation. Ross and others (1990) documented that percent infested trees and percent infested shoot tips were significantly higher in banded and broadcast-treated plots than in check plots during the third NPTM generation.

## METHODS

Twenty-two six tree by six tree plots with a two row buffer were established on an Upper Coastal Plain industrial forest site with a fine sandy silt loam near Diboll, Angelina County, TX, in early 2000. The study was a complete randomized block with 22 treatments replicated 4 times. The area was site prepared with pre-emergent herbicides and deep plowed with loblolly pine planted on the ridges.

The 22 treatments are shown in table 1. Mimic was applied five times each season, timed to first instar larvae with pheromone traps. Mimic® 2LV Insecticide (active ingredient tebufenozide) (Rohm and Haas, ownership of the product changed to Dow AgroSciences LLC, June 1, 2001) was applied following label instructions on a per acre basis timed with pheromone traps baited with synthetic NPTM lures. Dr. Don Grosman, Forest Pest Management, Texas Forest Service, Lufkin, TX, provided NPTM trap catch data and advice on Mimic timing for application. NPTM infestations were counted on a whole tree basis after the third generation in 2000, at the end of the season (fifth generation overwintering in the tips), after the third generation in 2002, and at the end of the season (fifth generation). Infestations were counted on the (1) terminal (infested or not infested), (2) top whorl except for the top terminal, (3) top half of the tree, and (4) bottom half of the tree (Kulhavy and others 2004). Each tip was examined as

<sup>1</sup> Regents Professor and T. L. L. Temple Professor, respectively, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, TX 75962; and Southern Pine Beetle Specialist, Texas Forest Service, Forest Pest Control, Lufkin, TX 75901.

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**Table 1—Herbicide and fertilizer treatments, 2000-2001**

2000		2001	
Herbicide <sup>a</sup>	Fertilizer	Herbicide <sup>a</sup>	Fertilizer
	<i>lbs. per acre<sup>b</sup></i>		<i>lbs. per acre<sup>b</sup></i>
VO*			
VO*	125		
VO*	250		
VO/AO*	125		
VO/AO*	250		
VO*		AO	
VO*	125	AO	125
VO*	250	AO	
VO/AO		AO	
VO/AO*	125	AO	125
VO/AO*	250	AO	
CHECK			

<sup>a</sup> VO = Velpar (10.7 oz) + Oust (2 oz.); Escort® = ¾ oz.; AO = Arsenal (4 oz.) + Oust (2 oz.).

<sup>b</sup> DAP = diammonium phosphate; Mimic = treatments replicated with and without Mimic; five applications of Mimic each season, 2000 and 2001 timed to the first instar larvae of the Nantucket pine tip moth with pheromone traps.

infested or uninfested. A total tree count was taken for the site for each of the treatments over the replications. Data were analyzed with SAS with an ANOVA using New Duncan's Multiple Range Test at p=0.05 (SAS 1988).

**RESULTS AND DISCUSSION**

There was no difference in survival for year 4 between the Mimic and non-Mimic treatments, with 85.4 percent survival for both treatments. There were no differences in survival among any treatments. There was 86.3 percent survival of Mimic and non-Mimic treatments in year 2.

Height in feet was not significantly greater for Mimic treatments in year 4; height averaged 19.32 feet for Mimic treatments and 18.32 feet for non-Mimic treatments. Among non-Mimic treatments, heights were equal between VO 250 (year 1) + AO (year 2), 18.99 feet; VO 125 (year 1) + AO 125 (year 2), 19.0 feet; VO/AO 125 (year 1) + AO 125 (year 2), 19.21 feet; and VO/AO 250 (year 1) and AO (year 2), 19.46 feet. These treatments were significantly greater than VO (year 1), 17.05 feet; and both were greater than the check (16.03 feet). For Mimic treatments, VO 125 (year 1) + AO 125 (year 2) was 19.85 feet, and VO/AO 250 (year 1) and AO (year 2) were 20.20 feet. Both were greater than VO (year 1, 18.01) and the check (16.03 feet). The VO was greater than the check for Mimic treatments.

Mimic-treated plots combined were significantly greater in year 4, 24.1 cubic feet volume compared to 21.3 for non-Mimic treatments. The only difference between treatments occurred between Velpar-Oust (year 1 treatment) + Arsenal-Oust (year 2 treatment) with the Mimic-treated plots with 24.0 cubic foot volume and the non-Mimic treatments with 20.5 cubic foot volume (table 2). Ground line diameter (inches) was not significantly greater in Mimic treatments by year 4 (4.7 inches Mimic, 4.5 inches non-Mimic).

**Table 2—Volume Index (cubic feet) for loblolly pine (year 4), following control of Nantucket pine tip moth with Mimic, years 1 and 2**

Treatments <sup>a</sup>				Volume index	
2000		2001		Mimic No	Mimic Yes
Herbicide	Fertilizer	Herbicide	Fertilizer		
				- - cubic ft <sup>b</sup> - -	
VO				16.1	19.6
VO	125			20.4	20.9
VO	250			21.7	21.4
VO/AO	125			23.1	23.8
VO/AO	250			21.7	23.2
VO		AO		20.5a	24.0b
VO	125	AO	125	23.8	28.3
VO	250	AO		23.9	28.3
VO/AO		AO		20.9	
VO/AO	125	AO	125	25.2	26.6
VO/AO	250	AO		25.6	26.5
CHECK				13.2	
Mean				21.3a	24.1b

<sup>a</sup> Refer to table 1 for treatments.

<sup>b</sup> Means with letters are significantly different between columns, p < 0.05; means without letters are not significantly different.

At the end of year 2, for non-Mimic treatments, NPTM infestations were significantly higher on the check plots [(10.46 infested tips) versus VO + 125 pounds DAP (9.7 infested tips); VO + AO + 125 pounds DAP (2000) (9.5 infested tips); and VO + AO (2000) and AO (2001) (9.32 infested tips)] compared to all other treatments. The lowest infestations were on VO + 250 pounds DAP (2000) and AO (2001) (5.19 infested tips) and VO (2000) and AO (2001) (5.65 infested tips). Intermediate infestations ranged from 7.07 to 8.42 infested tips. NPTM infestations were not taken in year 4 due to the height of the sample trees.

During a year of low to moderate NPTM infestations (2001), the most intensive cultural treatments had similar volume growth with or without Mimic for NPTM control. For Mimic applications, NPTM infestations were intermediate at the end of year 2 with intermediate treatments [VO + 125 pounds DAP (2000) and AO + 125 pounds DAP (2001); and VO + 250 pounds DAP (2000) and AO (2001)] (Kulhavy and others 2004).

**SUMMARY**

For 2001, a year of low to moderate NPTM infestations, the most intensive cultural treatments showed no difference in cubic feet volume growth with or without Mimic. For intermediate cultural treatments, Mimic applications had a significant increase in tree volume. The timing of spraying coupled with the cost of the insecticide and the labor for application need to be considered in long-term intensive management of industrial pine plantations. At the end of year 4, the only differences were in overall volume growth between Mimic and non-Mimic plots; differences among treatments occurred between VO + 250 pounds DAP (year 1) + AO (year 2). This indicates the use of Mimic, especially for low to moderate treatments, may not have a lasting effect on overall growth. Differences did

occur among treatments, but these mainly reflected the intensity of the site preparation and increased fertilization rather than NPTM control. Timing and frequency of Mimic applications need to be examined in years of high NPTM infestations.

## LITERATURE CITED

- Berisford, C.W. 1987. The Nantucket pine tip moth. Chapter 6. In: Berryman, A.A., ed. Forest insect outbreaks: patterns, causes and management strategies. New York: Plenum Publishing Company: 141-161.
- Berisford, C.W.; Kulman, H.M. 1967. Infestation rates and damage by the Nantucket pine tip moth in six loblolly pine categories. *Forest Science*. 13: 428-438.
- Cade, S.C.; Hedden, R.L. 1987. Growth impact of pine tip moth on loblolly pine plantations in Arkansas. *Southern Journal of Applied Forestry*. 11: 128-133.
- Cantrell, R.L.; Minogue, P.J.; Metcalfe, C.S.; Zutter, B.R. 1985. Silvicultural herbicide uses. In: Cantrell, R.L., ed. A guide to silvicultural herbicide use in the Southeastern United States. Auburn, AL: Auburn University: 1-14.
- Creighton, H.L.; Glover, G.R.; Zutter, B.R. 1986. Loblolly pine growth response to herbaceous weed control—a summary of 15 studies. *Proceedings of the Southern Weed Science Society*. 39: 193.
- Dubois, M.R.; McNabb, K.; Straka, T.J. 1999. Costs and cost trends for forestry practices in the South. *Forest Landowner*. 58(2): 3-8.
- Fettig, C.J.; Dulusky, M.J.; Bersiford, C.W. 2000. Nantucket pine tip moth phenology and timing of insecticide spray applications in seven Southeastern States. Res. Pap. SRS-18. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 21 p.
- Glover, G.R.; Quicke, H.E.; Lauer, D.K. 1994. Economics of early vegetation control in southern pine forests. *Southern Weed Science Proceedings*. 47: 83-84.
- Hertel, G.D.; Benjamin, D.M. 1977. Intensity of site preparation influences on pine webworm and tipmoth infestations on pine seedlings in north central Florida. *Environmental Entomology*. 6: 118-122.
- Hood, W.M.; Hedden, R.L.; Berisford, C.W. 1988. Hazard rating forest sites for pine tip moth, *Rhyacionia* spp. in the upper Piedmont Plateau. *Forest Science*. 34: 1083-1093.
- Kulhavy, D.L.; Yeiser, J.L.; Smith, L.A. 2004. Nantucket pine tip moth control and loblolly pine growth in intensive pine culture: two-year results. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 147-149.
- Lantagne, D.O.; Burger, J.A. 1988. Effects of site preparation intensity on the early growth of loblolly pine (*Pinus taeda* L.) and the incidence of pine tip moth (*Rhyacionia* spp.). *New Forests*. 2: 219-229.
- McCravy, K.M.; Berisford, C.W. 2001. Effects of vegetation control on parasitoids of the Nantucket pine tip moth, *Rhyacionia frustrana* (Lepidoptera: Tortricidae). *Florida Entomologist*. 84: 282-287.
- Meeker, J.R.; Kulhavy, D.L. 1992. Pine tip moth (Lepidoptera: Tortricidae) infestation rates as influenced by site and stand characteristics in loblolly pine plantations in east Texas. *Environmental Entomologist*. 21: 534-541.
- Michael, J.L. 1985. Growth of loblolly pine treated with Hexazinone, sulfometuron methyl and metsulfuron methyl for herbaceous weed control. *Southern Journal of Applied Forestry*. 9: 20-26.
- Miller, F.D., Jr.; Stephen, F.M. 1983. Effects of competing vegetation on Nantucket pine tip moth (Lepidoptera: Tortricidae) populations in loblolly pine plantations in Arkansas. *Environmental Entomology*. 12: 101-105.
- Nowak, J.T.; Berisford, C.W. 2000. Effects of intensive management practices on insect infestation levels and loblolly pine growth. *Journal of Economic Entomology*. 93: 336-341.
- Nowak, J.T.; Harrington, T.B.; Berisford, C.W. 2003. Nantucket pine tip moth development and population dynamics: influence of nitrogen fertilization and vegetation control. *Forest Science*. 49: 731-737.
- Pritchert, W.L.; Smith, W.H. 1972. Fertilizer response in young pine plantations. *Soil Science Society of America Proceedings*. 36(4): 660-663.
- Ross, D.W.; Berisford, C.W. 1990. Nantucket pine tip moth response to water and nutrient status of loblolly pine. *Forest Science*. 36: 719-733.
- Ross, D.W.; Bersiford, C.W.; Godbee, J.F., Jr. 1990. Pine tip moth, *Rhyacionia* spp., response to herbaceous vegetation control in an intensively site-prepared loblolly pine plantation. *Forest Science*. 36: 1105-1118.
- SAS Institute Inc. 1988. SAS/STAT user's guide. Cary, NC: SAS Institute Inc. 1028 p.
- Sun, J.H.; Kulhavy, D.L.; Roques, A. 1999. Effects of fertilizer and herbicide applications on Nantucket pine tip moth infestation (Lep., Tortricidae). *Journal of Applied Entomology*. 124: 191-195.
- Tiarks, A.E.; Haywood, J.D. 1985. *Pinus taeda* L. response to fertilization, herbaceous plant control, and woody plant control. *Forest Ecology and Management*. 14: 103-112.
- White, M.N.; Kulhavy, D.L.; Conner, R.N. 1984. Nantucket pine tip moth (Lepidoptera: Tortricidae) infestation related to site and stand characteristics in Nacogdoches County, Texas. *Environmental Entomology*. 13: 1598-1601.
- Yates, H.O.; Overgaard, N.A.; Koerber, T.W. 1981. Nantucket pine tip moth. Insect and Disease Leaflet 70. Washington, DC: U.S. Department of Agriculture, Forest Service. 7 p.
- Yeiser, J.L.; Boyd, J.M. 1989. Control of competitors yields two-year seedlings response. *Proceedings of the Southern Weed Science Society*. 42: 191-188.
- Yeiser, J.L.; Rhodenbaugh, E.J. 1994. Early survival and growth of loblolly pine seedlings treated with sulfometuron or Hexazinone plus Sulfometuron in southwest Arkansas. *Tree Planters' Notes*. 45: 116-120.
- Zutter, B.R.; Glover, G.R.; Gerstad, D.H. 1986. Effects of herbaceous weed control using herbicides on a young loblolly pine plantation. *Forest Science*. 32: 882-899.

# FREEZE INJURY TO SOUTHERN PINE SEEDLINGS

David B. South<sup>1</sup>

**Abstract**—Freeze injury to roots and shoots of pines is affected by genotype and nursery practices. Local sources of shortleaf pine and Virginia pine that are grown in nurseries in USDA hardiness Zones 6 and 7a are relatively freeze tolerant. However, loblolly pine, slash pine, and longleaf pine seedlings have been injured by a number of freeze events (0 to 24 °F) in hardiness Zone 7b and 8. Some fast-growing half-sib families from the Coastal Plain are more susceptible to freeze than Piedmont sources. Temperatures that produce freeze injury symptoms are lower when pines are acclimated to cold weather than when seedlings have been deacclimated due to several nights of warm nighttime temperatures. Unusually warm temperatures in January of 2004 deacclimated pine seedlings, and this resulted in root injury from a hard freeze (18 °F). Since shoots typically do not show injury (unless they are actively flushing), root injury is often overlooked, and many freeze-injured seedlings died quickly after planting. Since freeze injury symptoms are sometimes difficult to identify, foresters typically offer various reasons (other than a freeze) for the poor seedling performance. This paper reviews some data on freeze events that have occurred over the past century.

## INTRODUCTION

Although transplanted pine seedlings have been injured by a number of freezes in the past, foresters sometimes are unaware when a damaging freeze causes a reduction in out-planting survival. This is because freeze-damaged seedlings sometimes show no obvious signs of root injury (Krasowski and others 1993). Therefore, it is sometimes difficult to pinpoint the exact cause of death once seedlings have dried and turned brown. Injured roots eventually turn orange or brown. This paper presents a review of freeze injury to pine seedlings in the Southern United States.

There are four basic classes of injury that result from low temperatures: root injury, shoot injury, frost-heaving, and winter desiccation. Frost-heaving and winter desiccation will not be discussed in this review. Freeze injury to roots and shoots can be classified into three groups: pre-acclimation, acclimation, and deacclimation. Pre-acclimation injury (PAI) typically occurs during fall or early winter. PAI occurs before

seedlings have been exposed to a sufficient amount of chilling temperatures (< 46.5 °F). Acclimation injury (AI) affects seedlings after they have been acclimatized by short days and low temperatures. Deacclimation injury (DI) occurs after acclimation (or partial acclimation) has occurred and after a sufficient amount of warm nighttime temperatures has stimulated a resumption of cell division. Although DI occurs mainly in early spring (during or just before shoot growth), it sometimes occurs in the winter when unusually warm temperatures have stimulated cambial activity (table 1). The following is a summary of freeze events that have occurred in the Southern United States.

## 1899 FREEZE

February 11 to February 13 brought 2 nights of intense cold to the entire South. Record low temperatures were recorded throughout the United States, many of which still stand today. Temperatures fell to -2 °F in Tallahassee, FL, -16 °F in Minden,

**Table 1—Dates and temperatures resulting in injury to southern pines**

Date	°F	Type of freeze	Type of injury
Nov 5, 1991	19	Preacclimation	Needle burn
Nov. 25, 1950	-8	Preacclimation	Root and needle burn
Dec 12, 1962	-17	Acclimation	Needle burn
Dec 17, 1955	15	Preacclimation	Needle burn
Dec 23, 1989	0	Acclimation	Needle burn
Dec 25, 1983	5	Deacclimation	Root injury
Jan 7, 2004	18	Deacclimation	Root injury
Jan 11, 1977	-15	Acclimation	Needle burn
Jan 19, 1994	7	Acclimation	Root injury
Jan 19, 1957	20	Deacclimation	Needle burn
Jan 19, 1996	16	Acclimation	Root injury
Jan 21, 1985	0	Acclimation	Needle burn
Feb 5, 1996	15	Acclimation	Root (longleaf containers)
March 9, 1932	20	Deacclimation	Frost ring
April 7, 1938	24	Deacclimation	Frost ring

<sup>1</sup> Professor, School of Forestry and Wildlife Sciences and Alabama Agricultural Experiment Station, Auburn University, Auburn, AL 36849-5418.

LA (both are record lows for the State), and  $-4^{\circ}\text{F}$  in Montgomery, AL. Snow may have helped protect roots from the  $-10^{\circ}\text{F}$  temperature at Biltmore in North Carolina.

### 1932 FREEZE

February of 1932 was warmer than any previously recorded in Mississippi. The mean monthly temperatures were almost  $10^{\circ}\text{F}$  warmer than normal and longleaf pine (*Pinus palustris* Mill.) began diameter growth. Temperatures at Magnolia, MS, were above  $80^{\circ}\text{F}$  on March 1 and 2, but a sudden DI freeze occurred a week later. Nighttime temperatures dropped from about  $62^{\circ}\text{F}$  on March 3 to  $20^{\circ}\text{F}$  on March 9 (fig. 1). This caused frost rings to form on longleaf pine (Stone 1940).

### 1938 FREEZE

During March at Lubbock, TX, daytime temperatures were greater than  $70^{\circ}\text{F}$  for 22 days. On April 4 and 5, temperatures exceeded  $84^{\circ}\text{F}$ . A sudden DI freeze occurred a few days later when temperatures fell to  $24^{\circ}\text{F}$  on April 7 (also  $23^{\circ}\text{F}$  on April 8). This freeze injured at least 16 different woody species (Glock 1951) including loblolly pine (*Pinus taeda* L.). This freeze event disrupted newly formed cells in the cambium and resulted in frost rings.

### 1950 FREEZE

There was a warm fall in Illinois where temperatures were in the 80s during October. There was a sudden PAI freeze on November 11, and the temperature dropped to  $17^{\circ}\text{F}$  (fig. 2). A second freeze event occurred on November 25 when temperatures at the Union State Tree Nursery dropped to  $-8^{\circ}\text{F}$  (Minckler 1951). "Most of the 1-0 loblolly pine from eastern South Carolina seed sources were killed. The 1-0 loblolly stock from Maryland and Arkansas sources, on the other hand, showed a slight browning of the top needles but negligible killing. It was striking to see the beds of seedlings from the different seed sources side by side in the nursery. They presented a strong argument for recognizing the importance of seed source in forestry practices" (Minckler 1951). Loblolly pine seedlings were injured more than shortleaf pine (*Pinus echinata* Mill.).

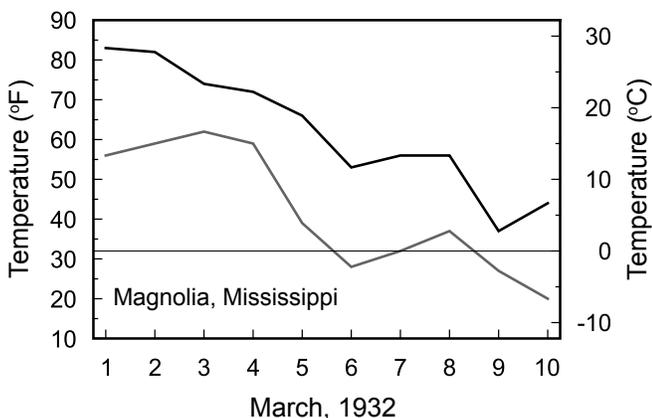


Figure 1—Maximum and minimum temperatures recorded at Magnolia, MS, for the first 2 weeks in March, 1932. The deacclimation-injury freeze on March 10 resulted in frost rings on longleaf pine (Stone 1940).

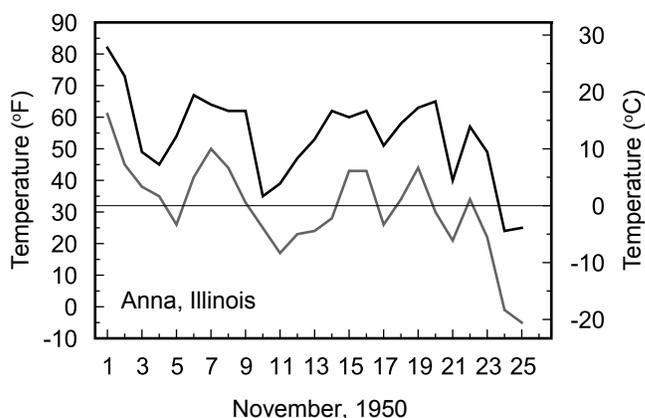


Figure 2—Maximum and minimum temperatures recorded at Anna, IL, for the first 3 weeks in November, 1950. The nursery manager at the Union State Tree Nursery indicated the  $-8^{\circ}\text{F}$  freeze in late November killed the loblolly pine seedlings (Minckler 1951).

### 1955 FREEZE

Temperatures at Akin, SC, reached  $75^{\circ}\text{F}$  on December 4. Freezing temperatures occurred from December 9 to 23 and this "exceptionally cold period" was associated with high, drying winds. On December 17, the temperature at the Savannah River Project dropped to  $15^{\circ}\text{F}$ . This PAI freeze resulted in a "dehydration burn" on newly planted slash pine and longleaf pine seedlings (Tofte and Hatcher 1956).

### 1957 FREEZE

During the winter, there was a 7-week warm period at Gainesville, FL. Warm nighttime temperatures initiated new growth on slash pines (*Pinus elliotii* Engelm.) (Weber 1957). Temperatures at Gainesville dropped to  $24^{\circ}\text{F}$  in some places (fig. 3) and  $20^{\circ}\text{F}$  in others. This DI freeze resulted in dead needles and brown terminal shoots.

### 1962 FREEZE

Record low temperatures occurred in Morgan County, TN and loblolly pine needles were injured (Thor 1967). Temperatures reached  $-17^{\circ}\text{F}$  on December 12-13, 1962, and January 24-25,

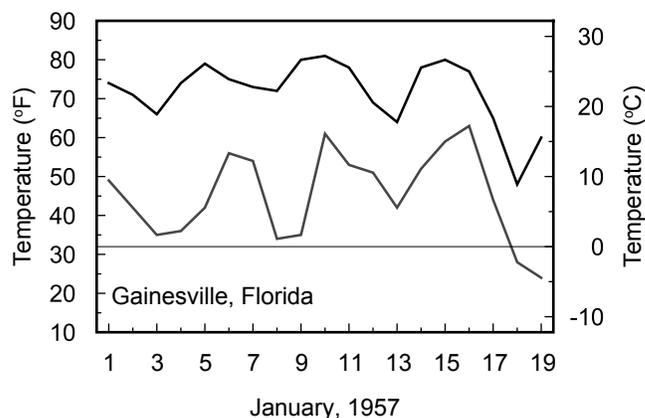


Figure 3—Maximum and minimum temperatures recorded at Gainesville, FL, for the first 3 weeks in January, 1957. The deacclimation-injury freeze injured new shoot growth on slash pine (Weber 1957).

1963, at the nearby town of Crossville, TN. AI freeze damage likely reduced loblolly pine growth if the seed originated from the Piedmont of north Georgia or the Coastal Plain of North Carolina. Sources with moderate foliar injury (> 35 percent of the trees having more than 24 percent brown needles) were from the South Carolina Coastal Plain and the Piedmont of North Georgia.

### 1977 FREEZE

January was a cold month, and temperatures at Red Bay, AL, dropped to -1 °F. Temperatures in Calloway County, KY, were as low as -15 °F on January 11 (Kolb and others 1985). One-year-old loblolly pine seedlings (in a progeny test) exhibited injury to foliage. There were strong genetic differences in susceptibility to the freeze. Families from the Mid-South Region were more tolerant than families from the Piedmont of North and South Carolina.

### 1983 FREEZE

Record low temperatures occurred throughout the South on December 25. This freeze killed many orange trees [*Citrus sinensis* (L.) Osbeck], and the damage was estimated at one billion dollars. The arctic high pressure system spread quickly

south (along with associated high winds), and the ground froze at a number of forest tree nurseries. Damage was confined mainly to nurseries in hardiness Zone 8 (table 2). Freeze injury to pine roots was not reported in Zone 6 or 7 (i.e., Kentucky, Tennessee, Arkansas, Oklahoma). Daytime temperatures at Auburn, AL, were above 50 °F for several weeks prior to the freeze (fig. 4). This PAI freeze resulted in injury to roots (fig. 5), and several papers documented this event (Carlson 1985, Lantz 1985, Rowan 1985).

### 1985 FREEZE

Nighttime temperatures during the first part of January were below freezing at many nurseries (fig. 6). An AI freeze on January 21-22 set state records in Virginia (-30 °F), North Carolina (-34 °F), and South Carolina (-19 °F). Although temperatures were generally lower than those recorded on Christmas 1983, there was not an unusually warm period preceding the freeze. Although the AI freeze killed many orange trees, minimal injury was noted on pines seedlings in nurseries. However, injury did occur if loblolly pine families were planted too far north. Pine families from hardiness Zones 8B and 9A were injured more than families from Zone 7 (Hodge and Weir 1993). In general, fast-growing families were more injured by the freeze than slower growing families.

**Table 2—Nursery location, December 25, 1983 temperature, USDA hardiness Zone, and associated root injury to pine seedlings**

Nursery	State	°F	USDA zone	Nursery manager's comments
Kentucky Dam	KY	-14	6	No root injury; severe needle burn on N. AL source
Pinson	TN	-9	6	No injury to loblolly pine
Chatsworth	GA	-3	7	No injury to loblolly pine
White City	AL	-2	7	Loblolly 3-37% injury
Little Rock	AR	-1	7	No injury to loblolly, shortleaf or virginia pine
Edwards	NC	2	7	No injury to loblolly pine
Goldsboro	NC	2	7	Longleaf 4-8%; no injury to loblolly and slash
Camden	AL	2	8	Longleaf 50%; no injury to loblolly pine
Prov. Forge	VA	3	7	No injury to loblolly pine
Opelika	AL	3	8	Loblolly 5 to 65%; slash 10-15%; longleaf 40-45%
Winona	MS	3	7	No injury to loblolly pine
Eutaw	AL	5	7	Loblolly 3-70% (depending upon family)
Newton	TX	6	8	No injury to loblolly pine
Selma	AL	6	8	Loblolly <2% injury; slash <1%
Buena Vista	GA	6	8	Loblolly 12-18%; slash 18%; sand 1%
Swansea	SC	6	8	No injury to loblolly or Virginia pine
Hodge	LA	6	8	No injury to loblolly; some frozen bags discarded
Autaugaville	AL	6	8	Loblolly 10 to 65 %; slash 49%; longleaf 61-88%
Atmore	AL	7	8	Longleaf 49-72%; loblolly 28 to 88%; slash 53-70%
Ashe	MS	7	8	Longleaf 9-15%; loblolly 5%
Cedar Springs	GA	7	8	Loblolly 1-2%; slash 2%; longleaf < 10%
Statesboro	GA	8	8	No injury to loblolly or slash pine
Jasper	TX	8	8	No injury to loblolly-minor needle burn
Munson	FL	8	8	Loblolly <4%; slash 2-17%; longleaf 6-63%
Glennville	GA	9	8	No injury to loblolly, longleaf and slash
Brewton	AL	10	8	Loblolly 10%; slash 21%; longleaf 50%
Washington	NC	10	8	No injury to loblolly pine
Lee	FL	11	8	Undercut longleaf 50%; loblolly <5%
Ravenel	SC	11	8	No injury to loblolly pine
Chiefland	FL	12	8	South Florida slash pine > 50%

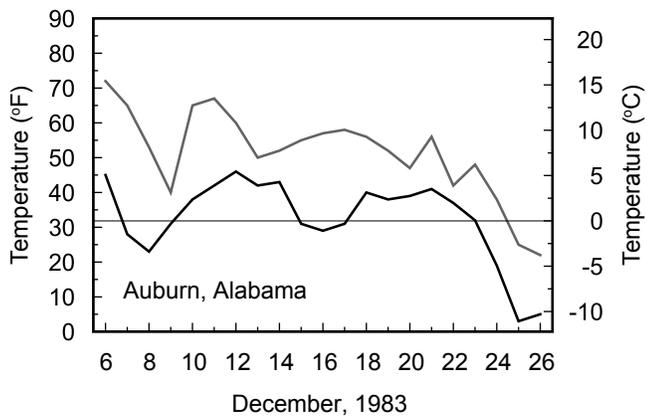


Figure 4—Maximum and minimum temperatures recorded at Auburn, AL, for the 3 weeks during December, 1983. The deacclimation-injury freeze injured pine seedling roots throughout hardiness Zone 8.



Figure 5—Root injury to a bare-root longleaf pine seedling from the Christmas 1983 freeze. The taproot shows injury symptoms several inches below the groundline.

### 1989 FREEZE

Bareroot longleaf pine were planted in Autauga County, AL, on December 13 and December 20. A hard freeze occurred on December 23; temperatures reached 0 °F and did not rise above freezing until December 27. It is estimated the freeze reduced survival by more than 50 percent (South and Loewenstein 1994).

### 1991 FREEZE

Very warm temperatures occurred in October and a PAI freeze occurred during the first week of November. Daytime temperatures a few weeks before the freeze were above 80 °F, and nighttime temperatures were above 50 °F (fig. 7). Within 60

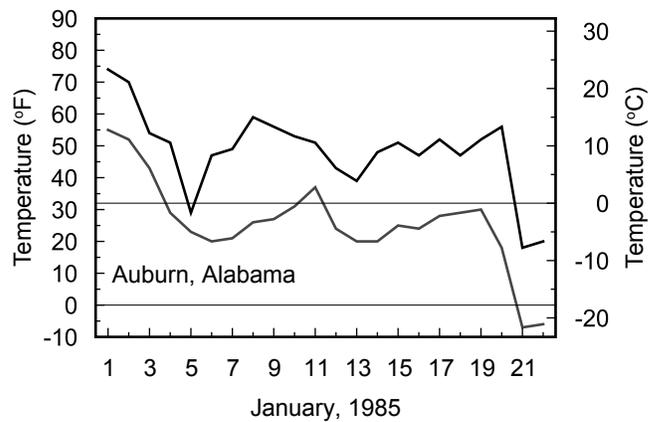


Figure 6—Maximum and minimum temperatures recorded at Auburn, AL, for the 3 weeks during January, 1985. This freeze injured few pines (of local origin) since nighttime temperatures before the event were generally below freezing.

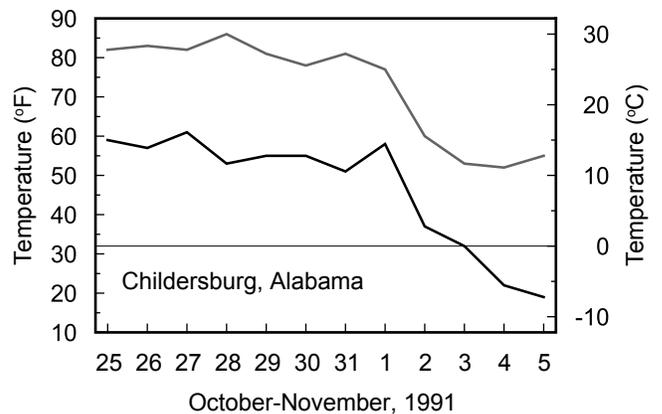


Figure 7—Maximum and minimum temperatures recorded at Childersburg, AL, for 2 weeks in October-November, 1991. This deacclimation-injury freeze affected a number of pine seedling roots planted prior to the freeze event.

hours, the temperature dropped approximately 40 °F. Minimum temperatures recorded at a north Alabama nursery were 19 °F, and at this location more than 95 percent of the seedlings exhibited some necrotic needles. Pine needles that were not elongating were not injured (South and others 1993). This PAI freeze apparently did not injure roots.

### 1994 FREEZE

Pine seedlings in Alabama and Mississippi were affected by an AI freeze that occurred on January 19 through January 20. At Camp Hill, AL, temperatures dropped 44 °F over a 36 hour period (low temperature = 7 °F). Subsequently, seedlings from several organizations exhibited low root growth, slow bud-break, and many seedlings were brown in March and April. A survey of planting chances in Alabama indicated survival of seedlings planted before the freeze ranged from 64 to 73 percent. If seedlings were planted after the freeze, survival ranged from 77 to 90 percent. This suggests that seedlings suffered freeze injury in the field (as opposed to in the nursery). First-year height growth of seedlings affected by the freeze was less than expected.

### 1996 FREEZE

Pine seedlings in Alabama were affected by a freeze that occurred on January 19. Temperatures dropped 52 °F in about a day (low temperature = 16 °F). A few days later, temperatures fell again to a low of 5 °F (February 9). Seedlings from one nursery were examined, and 97 percent of the samples from family 7-56 showed symptoms of freeze injury (South and others 2002). In December, a 16 °F freeze killed 400,000 container-grown longleaf pine seedlings at the Ashe Nursery in Mississippi (Tinus and others 2002).

### 2000 FREEZE

In many locations across the South, air temperatures dropped to below 20 °F on December 21. Nationally, it was the seventh coldest December on record. Frozen container-grown longleaf pine seedlings from three nurseries were allowed to thaw, and these seedlings were outplanted in sand at Auburn, AL, in January. By March 6, 100 percent of the seedlings survived from a nursery where air temperatures dipped to 21 °F. At another nursery, survival was 98 percent after air temperatures dropped to 14 °F. At the third nursery, survival averaged 87 percent after air temperatures dropped to 7 °F. These data are encouraging since the container plugs had frozen solid at each nursery. Apparently, the extra-cold weather in late November and early December caused the longleaf pine seedlings to acclimate more than in previous years where frozen containers died after outplanting (Tinus and others 2002).

### 2004 FREEZE

Unseasonably warm temperatures occurred during the first week of January. At some locations, nighttime temperatures were above 60 °F 2 days before the DI freeze (fig. 8). In some locations, temperatures (5 feet above the ground) dropped from 74 °F on January 5 to 18 °F on January 7. Temperatures of 17 °F were recorded at Florence, SC, and were 21 °F at Shreveport, LA, Meridian, MS, and Ft. Valley, GA. Although it did not get as cold, the absolute drop in temperature was even greater than that associated with the infamous Christmas 1983 freeze. Winds associated with the 2004 freeze were about 10 to 15 miles per hour. Seedling roots were injured while shoots initially appeared uninjured. As a result, millions of pine seedlings with injured roots were outplanted. Areas with poor seedling survival ranged from Smith County, TX, through Louisiana, Mississippi, Alabama, Georgia, and into southeastern South Carolina (Jasper County). Temperatures in Florida were not as cold, but at least one longleaf pine planting chance in the panhandle may have been affected by temperatures below 26 °F. Freeze pockets can be 10 °F colder than temperatures recorded at official weather stations. It has been estimated that financial losses from this freeze event exceeds one million dollars. Many foresters wondered why so many seedlings were dead by May.

Roots and shoots injured by the freeze showed no immediate signs of injury. Although symptoms can show up if seedlings are exposed to warm temperatures for about 24 to 48 hours, in many cases seedlings kept cool show no obvious outward signs of freeze injury.

Injured cambial and parenchyma cells were detected just above the groundline and down several inches below the root-collar (fig. 9). In some cases, the pith of the stem turned brown to black (Cameron and Lowerts, in press). Many out-planted

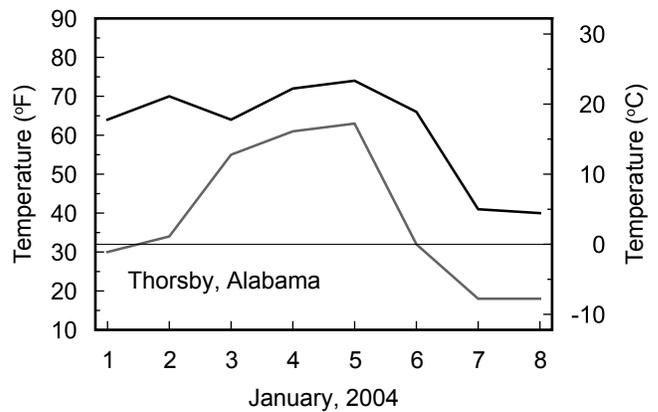


Figure 8—Maximum and minimum temperatures recorded at Thorsby, AL, for the first week in January, 2004. This deacclimation-injury freeze affected roots and reduced survival throughout hardiness Zone 8 (from East Texas to southeast South Carolina).



Figure 9—Root injury to loblolly pine seedlings from a 16 °F freeze on January 7, 2004. Air temperatures were above 70 °F just a few days prior to the freeze. These seedlings were lifted on 17 February and were stored until planting. Seedling stored had red-brown bark that slips with ease, and the cambium is a spongy and gray-brown in color. Seedling mortality occurred quickly after planting. The freeze injured roots extend several inches below the groundline. Color photo at [www.sfwis.auburn.edu/sfnmc/museum/frozen.html](http://www.sfwis.auburn.edu/sfnmc/museum/frozen.html).

seedlings exhibited a lack of new root growth. For the southern pines, new root growth is dependent upon current photosynthesis (not stored carbohydrates). As a result, when transport of carbohydrates to the roots is inhibited, new root growth is reduced. Therefore, reduced root growth is a symptom of freeze injury (Carlson 1985).

Areas with injured pine seedlings were in hardiness Zones 8 and 7b, and injured seedlings were mostly from Coastal Plain sources. Although temperatures on January 7 were actually lower in hardiness Zone 7, Piedmont sources in this Zone escaped injury. For example, Jackson, TN, recorded a temperature of 9 °F, but injury to pine seedlings was not reported. Likewise, no reports of injury were forthcoming from central Arkansas where temperatures dropped to 12 °F.

### HARDINESS ZONE AND SEED SOURCE

Four-month old container-grown seedlings can be injured by freezes in hardiness Zone 7a (Mexal and others 1979). However, if a bare-root nursery is located in hardiness Zone 6 or 7a, there appears to be little chance of a freeze injuring pine roots from local seed sources. Injury can occur if southern seed sources from Zone 8 are sown in Zones 6 or 7a nurseries. In contrast, nurseries located in Zone 8 have experienced root injury even when the genetic source is local. For example, in 1983 temperatures dropped to <5 °F at both Pinson, TN, and Opelika, AL, but freeze injury occurred only at the Opelika Nursery (table 2). Nurseries in Zones 6 and 7a do experience frost heaving and winter desiccation (Dierauf and Olinger 1977), but these injuries are different from the injury that results in broken cell membranes (Krasowski and others 1993). Freeze injury to pines is rare in Zones 9 or 10, but they do occasionally occur (Olmsted and others 1993, Weber 1957).

### GENETICS AND FREEZE INJURY

Freeze injury is under strong genetic control (Allen 1961, Duncan and others 1996, Hodge and Weir 1993, Kolb and others 1985, Minckler 1951, Thor 1967). Coastal Plain sources are more susceptible to a freeze than are most Piedmont sources. Some fast-growing Coastal Plain families (e.g., 7-56) are less tolerant of freezes than other sources (South and others 2002). In general, shortleaf pine is more freeze tolerant than loblolly pine. Slash pine and longleaf pine are less freeze tolerant than loblolly pine. Longleaf pine is less tolerant of freeze than others species (Hodges 1961), and acclimation is not greatly increased by exposure to cold temperatures (Parker 1961, 1965). As one might expect, cold tolerance of eastern white pine (*Pinus strobus* L.) is greater than that for longleaf pine, and this difference might be due to a lack of sugar buildup in longleaf pine needles (Parker 1959).

### ACCLIMATION AND FREEZE INJURING TEMPERATURES

It is apparent that acclimation plays a greater role in freeze injury than does the freeze temperature, per se. In general, preacclimated and deacclimated seedlings are injured at higher temperatures than acclimated seedlings. For example, acclimated loblolly pines in New Jersey apparently tolerated a -25 °F February 1934 freeze, but 2 years earlier new growth of deacclimated seedlings was killed by a light freeze (30 °F in June) (Wood 1936). Therefore, if the nighttime temperatures prior to a hard freeze have been low (e.g., fig. 6), seedlings are less likely to be injured than if nighttime temperatures before a freeze were high (e.g., fig. 4).

### FREEZE INJURY IS NOT RELATED TO THE PRESENCE OF A TERMINAL BUD

This null hypothesis has not been rejected by scientific studies. Freeze injury to newly formed needles on loblolly pine was not related to the presence or absence of a terminal bud (Duncan and others 1996, South and others 1993). Many seedlings injured in the 1983 freeze had terminal buds. Slash pines with terminal buds were injured by a 20 °F freeze (Weber 1957). Although a large seedling is more likely to have a terminal bud than a small seedling (Williams and others 1988), it has not been demonstrated that a seedling with a terminal bud is more resistant to a freeze than a similar-sized seedling without a terminal bud. The myth that a terminal bud is required before a seedling acclimates to cold temperatures may have started with observations in the spring. Injury to a late spring frost is likely to occur when seedlings have broken bud and are growing.

### CONCLUSIONS

Freeze injury to southern pines has occurred for millennia, and freezes likely maintain the northern boundary for these species. Injury to local seed sources is more likely to occur when seedlings are outplanted in hardiness Zone 8 than in Zones 6 or 7a. Coastal Plain sources that have deacclimated due to several days of warm nighttime temperatures are susceptible to injury from temperatures in the range of 16 to 20 °F (measured 5 feet above ground level). Southern pine seedlings exposed to warm nighttime temperatures can be injured by temperatures of 18 °F (December to January) or 20 °F (March or November). PAI or DI freeze events like that of Christmas 1983 and January 7, 2004, are likely to injure pines in Zone 8 again.

### LITERATURE CITED

- Allen, P.H. 1961. Florida longleaf pine fail in Virginia. *Journal of Forestry*. 59: 453-454.
- Carlson, W.C. 1985. Cold damage to loblolly pine seedlings. In: Lantz, C.W., tech. coord. 1984 southern nursery conferences proceedings. Atlanta, GA: U.S. Department of Agriculture, Forest Service, State and Private Forestry: 1-21.
- Cameron, R.S.; Lowerts, G.A. [In press]. A new method of diagnosing freeze damage in stems of bareroot loblolly pine seedlings. *Tree Planters' Notes*.
- Dierauf, T.; Olinger, H.L. 1977. January 1977 cold damage to loblolly seedlings at New Kent Nursery. Occasional Report 51. Virginia Division of Forestry. 4 p. <http://www.dof.virginia.gov/info/brochure-list.shtml> [Date accessed: unknown].
- Duncan, P.D.; White, T.L.; Hodge, G.R. 1996. First-year freeze hardiness of pure species and hybrid taxa of *Pinus elliottii* (Engelmann) and *Pinus caribaea* (Morelet). *New Forests*. 12: 223-241.
- Hodge, G.R.; Weir, R.J. 1993. Freezing stress tolerance of hardy and tender families of loblolly pine. *Canadian Journal of Forest Research*. 23: 1892-1899.
- Hodges, C.S. 1961. Freezing lowers survival of three species of southern pines. *Tree Planters' Notes*. 47: 23-24.
- Glock, W.S. 1951. Cambial frost injuries and multiple growth layers at Lubbock, Texas. *Ecology*. 32: 28-36.
- Kolb, T.E.; Steiner, K.C.; Barbour, H.F. 1985. Seasonal and genetic variations in loblolly pine cold tolerance. *Forest Science*. 31: 926-932.
- Krasowski, M.J.; Herring, L.J.; Letchford, T. 1993. Winter freezing injury and frost acclimation in planted coniferous seedlings: a literature review and case study from northeastern British Columbia. FRDA II. Canada-British Columbia partnership agreement on forest resource development. Prince George, BC: British Columbia Ministry of Forestry. 36 p.

- Lantz, C.W. 1985. Freeze damage to southern pine seedlings in the nursery. In: Lantz, C.W., tech. coord. 1984 southern nursery conferences proceedings. Atlanta, GA: U.S. Department of Agriculture, Forest Service, State and Private Forestry: 20-29.
- Mexal, J.G.; Timmis, R.; Morris, W.G. 1979. Cold-hardiness of containerized loblolly pine seedlings. Its effect on field survival and growth. Southern Journal of Applied Forestry. 3: 15-19.
- Minckler, L.S. 1951. Southern pine from different geographic sources show different responses to low temperature. Journal of Forestry. 49: 915-916.
- Olmsted, I.; Dunevitz, H.; Platt, W.J. 1993. Effects of freezes on tropical trees in Everglades National Park Florida, USA. Tropical Ecology. 34: 17-34.
- Parker, J. 1959. Seasonal variations in sugars of conifers with some observations on cold resistance. Forest Science. 5: 56-63.
- Parker, J. 1961. Seasonal trends in carbon dioxide absorption, cold resistance, and transpiration of some evergreens. Ecology. 42: 372-380.
- Parker, J. 1965. The ability of warm-climate pines to become cold hardy. Pakistan Journal of Forestry. 15: 156-160.
- Rowan, S.J. 1985. Impact of Christmas 1983 freeze on growth and survival of slash, loblolly, and longleaf pine seedlings from Alabama and Georgia nurseries. In: Lantz, C.W., tech. coord. 1984 southern nursery conferences proceedings. Atlanta, GA: U.S. Department of Agriculture, Forest Service, State and Private Forestry: 30-38.
- South, D.B.; Donald, D.G.M.; Rakestraw, J.L. 1993. Effect of nursery culture and bud status on freeze injury to *Pinus taeda* and *P. elliottii* seedlings. South African Forestry Journal. 166: 37-45.
- South, D.B.; Loewenstein, N.J. 1994. Effects of Viterro root dips and benomyl on root growth potential and survival of longleaf pine seedlings. Southern Journal of Applied Forestry. 18: 19-23.
- South, D.B.; Brown, P.; Dougherty, P.M. [and others]. 2002. Tip-dieback in young loblolly pine plantations. In: Outcalt, K.W. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 574-578.
- Stone, E.L. 1940. Frost rings in longleaf pine. Science. 92(2395): 478.
- Thor, E. 1967. A ten-year-old loblolly pine seed source test in Tennessee. Journal of Forestry. 65: 326-327.
- Tinus, R.W.; Sword, M.A.; Barnett, J.P. 2002. Prevention of cold damage to container-grown longleaf pine roots. In: Barnett, J.P.; Dumroese, R.K.; Moorhead, D.J., eds. Proceedings of workshops on growing longleaf pine in containers-1999 and 2001. Gen. Tech. Rep. SRS-56. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 63 p.
- Tofte, A.L.; Hatcher, J.B. 1956. Annual planting report: atomic energy commission Savannah River project: 1955-56 season. Internal Report. Washington, DC: U.S. Department of Defense. 61 p.
- Weber, G.F. 1957. Cold injury to young pine trees. Plant Disease Reporter. 41: 494-495.
- Williams, H.M.; South, D.B.; Glover, G.R. 1988. Effect of bud status and seedling biomass on root growth potential of loblolly pine. Canadian Journal of Forest Research. 18: 1635-1640.
- Wood, O.M. 1936. Early survival of some pine interplantings in southern New Jersey. Journal of Forestry. 34: 873-878.

# PHYSIOLOGICAL, ANATOMICAL, AND ECOLOGICAL CHARACTERISTICS OF SOUTHERN LIVE OAK

Yadong Qi, Jammie Favorite, Kit L. Chin, and Ying Xiao<sup>1</sup>

**Abstract**—Gas exchanges of sun-exposed and shaded leaves of southern live oak (*Quercus virginiana* Mill.) were studied monthly from May to September, 2000. Six healthy live oak trees with d.b.h. ranging from 21 to 148 cm on Southern University's campus in Baton Rouge, LA, were selected for the study. Instantaneous gas exchanges were measured during clear sky days from 9 a.m. to 4 p.m. using a portable gas exchange system. Leaf chlorophyll, moisture content, and environmental conditions were also monitored. Anatomy of sun-exposed and shaded leaves was studied in July using a scanning electron microscopy. Sun-exposed leaves had significantly higher net carbon dioxide (CO<sub>2</sub>) uptake rate, transpiration rate, and chlorophyll content, and significantly lower internal CO<sub>2</sub> concentration and moisture content than the shaded leaves. The leaf anatomy related well to the leaf physiology. The sun-exposed leaves had a remarkably denser trichome layer and more closely packed palisade mesophyll cells than the shaded leaves. The combined leaf anatomy and physiology indicate that southern live oak possesses a unique ecological advantage of self defense against various environmental stresses.

## INTRODUCTION

Southern live oak (*Quercus virginiana*, Mill.) is predominately a landscape and shade tree species that is considered a virtual emblem of the Old South. Live oak is a picturesque native tree found in the lower coastal plain of the Southeastern United States from southeastern Virginia south to Georgia and Florida including the Florida Keys; and west to southern and central Texas with scattered populations in southwestern Oklahoma and the mountains of northeastern Mexico (Harms 1990). Live oak can be seen growing in large yards, as specimen trees in parks, along streets, and overhanging the lanes of historic plantations. Georgia claims the live oak as its state tree. The trees grow on short, thick trunks, reaching a height of 40 to 60 feet at maturity. The live oak is the broadest-spreading of all oaks. Its large canopy will typically spread to nearly twice its height, which means it can shade an area of more than 100 feet. The trunk can grow anywhere from 3- to more than 6-feet-wide with limbs that run horizontally and sometimes sweep the ground under the massive weight (Ball 2003). The leaves are simple, elliptic or oblong, thick, leathery, oval, and dark evergreen. In the spring, this species drops its leaves and grows new leaves within several weeks. The flowers are catkins that occur in the early spring. They are monoecious (both sexes can be found on the same plant) and are pollinated by wind. The fruit is an acorn that occurs in clusters of one to five on peduncles 0.5 to 3 inches long (Odenwald and Turner 1980). The bark is thick, dark brown, and divided into ridges by deep narrow furrows. Southern live oak is intermediate in shade tolerance and once established withstands competition. This species likes moist, well-drained soil and is very drought tolerant and hurricane resistant. Southern live oak is extremely hard to kill because it sprouts vigorously from the root collar and roots (Hardin and others 2001). It is an excellent species for urban and community reforestation, providing maximum ecological and environmental benefits.

The United States is responsible for emitting more than 5 billion tons of carbon dioxide (CO<sub>2</sub>) a year (Smith 1996).

Increasing levels of atmospheric CO<sub>2</sub> and other greenhouse gases are thought by many to be leading to increased atmospheric temperatures (Nowak 1994a). Trees act as a sink for atmospheric CO<sub>2</sub> by storing carbon (C) through their growth processes. Stored C is used to construct new tissue and repair damage (Landsberg and Gower 1997). Trees in urban areas offer double benefits: (1) by reducing atmospheric CO<sub>2</sub> directly, sequestering and storing it in a form of C; and (2) when located properly, by shading buildings during summer and blocking winter winds, which reduce heating and cooling cost and result in lower CO<sub>2</sub> emissions from fossil-fuel power plants (Nowak 1994b). To maximize C sequestration and other benefits of urban trees, large and long-living shade tree species such as southern live oak should be planted in the suitable urban areas so that more C can be stored and the maximum amount of benefits from urban trees can be achieved.

Several papers pertinent to southern live oak physiology have been published, but they mainly dealt with the seedlings or saplings growing in containers (Beeson 1994; Devitt and others 1993; Devitt and others 1994; Devitt and others 1997; Gresham and others 1991; Levitt and others 1995; Messina and Duncan 1993; Pegoraro and others 2004; Rajashekar and Burke 1996; Tognetti and Johnson 1999a, 1999b). It is not possible to extrapolate the seedling results to mature trees. Except for the early publication by the authors on general leaf anatomy of southern live oak (Qi and Ying 2003), there has been no published information available on comparative physiology and anatomy of sun-exposed and shaded leaves of mature live oak trees. Study of mature trees is necessary for accurate estimation of the canopy level C uptake and transpiration potentials.

The purpose of this study was to investigate the physiological, anatomical, and ecological characteristics of mature southern live oak. The specific objectives included: (1) to compare the CO<sub>2</sub> uptake rate (net photosynthesis), transpiration rate, internal CO<sub>2</sub> concentration, chlorophyll content, and leaf

<sup>1</sup> Professor of Urban Forestry, Southern University and A&M College, Urban Forestry Program, Baton Rouge, LA 70813; Coastal Resources Scientist, Louisiana Department of Natural Resources, Baton Rouge, LA 70804; Professor of Horticulture, Plant and Soil Science Department, Southern University, Baton Rouge, LA 70813; and Research Associate, Socolofsky Microscopy Center, Louisiana State University, Baton Rouge, LA 70803, respectively.

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moisture content of sun-exposed and shaded leaves; and (2) to investigate the anatomical difference between sun-exposed and shaded leaves of mature southern live oak trees. The results obtained will increase scientific knowledge and understanding of the ecology and physiology of southern live oak, which will be useful for modeling and quantification of total C sequestration and water use capacities of the species. It is hoped that the research will increase public awareness of the ecological benefits provided by the urban and community forests.

## MATERIALS AND METHODS

### Study Site

A study site on Southern University's campus (latitude 30°53' N and longitude 91°19' E) in Baton Rouge, LA, was selected where healthy mature southern live oak trees were found growing. Six trees were chosen to study gas exchange rates monthly from May, 2000, through September, 2000. The base line data on the experimental trees including height, d.b.h., crown radius, leaf area index and total leaf area were collected and summarized in table 1.

### Measurements of Gas Exchanges

For each tree, three sun-exposed and three shaded leaves were randomly selected bi-hourly from 9 a.m. to 4 p.m. for measurements of CO<sub>2</sub> uptake and transpiration rates during clear sky days. Two consecutive clear days per month were needed to finish the measurements of all six trees. Instantaneous gas exchange rates of photosynthesis and transpiration were measured using a closed portable gas exchange system (Model LI-6200 with a quarter-liter chamber, Lincoln, Nebraska, USA). This system was programmed to monitor the rate at which CO<sub>2</sub> concentration in the chamber changed over a 40-second interval. The net photosynthesis rate was then calculated using the rate of change and other factors, such as the temperature, pressure, chamber volume, and the amount of leaf area enclosed. Air and leaf temperatures, relative humidity, and photosynthetic active radiation were monitored simultaneously. When a leaf was enclosed in the leaf chamber, the humidity within the chamber tended to rise. This was balanced by the flow of drier air that was returned to the chamber from the analyzer. Transpiration rate was calculated from the change in humidity with time and the flow rate of dry air. For each month, the mean net photosynthesis rate, internal CO<sub>2</sub> concentration, and transpiration rate of sun-exposed and shaded leaves were obtained by averaging the bi-hourly measurements over 2 consecutive days.

**Table 1—Baseline data for the southern live oak trees used for gas exchange measurements**

Tree no.	d.b.h.	Height	Crown radius	Drip line area	LAI
	<i>cm</i>	<i>m</i>		<i>m</i> <sup>2</sup>	
1	21.20	10.97	3.54	39.27	1.48
2	35.50	10.36	5.83	106.92	2.18
3	43.00	9.75	5.12	82.38	2.03
4	107.00	14.63	12.88	520.99	4.14
5	113.50	14.02	14.55	665.47	2.44
6	148.00	16.46	13.49	571.49	2.06

### Measurements of Leaf and Soil Moisture Content

Six sun-exposed leaves and six shaded leaves were sampled from each of the six trees monthly from June to September. The fresh weight was measured immediately after leaves were collected, and the dry weight was measured after drying the leaves at 70 °C in an oven for up to 48 hours. Six soil samples were collected within 0 to 12 inches depth from the areas where the experimental trees grew. The fresh weight of the soil was measured immediately after collection, and the dry weight of the soil was measured after the soil was dried at 70 °C in an oven for up to 72 hours. The formula for obtaining leaf and soil moisture content is: moisture content (%) =  $(Wt_{\text{fresh}} - Wt_{\text{dry}}) / Wt_{\text{dry}} \times 100$ .

### Measurements of Leaf Chlorophyll Content

Five sun-exposed and 5 shaded leaves per tree, for a total of 30 sun-exposed and 30 shaded leaves for all 6 trees, were collected monthly. Leaf chlorophyll content was measured with a chlorophyll meter (Spad 501, Minolta Corporation, Japan) in percentage and then converted to the unit of μmol/m<sup>2</sup> based on an empirical equation (Yadava 1986): chlorophyll(μmol/m<sup>2</sup>) = 6.864 + 8.864 x chlorophyll (%).

### Scanning Electron Microscopy of Leaves

Six mature sun-exposed and six shaded leaves were collected in July. Each leaf was dissected along the main vein, and three small pieces (5mm x 8mm) were cut perpendicularly to the main vein within the central area of the leaf. The leaf pieces were fixed in FAA (ethanol, glacial acetic acid, and formaldehyde), dehydrated in ethanol series, and dried in CO<sub>2</sub> using Denton DCP-1 critical point drying apparatus. Leaves were then mounted on stubs, coated with 25 nm gold palladium using a Hummer II sputter coater, and examined using a Cambridge S-260 scanning electron microscope.

### Statistical Analysis

Data were analyzed using analysis of variance and differences between means were determined using Tukey's Studentized Range (HSD) test, P ≤ 0.05.

## RESULTS AND DISCUSSIONS

### Leaf Gas Exchange

Significant differences were detected in photosynthetic rate, internal CO<sub>2</sub> concentration, and transpiration rate between sun-exposed and shaded leaves for each month from May to September (figs. 1, 2, 3). Photosynthetic rates of sun-exposed leaves were significantly higher than the rates of shaded leaves. The sun-exposed leaves took up more than twice the amount of CO<sub>2</sub> than the shaded leaves (fig. 1). Internal CO<sub>2</sub> concentration of sun-exposed leaves was significantly lower than shaded leaves (fig. 2). Internal CO<sub>2</sub> is the amount of CO<sub>2</sub> within the mesophyll tissues, specifically the sponge mesophyll. Because the shaded leaves took up less CO<sub>2</sub>, a higher CO<sub>2</sub> level remained within the mesophyll tissues. Transpiration rates of sun-exposed leaves were significantly higher than shaded leaves (fig. 3). Sun-exposed leaves were exposed to direct solar radiation, which was directly responsible for higher transpiration rates. Combining the 5 months measurements showed that under relatively same light and temperature environments, the sun-exposed leaves were significantly different from the shaded leaves in physiological performances including photosynthesis rate, internal CO<sub>2</sub> concentration, and transpiration rate (table 2).

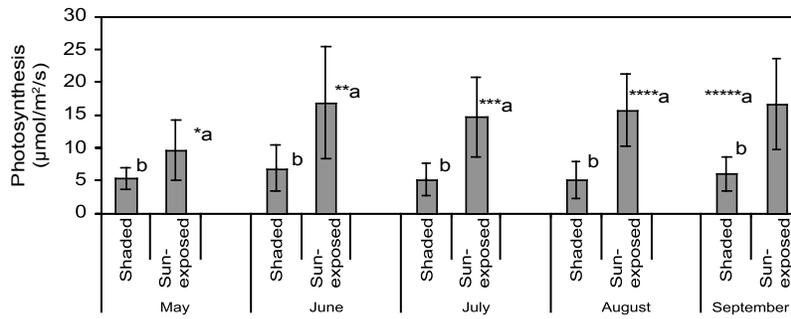


Figure 1—Photosynthesis of sun-exposed and shaded leaves of southern live oak during a growing season. Note: The means with different letters within each month are significantly different. \*p=0.001; for all \*\*, \*\*\*, \*\*\*\*, and \*\*\*\*\* p≤0.0001.

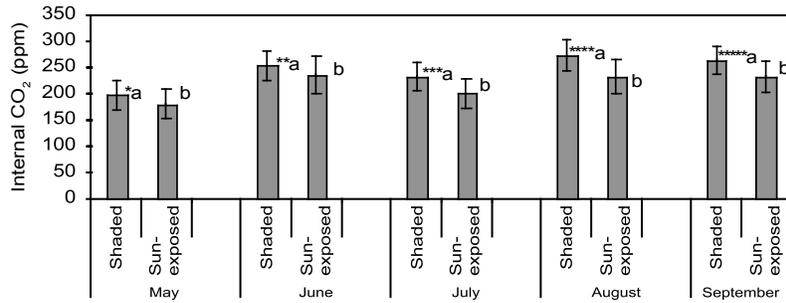


Figure 2—Internal CO<sub>2</sub> of sun-exposed and shaded leaves of southern live oak trees during a growing season. Note: The means with different letters within each month are significantly different; \*p=0.0278, \*\*p=0.0078, for all \*\*\*, \*\*\*\*, and \*\*\*\*\* p≤0.0001.

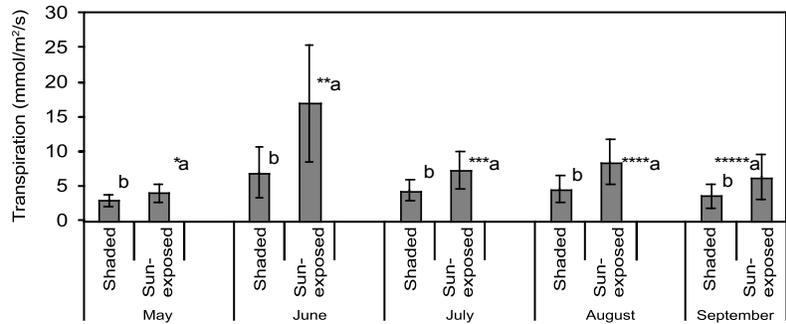


Figure 3—Transpiration of sun-exposed and shaded leaves of southern live oak during a growing season. Note: The means with different letters within each month are significantly different; \*p=0.0018, \*\*p=0.0021, for all \*\*\*, \*\*\*\*, and \*\*\*\*\* p≤0.0001.

**Table 2—Comparisons of gas exchange measurements of sun-exposed and shaded leaves**

	Sun-exposed leaves <sup>a,b</sup>	Shaded leaves <sup>a,b</sup>
N(sample size)	295	289
Light (µmol/m <sup>2</sup> /s)	1,226.96 ± 431.18 a	1,214.83 ± 438.50 a
Tair (°C)	35.50 ± 3.77 a	36.00 ± 3.75 a
Photosynthesis (µmol/m <sup>2</sup> /s)	15.44 ± 6.78 a	5.68 ± 2.84 b
Internal CO <sub>2</sub> (ppm)	220.94 ± 36.42 b	251.78 ± 35.38 a
Transpiration (mmol/m <sup>2</sup> /s)	6.81 ± 3.21 a	4.03 ± 1.83 b

<sup>a</sup> Mean ± standard deviation.

<sup>b</sup> Pairs of values followed by the same lowercase letter are not significantly different at the p ≤ 0.05 level.

## Leaf Chlorophyll Content and Moisture Content

Chlorophyll contents of sun-exposed leaves were significantly higher than shaded leaves (fig. 4). The data for May and July were not available due to equipment repair. The leaf moisture content was monitored between the months of June through September. Sun-exposed leaves had significantly lower moisture percentages than the shaded leaves in July, August, and September (fig. 5). This could be attributed to the fact that the sun-exposed leaves lost more water due to their higher transpiration rate (fig. 3). Overall, the highest leaf moisture percentage was in June followed by August, July, and September. The leaf moisture level was well-correlated with the soil moisture content, which was also the highest in June (11 percent), followed by August (9.86 percent), July (6.85 percent) and September (6.41 percent).

## Leaf Anatomy

The scanning electron micrographs of sun-exposed and shaded southern live oak leaves are illustrated in figure 6. The adaxial (upper) surfaces were covered with cuticle that was smooth in the sun-exposed leaf (fig. 6A) and rough and furrowed in the shaded leaf (fig. 6B). The smooth cuticle layer acts as an uninterrupted film that protects leaves by diminution of water loss and enhancement of reflection of the sunlight. The abaxial (lower) surfaces were covered with flattened, multicellular, shield-shaped trichomes (leaf hairs) that were much denser and fully differentiated in the sun-exposed leaf (fig. 6C) than in the shaded leaf (fig. 6D). The stomata were more exposed and visible in the shaded leaf (fig. 6D), while

the thick trichome layer of the sun-exposed leaf (fig. 6C) acts like a carpet to give protection to stomata against desiccation, against various chemical and physical influences, to protect leaves against being fed upon by animals, and against infestation by parasites. The leaf transverse (cross-section) structure shows that the palisade tissue consisted of three layers of parenchyma cells that were clearly defined and more compactly arranged in the sun-exposed leaf (fig. 6E) than in the shaded leaf (fig. 6F). The compact arrangement of the palisade parenchyma cells in the sun-exposed leaves provided more surface area of leaf interior containing chloroplasts. This resulted in higher chlorophyll content per unit of leaf area (fig. 4), and thus increased photosynthesis efficiency and net photosynthesis rate (fig. 1). The shaded leaf had loosely packed palisade cells (fig. 6F) compared to the sun-exposed leaf (fig. 6E). Also, sun-exposed southern live oak leaves were smaller and glossier than shaded leaves (Data not shown here). This agreed with Kozłowski and Pallardy (1997), who concluded that shade-grown leaves of broad-leaved trees are larger and thinner than sun-grown leaves, providing more efficient light harvesting per unit of dry weight invested. Hence, shaded leaves confer a greater potential for plant growth per unit of leaf dry weight and also have fewer palisade layers than leaves grown in the full sunlight.

## CONCLUSIONS

The distinctive anatomical differences between sun-exposed and shaded leaves of southern live oak are mainly attributed

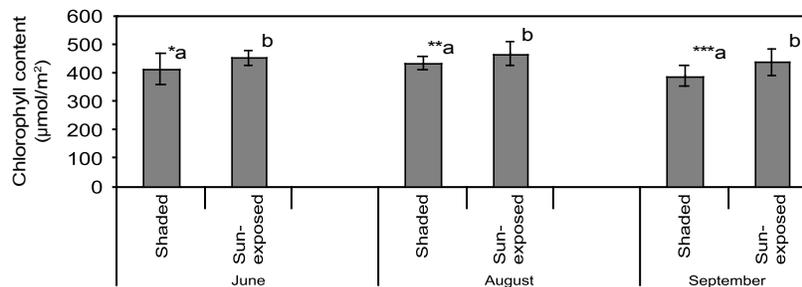


Figure 4—Chlorophyll content of sun-exposed and shaded leaves of southern live oak during a growing season. Note: The means with different letters within each month are significantly different; \* $p=0.0002$ , \*\* $p=0.0105$ , \*\*\* $p=0.0003$ .

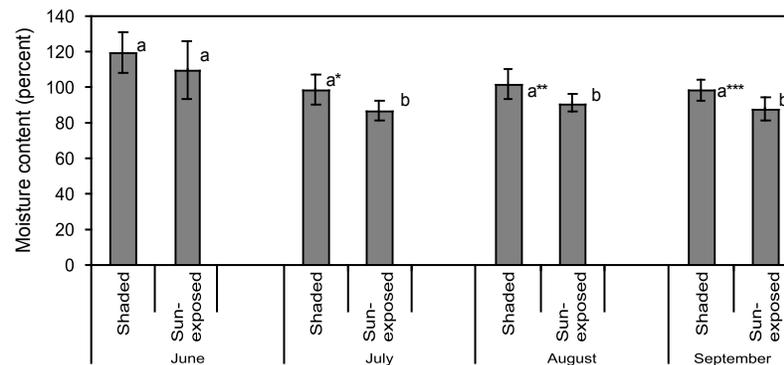


Figure 5—Leaf moisture content of sun-exposed and shaded leaves of southern live oak during a summer season. Note: The means with different letters within each month are significantly different; \* $p=0.0026$ , \*\* $p=0.069$ , \*\*\* $p=0.019$ .

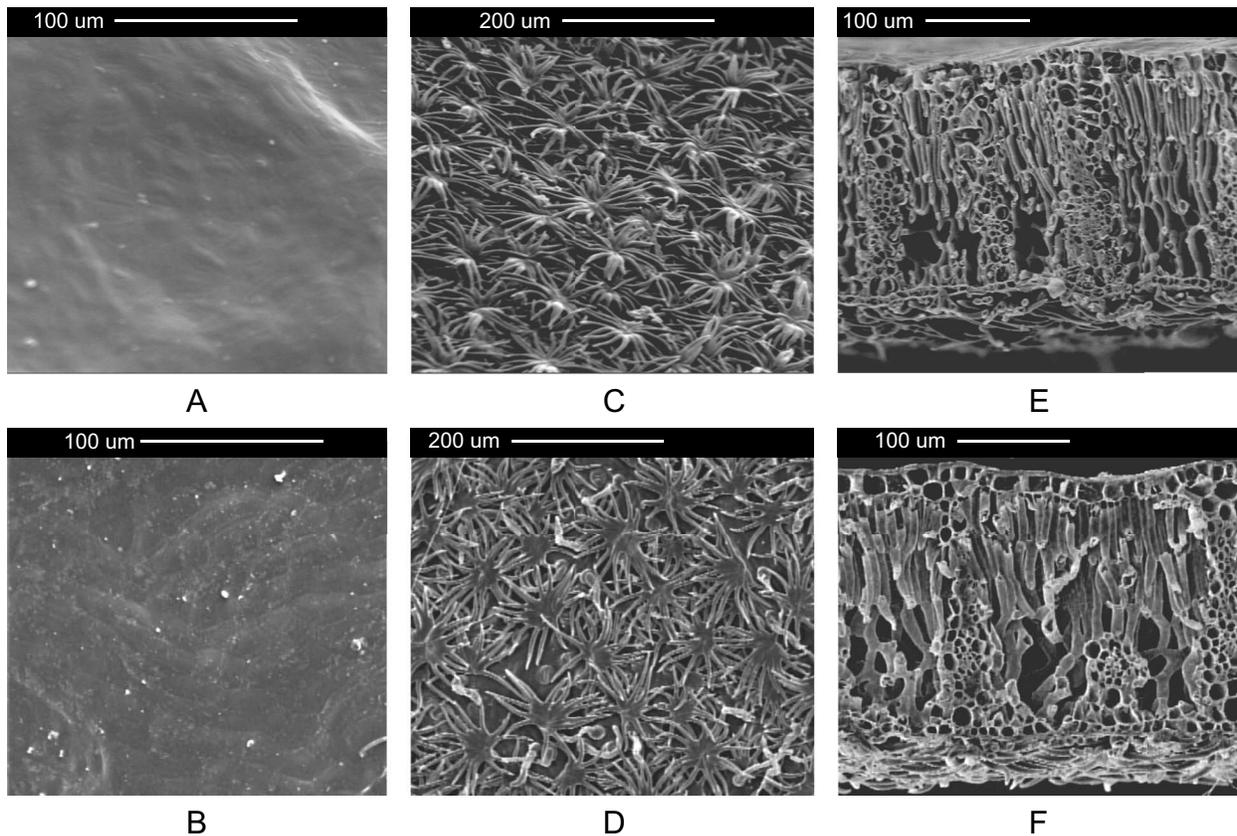


Figure 6—Scanning electron micrographs of sun-exposed and shaded leaves of southern live oak. (A) adaxial surface of a sun-exposed leaf; (B) adaxial surface of a shaded leaf; (C) abaxial surface of a sun-exposed leaf; (D) abaxial surface of a shaded leaf; (E) transverse view of a sun-exposed leaf; and (F) transverse view of a shaded leaf.

to photomorphogenesis and environmental adaptation. Sun-exposed leaves possess a denser trichome layer and highly packed palisade tissues which enhance net CO<sub>2</sub> uptake and chlorophyll content. The trichome layer may function as a mechanical barrier against biotic attack, as an additional resistance to the diffusion of water vapor from leaf interior to the atmosphere, as a reflector reducing the radiant energy absorbed by the leaf, and as an absorber to help screen out harmful UV-B radiation from the sun.

The combined anatomical and physiological characteristics presented in this paper indicate that southern live oaks possess a unique ecological advantage of self-defense against various environmental stresses. The information will be useful to urban forestry and forestry professionals in tree selection for urban and community reforestation. Since live oak is a hardy, evergreen, long-lived, and easily transplanted tree and grows and develops into a mature tree with a large canopy and massive trunk, planting live oak in the right places will provide many ecological and environmental benefits and maximize C storage benefits of urban trees.

#### LITERATURE CITED

- Ball, J. 2003. Live oak: the ultimate southerner. *American Forests Magazine*. 109(3): 45-47.
- Beeson, R.C. 1994. Water relations of field-grown *Quercus-virginiana* Mill. from preharvest through containerization and 1 year into a landscape. *Journal of the American Society for Horticultural Science*. 119(2): 169-174.
- Devitt, D.A.; Berkowitz, M.; Schulte, P.J.; Morris, R.L. 1993. Estimating transpiration for 3 woody ornamental tree species using stem-flow gauges and lysimetry. *Woody Hortscience*. 28(4): 320-322.
- Devitt, D.A.; Morris, R.L.; Neuman, D.S. 1994. Evapotranspiration and growth-respose of 3 woody ornamental species placed under varying irrigation regimes. *Journal of the American Society for Horticultural Science*. 119(3): 452-457.
- Devitt, D.A.; Smith, S.D.; Neuman, D.S. 1997. Leaf carbon isotope ratios in three landscape species growing in an arid environment. *Journal of Arid Environments*. 36(2): 249-257.
- Gresham, C.A.; Williams, T.M.; Lipscomb, D.J. 1991. Hurricane Hugo wind damage to Southeastern United States coastal forest tree species. *Biotropica*. 23(4). Part A: 420-426.
- Hardin, J.W.; Leopold, D.J.; White, F.M. 2001. Harlow and Harrar's textbook of dendrology. Ninth ed. New York, New York: McGraw-Hill, Inc. 534 p.
- Harms, W.R. 1990. Live oak. In: Burns, R.M.; Honkala, B.H., tech coords. *Silvics of North America*. 2. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 751-754.
- Kozlowski, T.T.; Pallardy, S.G. 1997. *Physiology of woody plants*. Second ed. New York: Academic Press. 411 p.
- Landsberg, J.J.; Gower, S.T. 1997. *Applications of physiological ecology to forest management*. New York: Academic Press. 354 p.
- Levitt, D.G.; Simpson, J.R.; Tipton, J.L. 1995. Water-use of 2 landscape tree species in Tucson, Arizona. *Journal of the American Society for Horticultural Science*. 120(3): 409-416.
- Messina, M.G.; Duncan, J.E. 1993. Irrigation effects on growth and water-use of *Quercus-virginiana* Mill on a Texas lignite surface-mined site. *Agricultural Water Management*. 24(4): 265-280.

- Nowak, D.J. 1994a. Air pollution removal by Chicago's urban forest. In: McPherson, E.G.; Nowak, D.J.; Rowntree, R.A., eds. Chicago's urban forest ecosystem: result of the Chicago urban forest climate project. Gen. Tech. Rep. NE-186. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 63-82.
- Nowak, D.J. 1994b. Atmospheric carbon dioxide reduction by Chicago's urban forest. In: McPherson, E.G.; Nowak, D.J.; Rowntree, R.A. eds. Chicago's urban forest ecosystem: result of the Chicago urban forest climate project. Gen. Tech. Rep. NE-Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 83-94.
- Odenwald, N.G.; Turner, J.R. 1980. Plants for the South. Baton Rouge, LA: Claitor's Publishing Division. 565 p.
- Pegoraro, E.; Rey, A.; Greenberg, J. [and others]. 2004. Effect of drought on isoprene emission rates from leaves of *Quercus virginiana* Mill. Atmospheric Environment. 38(36): 6149-6156.
- Qi, Y.; Ying, X. 2003. Scanning electron microscopy of leaves of southern live oak. Microscopy and Microanalysis. 9(supplement 2): 1336-1337.
- Rajashekar, C.B.; Burke, M.J. 1996. Freezing characteristics of rigid plant tissues - development of cell tension during extracellular freezing. Plant Physiology. 111(2): 597-603.
- Smith, D. 1996. Restoring the balance. American Forests. 103(4): 11-38.
- Tognetti, R.; Johnson, J.D. 1999a. The effect of elevated atmospheric CO<sub>2</sub> concentration and nutrient supply on gas exchange, carbohydrates and foliar phenolic concentration in live oak (*Quercus virginiana* Mill.) seedlings. Annals of Forest Science. 56(5): 379-389.
- Tognetti, R.; Johnson, J.D. 1999b. Responses of growth, nitrogen and carbon partitioning to elevated atmospheric CO<sub>2</sub> concentration in live oak (*Quercus virginiana* Mill.) seedlings in relation to nutrient supply. Annals of Forest Science. 56(2): 91-105.
- Yadava, U.L. 1986. A rapid and non-destructive method to determine chlorophyll in intact leaves. HortScience. 21: 1449-1450.

# ICE DAMAGE EFFECTS ON AN OLD-FIELD, THINNED AND FERTILIZED LOBLOLLY PINE STAND IN SOUTH CAROLINA

Bryan C. McElvany, Beth W. Richardson, and E. David Dickens<sup>1</sup>

**Abstract**—On January 26, 2004, an ice storm impacted 15 South Carolina counties. An established fertilization study area in Clarendon County, SC, was in the affected region. This old-field, thinned, loblolly pine (*Pinus taeda* L.) stand was fertilized in the spring of 1998. Treatments consisted of: (1) control; (2) poultry litter (7 tons acre<sup>-1</sup>); and (3) diammonium phosphate (DAP) (125 pounds acre<sup>-1</sup>) and urea (385 pounds acre<sup>-1</sup>). Tree ice damage was measured six growing seasons after fertilization. Total numbers of trees damaged and severity of that damage was determined for each treatment 5 weeks after the storm. Percentage of total trees damaged was not significantly different between the treatments ( $p=0.1373$ ), with a mean damage percentage of 37 percent for the control, 39 percent for poultry litter, and 45 percent for inorganic fertilizer. Percentage of severely damaged trees was also not significantly different ( $p=0.9684$ ), with means of 2.0 percent for the control, 2.0 percent for broiler litter, and 2.3 percent for inorganic fertilizer.

## INTRODUCTION

The study area was originally established to examine the effects of fertilization (poultry litter and inorganic fertilizer) on a relatively fertile old-field loblolly pine plantation. The site prior to fertilization exhibited substantial background fertility. Soil and foliage samples were collected prior to fertilization, and these tests indicated that foliar and soil nutrient levels were at or above sufficiency for loblolly pine (Allen 1987, Wells and others 1973). The addition of fertilizer materials did not significantly affect loblolly pine mean diameters, heights, basal area, or volume production on this relatively fertile old-field site 2, 4, and 6 years after treatment.

In late January, 2004, a severe winter storm impacted 15 South Carolina counties. Ice accumulation in the area persisted on the trees anywhere from an estimated 24 to 48 hours. The South Carolina Forestry Commission estimated that over 95 million dollars of damage occurred in this region. Five weeks after the storm, the study area was examined. The objectives were to determine if ice damage differences existed between treatments 6 years after fertilization.

## MATERIALS AND METHODS

The study area is located in Clarendon County, SC, in the Atlantic Coastal Plain physiographic region. The soil was mapped and verified as the Norfolk soil series (fine-loamy Typic Kandiudults). The entire plantation was thinned in January, 1998, at age 10 years from 750 trees acre<sup>-1</sup> (TPA) and 155 square feet acre<sup>-1</sup> basal area to 250 TPA and 50 square feet acre<sup>-1</sup> basal area. Treatments included: (1) control; (2) inorganic fertilizer application of 125 pounds acre<sup>-1</sup> DAP plus 385 pounds acre<sup>-1</sup> urea; and (3) poultry litter at a rate of 7 wet tons acre<sup>-1</sup>. Treatments were applied in late spring 1998. Baseline measurements were taken in 1998, and measurements were taken 2, 4 and 6 years after treatment.

Ice damage was evaluated 5 weeks after the storm. Damage was categorized as moderate or severe based on the extent of crown disturbance. A tree with three remaining live branches

or less was considered severely damaged. A tree was considered moderately damaged if more than three live branches remained, but crown damage was apparent. Total ice damage consisted of moderate and severe damage combined. A one-way analysis of variance using Duncan's multiple range test at  $\alpha = 0.05$  was used to determine statistical differences on ice damage.

## RESULTS

Ice damage was found not to be significantly different between the treatments. The percentage of total trees affected was 37 percent in the control plots, 39 percent in the poultry litter plots, and 45 percent in the inorganic fertilized plots. The percentage of total trees severely damaged was 2.0 percent for control, 2.0 percent for poultry litter, and 2.3 percent for inorganic fertilizer (fig. 1). The distribution of the damage across the diameter classes indicates that total ice damage was more pronounced on the smaller diameter classes (suppressed trees) and the larger diameter classes (dominant trees) (fig. 2).

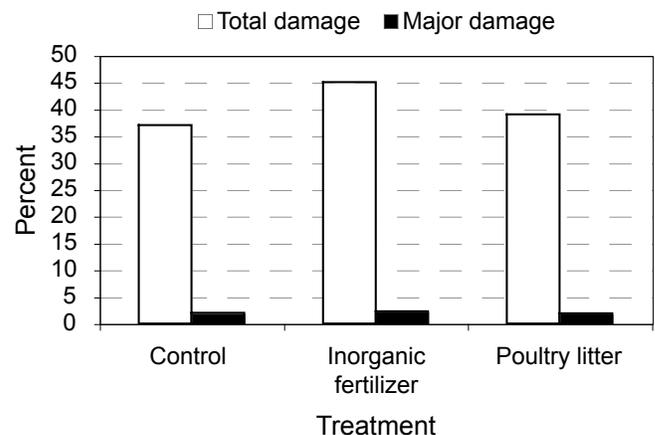


Figure 1—Total ice damage and severe ice damage as a percentage of total trees 6 years after treatment on a thinned, old-field, loblolly pine stand in Clarendon County, SC.

<sup>1</sup> Research Coordinator I, University of Georgia, Warnell School of Forest Resources, Statesboro, GA 30460; Area Forestry Extension Agent, Clemson University, Orangeburg, SC 29116; and Associate Professor, University of Georgia, Warnell School of Forest Resources, Statesboro, GA 30460, respectively.

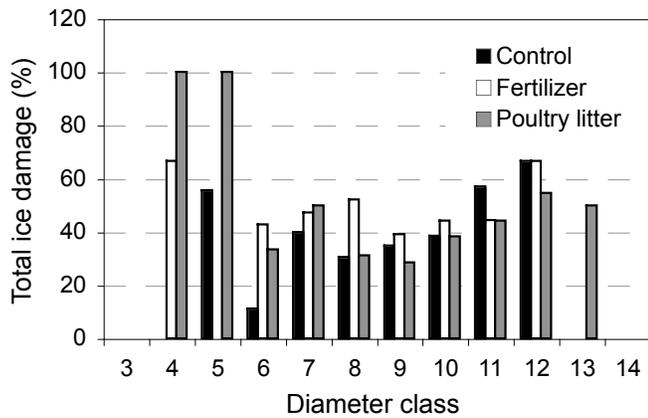


Figure 2—Total ice damage as a percent of total trees by diameter class and treatment 6 years after treatment on a thinned, old-field, loblolly pine stand in Clarendon County, SC.

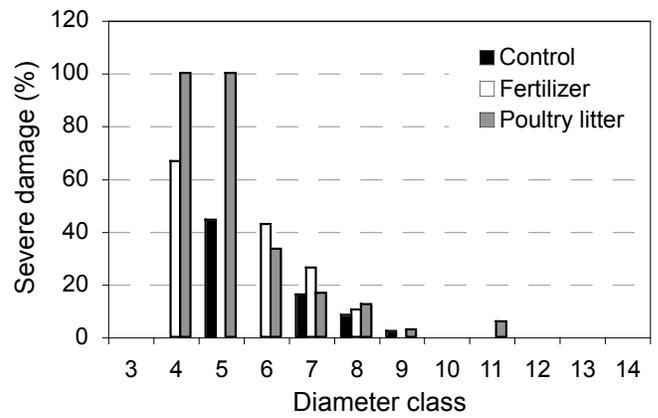


Figure 3—Severe ice damage as a percent of total trees by diameter class and treatment 6 years after treatment on a thinned, old-field, loblolly pine stand in Clarendon County, SC.

Severe ice damage was more pronounced in the smaller diameter classes (fig. 3).

### DISCUSSION

The facts that this stand was planted on a relatively fertile, old-field, and the ice storm occurred 6 years after fertilization, are very important when interpreting these results. In this study, damage did not differ significantly between treatments. Ice damage on sites with different fertility conditions at the time of fertilization may be somewhat different than the damage

that occurred in this stand. Also, an ice storm that occurs closer to the fertilization application may have varying differences in damage.

### LITERATURE CITED

Allen, H.L. 1987. Forest fertilizers: nutrient amendment, stand productivity, and environmental impact. *Journal of Forestry*. 85: 37-46.

Wells, C.G.; Crutchfield, D.M.; Berenyi, N.M.; Davey, C.B. 1973. Soil and foliar guidelines for phosphorus fertilization of loblolly pine. Res. Pap. SE-110. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 15 p.

# SURVEY OF TWENTY-SIX HYBRID POPLAR LINES FOR POPLAR BORER

W. Doug Stone, T. Keith Beatty, and T. Evan Nebeker<sup>1</sup>

**Abstract**—An insect survey was completed on 26 lines of hybrid poplar (*Populus nigra* x *P. maximowiczii*) that had the Roundup® Ready and Bt (*Bacillus thuringiensis*) genes. The survey was conducted in Kentucky in cooperation with MeadWestvaco. A total of 260 trees were evaluated. Survival rate averaged 74.2 percent among the lines. Poplar borer [*Saperda calcarata* (Say) Coleoptera: Cerambycidae] infested 22.2 percent of the trees. Other insects were present but to a lesser degree. Resistance to insect attack appeared evident in some lines but not in all. Experimental hybrid lines have not been approved for release, and this study adds to the information concerning herbivory on genetically modified material.

## INTRODUCTION

*Populus* species are the fastest growing trees planted commercially in North America with expectations of becoming the new pulp and energy fiber for the future. In the northwestern United States, 50,000 acres of poplar plantations have been planted (DeBell and others 1998, Stanton and others 2002). *Populus* plantation management is very similar to conventional agriculture in that insect control is one of the main challenges. Uniform age and size of the plantation creates a monoculture setting that results in a less complex system than that of a natural forest stand. Because of the monoculture habitat, natural checks and balances that decrease pest populations are reduced (Reichenbacher and others 1996). With advances in science and technology, researchers are testing genetically modified *Populus* clones which have genes tolerant to glyphosate (active ingredient in Roundup® herbicide) developed by Monsanto and a rebuilt Cry3A *Bacillus thuringiensis* toxin gene provided by Mycogen for resistance to the cottonwood leaf beetle (*Chrysomela scripta* F.).

## METHODS

### Insect Survey and Data Analysis

This survey was conducted on October 4-6, 2002, in a 3-year-old *Populus* plantation grown on MeadWestvaco land in Kentucky. The plantation was an experimental study using hybrid poplar (*Populus nigra* x *P. maximowiczii*) provided by Richard Meilan, Oregon State University. The hybrid poplars with the Roundup® Ready and Bt genes used in this study have not been approved for release. In any field trial, it is important to know the impact of insects. The cottonwood leaf beetle was not present in study plots; however, the poplar borer [*Saperda calcarata* (Say) Coleoptera: Cerambycidae] (fig. 1) was present and is the subject of this study. There was a total of 520 trees in the study area with 26 hybrid poplar transgenic lines represented by 4 treatments replicated 5 times. The treatments were part of an earlier MeadWestvaco study. We conducted a 50 percent survey that included 2 treatments in each of the 5 replications for a total of 260 trees. At each tree, we sight identified and tallied all insect damage. Calipers were used to measure basal diameter (diameter at ground level) and d.b.h. (diameter at breast height). A Suunto® compass was used to determine the directional pattern of

attacks. Tree height was measured using a Haglof® Vertex III hypsometer.

Trees with and without poplar borer were analyzed using analysis of variance (ANOVA), Fisher's PLSD, and  $X^2$  (SAS Institute 2000), with d.b.h., basal diameter, tree height,

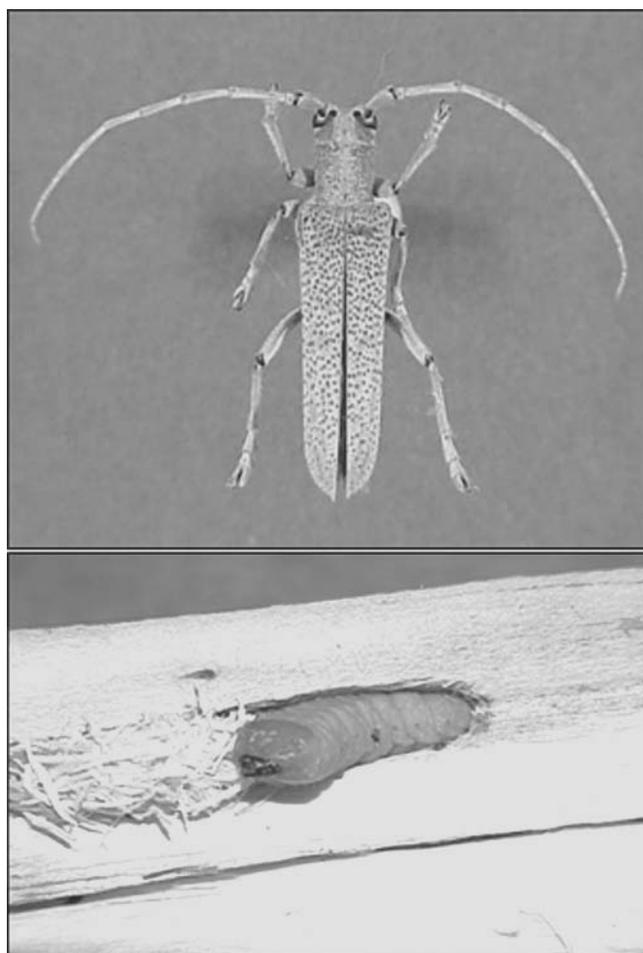


Figure 1— Mature adult and larva of the poplar borer. Photos taken by Doug Stone, February 2003.

<sup>1</sup> Research Associate, Department of Entomology and Plant Pathology, Mississippi State University, Mississippi State, MS 39762; County Forester, Mississippi Forestry Commission, Kiln, MS 39556; and Professor, Department of Entomology and Plant Pathology, Mississippi State University, Mississippi State, MS 39762, respectively.

direction of poplar borer attacks, and mean number of poplar borers tested ( $\alpha = 0.05$ ).

## RESULTS

The *Populus* lines with the Bt gene had no signs of CLB damage, as expected. Survival rate of lines averaged 74.2 percent (193 present/260 possible) (fig. 2). Poplar borers were present, and the data showed that some genetic lines had significantly more mean poplar borers than others. Poplar borers accounted for most of the insect activity with 22.2 percent (43 trees) infested. Fisher's PLSD T-test was used to compare the three variables (d.b.h., height, and basal diameter) among trees with or without poplar borers. Trees with or without poplar borers did not differ significantly in d.b.h. and basal diameter at  $\alpha = 0.05$ . Trees with poplar borers had an average diameter of  $2.33 \pm 0.15$  inches and basal diameter of  $5.02 \pm 0.21$  inches. Trees without poplar borers had an average diameter of  $2.23 \pm 0.09$  inches and basal diameter of  $4.59 \pm 0.16$  inches. There was no significant difference in height of infested and uninfested trees.

### Mean Poplar Borer Present

Fisher's PLSD T-test was used to compare mean poplar borer attacks among the different lines (fig. 3). The only significant differences were for lines 18 and 21, with no poplar borer attacks as compared to line 6. Because of the small sample size, further surveys with larger sample sizes need to be conducted to determine if any differences exists among the other

lines. Lines 1, 3, 19, 25, and 26 are not included because they had < 20 percent survival, while lines 2, 5, 6, 13, 17, and 24 had 100 percent survival. The best lines appear to be 18 and 21, with no poplar borer attacks and 80 and 90 percent survival, respectively.

### Directional Pattern of Attacks

Chi-square test was used to determine if there was any significant directional difference in poplar borer activity. If the poplar borer had randomly bored into the tree, the statistical percentage for the 8 directions would have been 12.5 percent overall. There was significant difference from the hypothesized 12.5 percent among all directions. Out of 90 poplar borers (fig. 4), highest number of attacks was on the south side of the tree, which was almost double the number of attacks on north side. The lowest percent occurred on the northwest and southwest sides of the tree. Further studies will be required to determine if a preference does exist.

## DISCUSSION

Earlier studies on the impact of the poplar borer showed that they can contribute to breakage and degradation of natural and plantation grown eastern cottonwoods in stands 3-years-old and older (Abrahamson and Newsome 1972, Nebeker and others 1985). During high winds and after thinnings, trees infested with poplar borer are more likely to break, which reduces total stand volume. A 22.2 percent infestation rate in this 3-year-old stand was much higher than in previous studies

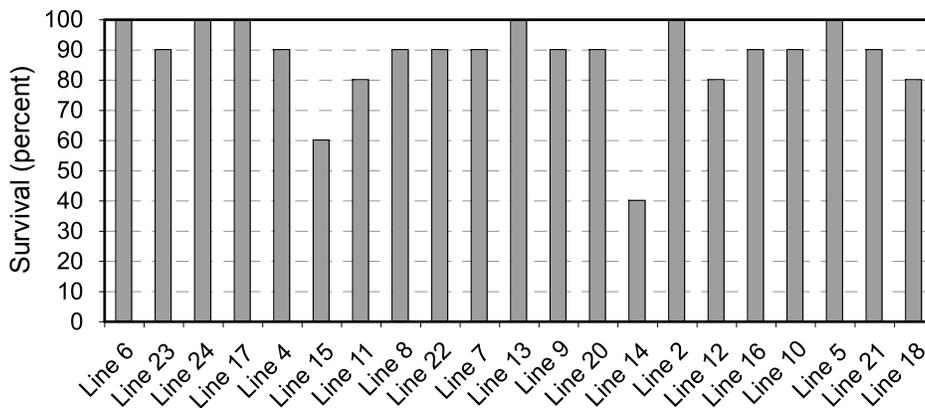


Figure 2—Survival rate of sampled clone lines.

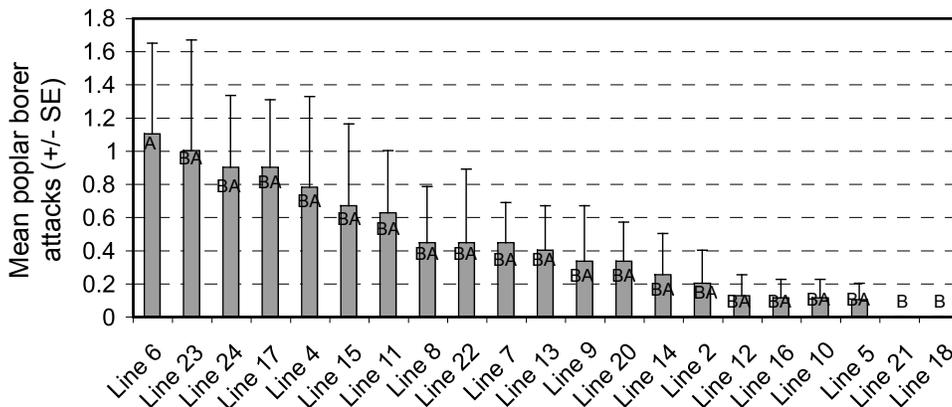


Figure 3—Mean poplar borers attacks among each sampled clone line.

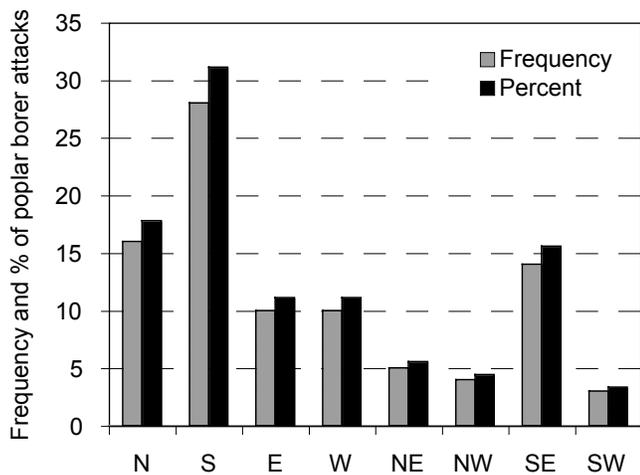


Figure 4—Frequency and percent of the eight cardinal directions with respect to poplar borer attacks on the bole of the cottonwood.

(Abrahamson and Newsome 1972, Nebeker and others 1985). In addition, previous studies demonstrated an increase in poplar borer activity with respect to tree age. One might conclude that poplar borer activity would have continued to increase at this site if it had not been cut. This study provided a preliminary look at line susceptibility to poplar borer attack.

Improvements in genetics are an important part of overall tree health and culture. By maximizing tree health, growth will improve which will increase yields and shorten rotation age. With increased demands on wood products, it is crucial that research continue in the area of tree improvement. Also, it is very important that the impact of insects is not overlooked so nurseries can release the best possible genetic lines for use.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Abrahamson, L.P.; Newsome, L. 1972. Tree age influences trunk borer infestation in cottonwood plantations. *Forest Science*. 18(3): 231-232.
- DeBell, J.D.; Gartner, B.L.; DeBell, D.S. 1998. Fiber length in young hybrid *Populus* stems grown at extremely different rates. *Canadian Journal of Forest Research*. 28: 603-608.
- Nebeker, T.E.; Schmitt, J.J.; Solomon, J.D.; Honea, C.R. 1985. Clonal resistance to and incidence of the poplar borer in southern cottonwood plantations. In: Shoulders, E., ed. Proceedings of the third biennial southern silvicultural research conference. Gen. Tech. Rep. SO-54. New Orleans, LA: U.S Department of Agricultural, Forest Service, Southern Forest Experiment Station: 247-251.
- Reichenbacher, R.R.; Schultz, R.C.; Hart, E.R. 1996. Impact of artificial defoliation effect on *Populus* growth, biomass production, and total nonstructural carbohydrate concentration. *Environmental Entomology*. 25: 632-642.
- SAS Institute Inc. 2000 SAS OnlineDoc: SAS/STAT user's guide, version 8.0. Cary, NC: SAS Institute Inc.
- Stanton, B.; Eaton, J.; Johnson, J. [and others]. 2002. Hybrid poplar in the pacific northwest-the effects of market driven management. *Journal of Forestry*. 6: 28-33.

# EFFECTS OF SILVICULTURAL OPERATIONS IN A MISSISSIPPI RIVER BOTTOMLAND HARDWOOD FOREST ON GROUND BEETLES IN THE GENUS *BRACHINUS*

Lynne C. Thompson and Brian Roy Lockhart<sup>1</sup>

**ABSTRACT**—Little information is available on how insects are affected by anthropogenic influences in the bottomland forests of the West Gulf Coastal Plain. This study investigates one genus of ground beetles that lives in managed forested landscapes to discover which species are positively and negatively influenced by human disturbances. Ground beetles (Carabidae) were collected from a bottomland hardwood forest in the Mississippi River floodplain that received three harvesting treatments in 1995 (three replicates each of clearcut, selection, and control). Beetles were analyzed to assess the effects of forest disturbance over time. Four species in the genus *Brachinus* accounted for about 66 percent of all specimens collected. *Brachinus* larvae are ectoparasites on the pupae of water beetles, and the adults prefer moist habitats. In 1996, the year after applying treatments, the selection cuts yielded almost three times as many *Brachinus* (63 percent of 3,696 total) as the control (19 percent) and clearcut (19 percent) treatments. One year later, in 1997, both the control (45 percent of 2,572 total) and selection cuts (40 percent) yielded almost three times the number of *Brachinus* than the clearcuts (14 percent). In 2000 (an exceptionally dry summer), both the control (44 percent of 465 total) and selection cuts (45 percent) yielded four times the number of *Brachinus* than the clearcuts (11 percent). The steady loss of beetles during the study is believed to be due to several summer floods followed by several summer droughts. Nonetheless, this study demonstrates that the selection cuts continued to provide the habitat needs of these beetles, and the clearcuts continued to provide less suitable habitat, despite a lush growth of plants in 2000.

## INTRODUCTION

According to Elzinga (2000), about 40 percent of all insects are beetles, and they provide a wide range of functional roles within forests, such as herbivores, predators, scavengers, decomposers, and fungivores. Ground beetles (family Carabidae) are a large, very diverse group of about 25,000 species worldwide, with about 2,200 species in North America; it is the fifth largest beetle family (Elzinga 2000). Ground beetles are found under litter, stones, and debris, mostly associated with damp habitats. When disturbed, ground beetles run quickly but seldom fly. Most adults and larvae are generalist predators, but some are highly specialized on specific hosts. A few are herbivorous on seeds. These beetles are active searchers in soil litter. Because of their ease of collection, ground beetles have been used in the past as indicators of habitat conditions and/or change (Niemela and others 1993, Thiele 1977).

Studies of ground beetles in bottomland hardwoods are few, with most being faunal surveys (Allen and Thompson 1977, Goff 1952). Two recent studies from the south-central United States provide more analytical information on the effects of disturbance on these beetles. Thompson and Allen (1993) studied the beetles in the Saline River bottom in south-central Arkansas, and Warriner and others (2002) documented beetle diversity from two stream bottoms: one in the Delta National Forest in west-central Mississippi and the other in Monroe County in northeastern Mississippi. Ground beetles in the genus *Brachinus* were recovered in both these studies.

The genus *Brachinus* are colorful insects, with orangish head and prothorax and metallic black or dark blue-green wing covers that appear cut-off at their ends. They have the common name bombardier beetles because they defend themselves

by squirting a hot, toxic liquid from their anus. Little is known of their biology and ecology. They are typically found near all sorts of water bodies. They hide under stones, logs, debris, and so forth during the day and come out to forage at night. The adults are general scavengers on dead and dying arthropods; the larvae are probably parasites on water beetle pupae. Some of the beetles in this genus cannot fly but many can and are attracted to lights. Adults usually overwinter and become active between March and October (Erwin 1970).

Little information is available on how ground beetles are affected by anthropogenic influences in bottomland forests of the West Gulf Coastal Plain. The *Brachinus* were studied because they dominated the ground beetle fauna, and little is known about them or their response to forest disturbance.

## METHODS

### Study Site

The study site is located on Pittman Island in Issaquena County, MS, on lands owned by Anderson-Tully Company (fig. 1). The island is located within the levee system of the Mississippi River and has typical ridge/swale topography with riverfront hardwood species associations (Hodges and Switzer 1979). Soils are mostly silt loam and clay. Past silvicultural activities included a partial harvest in 1979 and infrequent light harvests before 1969.

Two reproduction cutting methods were used. The clearcut involved removing all merchantable stems during the winter of 1995-1996. In April, 1996, all remaining stems > 5 cm diameter at breast height (d.b.h.) were felled. The selection cut, as practiced by Anderson-Tully Company, involved the removal of approximately one-third to one-half of the total

<sup>1</sup> Professor, Arkansas Forest Resources Center, School of Forest Resources, University of Arkansas at Monticello, Monticello, AR 71656; and Research Forester, USDA Forest Service, Southern Research Station, Center for Bottomland Hardwoods Research, Stoneville, MS 38776, respectively.

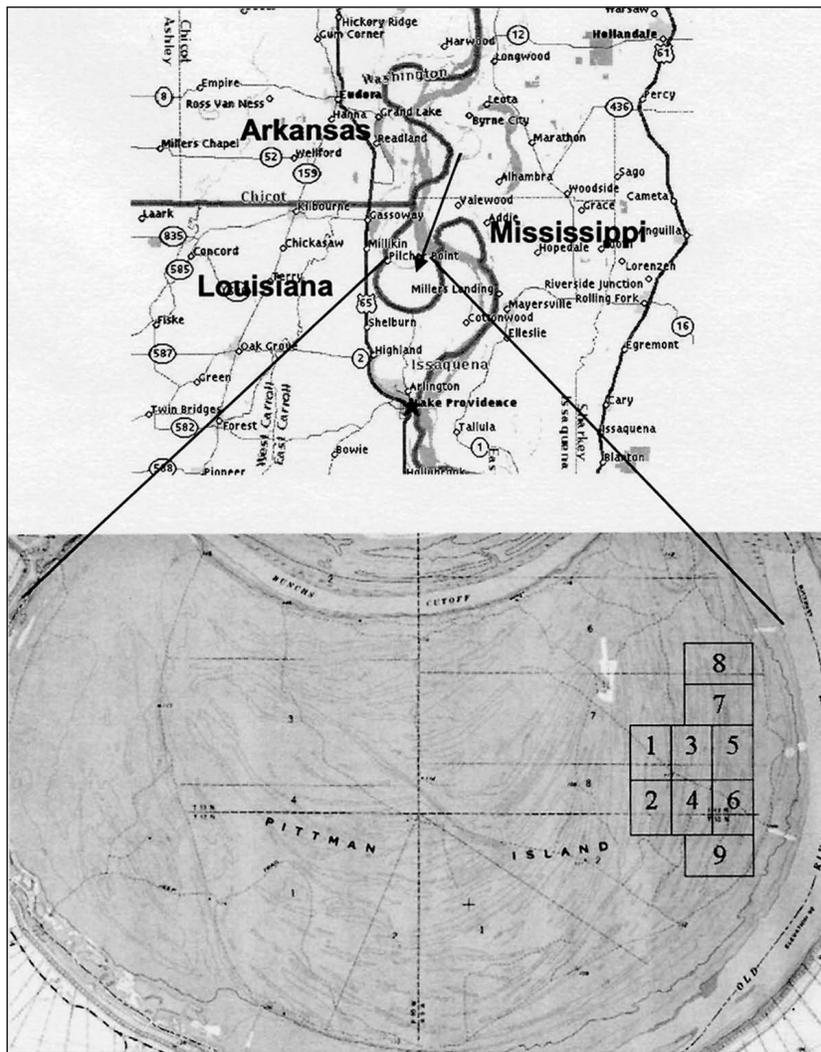


Figure 1—Location of Pittman Island, MS, near the northeastern corner of Louisiana, and showing treatment layout with stands 1, 6, and 7 clearcuts, 4, 5, and 8 selection cuts, and 2, 3, and 9 controls.

stand basal area and favored, to retain for future development, desirable species such as green ash (*Fraxinus pennsylvanica* Marsh.), sweet pecan [*Carya illinoensis* (Wangenh.) K. Koch], and Nuttall oak (*Quercus texana* Buckl.). The harvesting treatments and control were about 20 ha in size and were replicated 3 times in a randomized design (fig. 1).

### Stand Variables

Pre-treatment sampling occurred on 16 0.1-ha circular plots systematically located along 4 transects in each of the 9 stands. All trees > 9.6 cm d.b.h. were measured by species, d.b.h., crown classification, and topographic position (ridge or swale). Soil pH and texture measures were taken from the plots in each stand and averaged after determination. Canopy coverage was measured after harvest using a standard spherical crown densiometer.

### Beetle Collecting

Beetles were collected using 20 pitfall traps per stand, with the traps spaced at 10-m intervals along a transect bisecting each stand and running along the ridge. Each trap consisted

of a cylinder made from a 15-cm long section of 10-cm diameter white PVC pipe. The cylinder was buried vertically (with open end up) and level with the ground surface. A 700-ml plastic drinking cup was placed in the cylinder and filled about one-third full with preserving fluid, a 1:1 mixture of ethylene glycol and water. To simplify content removal, an easily removable strainer (made from another plastic cup and aluminum window screen) was placed into the bottom of each drinking cup. A 0.09-m<sup>2</sup> plywood rain lid, held about 5 cm over the cup using three large nails as legs, reduced the amount of water entering each trap. Beetles were separated from the trap contents in the laboratory, soaked in warm soapy water to clean the body of dirt and fats, rinsed, placed in 80 percent ethyl alcohol for 1 month, and then pinned for identification. Traps were serviced weekly from July 18 to November 19 in 1996, July 08 to November 17 in 1997, and June 14 to November 11 in 2000. Flooding occasionally influenced the site and beetle sampling. In 1996, the entire site was flooded from mid May to mid June, in 1997 from early March to mid April, in 1998 from late April to late May, and in 1999 from early to mid February. No flooding occurred in the extremely dry summer of 2000.

Beetles were identified to genus using Ball and Bousquet (2001). Representative specimens of difficult-to-identify beetles were sent to George Ball (E.H. Strickland Entomological Museum, University of Alberta) for identification. The four *Brachinus* species identified by Ball included *B. adustipennis* Erwin, *B. alternans* Dejean., *B. ovipennis* LeConte, and *B. quadripennis* Dejean. Identifications to species were made using characters provided by George Ball.

### Analysis

Stand parameters were analyzed using the mean of 16 subsamples taken from each stand and the PROC GLM in SAS (SAS Institute Inc. 1999). Significance was accepted at  $\alpha \leq 0.05$ . Correlation analysis with PROC CORR in SAS was used to relate canopy coverage for the years 1996 and 1997 to *B. alternans* numbers, the only species with ample numbers across these 2 years and treatments. Because canopy coverage varied little between the 2 years, years were pooled to increase statistical sensitivity. The influence of treatments on beetles was analyzed using Chi-Square analysis in SPSS (SPSS Inc. 2004) on beetle counts by year and treatment. The analysis revealed departures from equal representation among the treatments. To assess species preferences for specific treatments, the presence-absence data by treatment, year, and replicate for the four *Brachinus* species was analyzed using the Cluster Analysis procedure in PC-ORD (McCune and Mefford 1999). We used the Flexible Beta linking method ( $\beta = -0.25$ ) and the Sorensen (Bray-Curtis) distance measure of the cluster routine.

## RESULTS AND DISCUSSION

### Stand Variables

The 1995 pre-harvest parameters (table 1) clearly show no differences in common tree and soil measurements. This shows that subsequent treatment effects are likely the result of post-harvest influences. As expected, the post-harvest sampling showed harvesting significantly altered canopy coverage (table 1). However, correlation analysis of *B. alternans* numbers with canopy coverage showed weak relationships ( $r = 0.443$ ,  $P = 0.0749$ ), so canopy coverage provides little predictive value in assessing why this species may have "preferred" specific treatments.

### Beetles

A total of 10,235 ground beetles representing 40 species were collected over the 3 years. Of these, 6,733 or 66 percent, were *Brachinus* individuals, comprising four species. The *Brachinus* are studied because they dominated the ground beetle fauna. Table 2 shows the *Brachinus* count by species, year, and treatment. Of the *Brachinus* taxa, *B. alternans* dominated the site with 97 percent of the specimens. Evidently, this forested island provides suitable habitat for this species.

The contingency table analysis of counts by year and treatment revealed significant differences among treatments, with fewer beetles collected in the clearcuts over all 3 years than would be expected by chance (Pearson Chi-Square = 550.9, 4 df;  $P = 0.000$ ) (table 3). Thus, these beetles do not prefer cleared areas. Instead, they preferred the control and selection cuts, although this tendency was less obvious in 1996,

**Table 1—Stand parameters measured pre-treatment in 1995 and post-treatment in 1996, 1997, and 1998**

Parameter	Year	Treatments						F value	P > F
		Control		Selection cut		Clearcut			
		Mean	SE	Mean	SE	Mean	SE		
Pre-treatment									
Trees per ha	1995	467	22	438	28	478	28	1.31	0.4000
Basal area per ha	1995	27	2.35	27	0.24	27	1.52	0.34	0.8400
Soil pH (0--7.5 cm)	1995	6.3	0.05	6.4	0.06	6.3	0.07	3.94	0.1064
Soil texture (0--7.5 cm)	1995	Clay	Clay	Clay	Clay	Clay	Clay		
Soil texture (22.9--30.5 cm)	1995	Silty clay	Silty clay	Silty clay	Silty clay	Clay	Clay		
Post-treatment									
Canopy coverage	1996	95	0.11	62	1.97	0	0.00	909.11	0.0001
	1997	92	2.12	65	1.57	0	0.00	405.54	0.0001
	1998	69	2.19	44	0.96	0	0.00	238.66	0.0001

**Table 2—Number of each *Brachinus* species collected from pitfall traps by treatment and year at Pittman Island, MS**

Species	Treatments									Totals
	Check			Selection cut			Clearcut			
	1996	1997	2000	1996	1997	2000	1996	1997	2000	
<i>B. adustipennis</i>	6	0	0	10	0	0	53	6	0	75
<i>B. alternans</i>	681	1,137	191	2,282	1,031	202	627	342	47	6,540
<i>B. ovipennis</i>	2	22	7	12	5	6	4	22	3	83
<i>B. quadripennis</i>	0	2	5	17	3	2	2	2	2	35
Totals	689	1,161	203	2,321	1,039	210	686	372	52	6,733

**Table 3—Percentage of all *Brachinus* collected from pitfall traps by year and treatment at Pittman Island, MS**

Year	Check	Treatments		Total
		Selection cut	Clearcut	
----- percent -----				
1996	18.6	62.8	18.6	3,696
1997	45.1	40.4	14.5	2,572
2000	43.6	45.2	11.2	465
Total				6,733

just after the harvest. Also, the numbers of beetles declined precipitously during the collecting season in 2000, apparently due to an extended drought.

Cluster analysis (fig. 2) showed there was no pattern of preference for silvicultural treatments by beetle species, with all three treatments typically associated with the principal clusters. *B. alternans* was present in all years and treatments, so this species has little predictive value in assessing treatment preferences. *B. ovipennis* and *B. adustipennis* provide the major separation, but no clear treatments preferences are present.

Warriner and others (2002) found more *B. alternans* in bottomland stands thinned 2 years earlier, than in un-thinned stands. Similarly, Thompson and Allen (1993) noted that *B. alternans*

was most common in an experimental bottomland clearcut (with treatments that included both with and without deadening of unmerchantable residual trees) than in the undisturbed controls. They also reported *B. alternans* numbers were much lower in the clearcut that was sheared and chopped.

Thus, our results further indicate that *B. alternans* is widespread and abundant, and tolerant of moderate disturbance. Furthermore, this study reinforces that selection cuts provide adequate habitat for these beetles, and the clearcuts provide less suitable habitat.

### ACKNOWLEDGMENTS

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### LITERATURE CITED

- Allen, R.T.; Thompson, R.G. 1977. Faunal composition and seasonal activity of Carabidae (Insecta: Coleoptera) in three different woodland communities in Arkansas. *Annals of the Entomological Society America*. 70: 31-34.
- Ball, G.E.; Bousquet, Y. 2001. Carabidae Latreille, 1810. In: Arnett, R.H.; Thomas, M.C., eds. *American beetles*, volume I. Chapter six. Boca Raton, FL: CRC Press: 33-132.
- Elzinga, R.J. 2000. *Fundamentals of entomology*, fifth ed. Upper Saddle River, NJ: Prentice-Hall. 495 p.

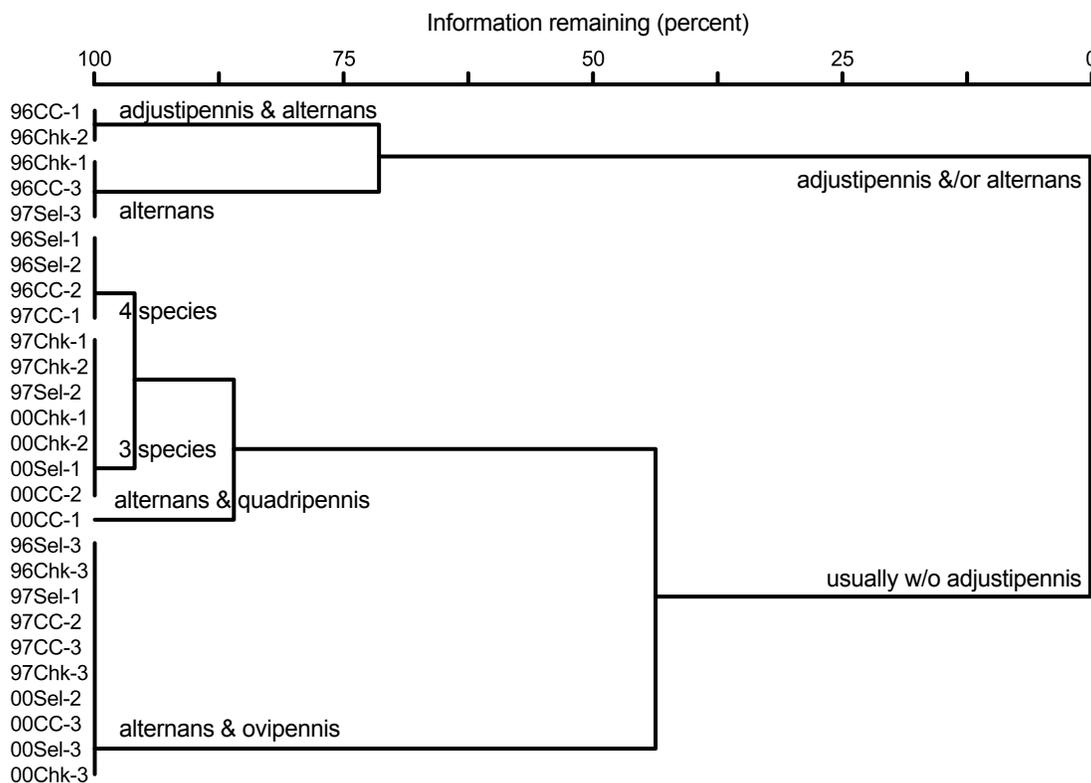


Figure 2—Dendrogram showing relationships among silvicultural treatments, years, and replicates for *Brachinus* species based on presence/absence data. [key: last 2 numbers of year, abbreviated treatment (control = Chk, selection cut = Sel, clearcut = CC) and replicate number (1, 2, or 3)].

- Erwin, T.L. 1970. A reclassification of bombardier beetles and a taxonomic revision of the North and Middle American species (Carabidae: Brachinida). *Quaestiones Entomologicae*. 6: 4-215.
- Goff, C.C. 1952. Floodplain animal communities. *American Midland Naturalist*. 57: 478-486.
- Hodges, J.D.; Switzer, G.L. 1979. Some aspects of the ecology of southern bottomland hardwoods. In: *Proceedings of the Society of American Foresters annual meeting*. Bethesda, MD: Society of American Foresters: 360-365.
- McCune, B.; Mefford, M.J. 1999. PC-ORD. Multivariate analysis of ecological data. Version 4.17. Glendon Beach, OR: MjM Software Design. 232 p.
- Niemela, J.; Langor, D.; Spence, J.R. 1993. Effects of clear-cut harvesting on boreal ground-beetle assemblages (Coleoptera: Carabidae) in western Canada. *Conservation Biology*. 7: 551-561.
- SAS Institute Inc. 1999. SAS/STAT user's guide, version 8. Cary NC: SAS Institute, Inc. 2552 p.
- SPSS Inc. 2004. SPSS Base 13.0 user guide. Chicago, IL: SPSS Inc. 677 p.
- Thiele, H.U. 1977. Carabid beetles in their environments. New York: Springer-Verlag. 369 p.
- Thompson, L.C.; Allen, R.T. 1993. Site preparation affects ground beetles in a clearcut bottomland hardwood forest in southeastern Arkansas. In: Brissette, J.C., ed. *Proceeding of the seventh biennial southern silvicultural research conference*. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 57-64.
- Warriner, M.D.; Nebeker, T.E.; Leininger, T.D.; Meadows, J.S. 2002. The effects of thinning on beetles (Coleoptera: Carabidae, Cerambycidae) in bottomland hardwood forests. In: Outcalt, K.W., ed. *Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 569-573.



# **Fire**

*Moderators:*

**BRIAN OSWALD**

Stephen F. Austin State University

and

**DAVID VAN LEAR**

Clemson University



# CHANGES IN THE DISTURBANCE REGIME OF UPLAND YELLOW PINE STANDS IN THE SOUTHERN APPALACHIAN MOUNTAINS DURING THE 20<sup>TH</sup> CENTURY

Patrick H. Brose and Thomas A. Waldrop<sup>1</sup>

**Abstract**—A dendrochronology study was conducted in four upland yellow pine communities in Georgia, South Carolina, and Tennessee to determine whether the number and frequency of stand-level disturbances had changed since 1900. Increment cores of Table Mountain pine (*Pinus pungens* Lamb.), pitch pine (*P. rigida* Mill.), shortleaf pine (*P. echinata* Mill.), and chestnut oak (*Quercus prinus* L.) were obtained from the stands and analyzed for major, moderate, and minor canopy releases. Cross sections of intermediate hardwoods were collected and examined for fire scars. Historical drought and hurricane records were obtained from the National Oceanic and Atmospheric Administration. These records and the data from the cores and cross sections were analyzed for changes in the number and frequency of canopy releases, droughts, fires, and tropical storms in 2 50-year increments, pre- and post-1950. The number of canopy releases, droughts, fires, and tropical storms decreased considerably after 1950. These disturbances are less common now than they were a century ago and no longer coincide in occurrence. This change may result in dramatic repercussions for sustaining these conifer communities.

## INTRODUCTION

Disturbance events have been an integral part of Southern Appalachian forests for millennia (Yarnell 1998). Three important large-scale disturbances for this region are droughts, fires, and hurricanes. Singularly and interactively, these disturbances shape the composition and structure of upland forests. For example, a hurricane may predispose an area to burning by increasing fuel loadings, or a drought may increase fire intensity and severity, causing additional tree mortality. It is important that managers of upland yellow pine (UYP) forests understand how these disturbances are related on a temporal scale and how their occurrence has changed over time.

UYP forests are located throughout the Southern Appalachian Mountains on xeric, mid-elevation, south- and west-facing ridges (Zobel 1969). Their canopies are dominated by pitch, shortleaf, Table Mountain, and Virginia pines, while their mid-stories consist primarily of hardwoods, especially chestnut oak. Because of their position in the landscape and species mix, UYP forests offer an excellent opportunity to study droughts, fires, and hurricanes.

Dendrochronology can be used to identify past disturbances and how they have changed through time by combining radial-growth analysis, timelines for species establishment, and recorded history. Previous studies in UYP communities (Armbrister 2002, Williams and Johnson 1990) focused on the role of fire in establishing these stands and, to a lesser degree, the decline in fire occurrence after the onset of organized fire-control policies circa 1925 (Yarnell 1998). They did not investigate whether the frequency of other disturbances also may have changed as fire was becoming less common. For this study, we used dendrochronology in UYP stands to determine whether the number and frequency of canopy releases, droughts, fires, and hurricanes have changed over time.

## METHODS

### Study Stands

This study was conducted in four UYP stands (designated GA, SCI, SCII, and TN) on the Chattahoochee National Forest in northern Georgia, Sumter National Forest in western South Carolina, and Great Smoky Mountains National Park in eastern Tennessee. The stands were situated on the tops and upper side slopes of south- and west-facing ridges. Elevations ranged from 1,400 to 3,600 feet, and soils were well-drained sandy or silt loams formed in place by the weathering of gneiss, sandstone, and schist parent material (Carson and Green 1981, Davis 1993, Herren 1985). Consequently, soils were of low fertility and strongly acidic. Climate was warm, humid, and continental; average monthly high temperatures ranged from 25 °F in January to 85 °F in July. Mean annual precipitation ranged from 53 to 73 inches distributed evenly throughout the year.

Composition, structure, and size of the four UYP stands were similar. In general, they were 10 to 30 acres each and consisted of 10 to 20 woody species distributed in 3 distinct strata. The main canopy was 50- to 65-feet tall, broken and patchy, and consisted almost exclusively of 2 or more of the UYP species and chestnut oak. A ubiquitous midstory stratum (10- to 40-foot tall) generally lacked a pine component. It consisted almost exclusively of chestnut oak and other hardwood species such as blackgum (*Nyssa sylvatica* Marsh.), red maple (*Acer rubrum* L.), scarlet oak (*Q. coccinea* Muenchh.), and sourwood [*Oxydendrum arboreum* (L.) DC.]. Together, the main and sub canopies contained 1,100 to 1,400 stems and 130 to 175 square feet of basal area per acre. The understory stratum (3- to 10-feet tall) ranged from absent to imperviously dense. When present, it was dominated by ericaceous shrubs, especially mountain laurel (*Kalmia latifolia* L.), and lacked hardwood and pine seedlings as well as herbaceous plants.

<sup>1</sup> Research Silviculturist, USDA Forest Service, Northeastern Research Station, Irvine, PA; and Research Forester, USDA Forest Service, Southern Research Station, Clemson, SC 29634, respectively.

## Sampling Procedures

In each stand in the fall of 1999, 30 to 45 0.05-acre rectangular plots were located systematically to ensure uniform coverage or selected from an ongoing study (Waldrop and Brose 1999). From each plot, at least one increment core was extracted from the uphill side of six to eight randomly selected dominant and intermediate trees at a height of 1 foot above the ground to intersect hidden, internal scars. Cores with visible defects were retained, but others were extracted until a sound core was obtained. Typically, only one core was needed from most trees, and only several trees required more than two cores. It was not possible to obtain bole cross sections from these larger trees due to landowner restrictions, difficulty accessing some stands, or safety constraints. However, we did obtain six to eight cross sections from suppressed trees and shrubs on each plot.

## Lab Procedures

Nearly 1,000 cores were collected from the four UYP stands. These were air dried for several weeks, mounted, and sanded with increasingly finer sandpaper (120, 220, 320, and 400 grit) to expose the annual rings. More than 900 cross sections collected from the stands were dried and sanded similarly. An initial establishment date for each core and cross section was determined by aging to the innermost ring or pith under a 40-power dissecting microscope.

The 18 oldest, best-quality (free of visible defects) cores from each stand were selected for radial growth analysis. These were skeleton-plotted to identify signature years for cross-dating to recognize false or missing rings (Stokes and Smiley 1996). After proper ages were verified for these cores, annual rings were measured to the nearest 0.002 mm with a Unislide "TA" Tree-Ring Measurement System (Velmex, Inc., Bloomfield, NY). The COFECHA 2.1 quality assurance program in the International Tree-Ring Data Bank Program Library (Cook and others 1997) was used to verify the accuracy of the dating.

After dating and measuring, each core was examined for major, moderate, and minor releases using the JOLTS program (Holmes 1999) in the International Tree-Ring Data Bank Program Library based on criteria established by Lorimer and Frelich (1989). A major release was defined as a  $\geq 100$ -percent increase in average growth that lasted at least 15 years and a moderate release as a  $\geq 50$ -percent increase lasting 10 to 15 years. These correspond to large, canopy-level disturbances that release residual trees from competition until crown closure reoccurs. Nowacki and Abrams (1997) defined a minor release as a  $\geq 25$ -percent increase in average growth lasting 5 to 10 years. This criterion identifies partial crown releases that provide increased sunlight to adjacent canopy trees.

## Dating of Disturbances

All cores and cross sections that contained an internal or external scar were skeleton-plotted and crossdated to assign an absolute date to each scar. Because scars can be caused by means other than fires, we determined that three or more scars had to occur in the same year in the same stand for a scar to be considered of fire origin.

The Palmer Drought Severity Index (PDSI), available for 1895 to 1999 from the National Oceanic Atmospheric Administration (NOAA 2000), provided monthly precipitation and temperature data for each stand on a State and sub-regional basis.

Records of hurricanes and tropical storms since 1850 also were available (NOAA 2003) and showed the routes of these storms.

## Statistical Analysis

We divided our timeline into 2 50-year periods: 1900 to 1949 and 1950 to 1999. This division corresponds to when organized fire control finally became effective in the region (Yarnell 1998). Analysis of variance with the Newman-Keuls mean separation test (SAS 2002) was used to test whether the number of major, moderate, and minor canopy releases differed between and within these periods. Data were analyzed as a randomized complete-block design with stand serving as the blocking factor, time period as the factor, and number of major, moderate, and minor releases as the dependent variable. Residuals were examined to ensure that model assumptions were met;  $\alpha$  was 0.05 for the analysis.

The FHX2 program (Grissino-Mayer 2004) can be used to characterize the interval between successive canopy releases and to evaluate the goodness of fit between disturbance frequencies and normal and Weibull distributions. The frequency data were skewed so we used the Weibull distribution as a measure of central tendency. We tested the means of the transformed data with *T*-tests (unequal variances) to detect differences in mean disturbance interval of major, moderate, and minor releases among and within eras;  $\alpha$  was 0.125 for these tests.

## RESULTS

In all, 293 release events were identified from the 72 cores. These were distributed as 176 (60 percent) minor releases, 85 (29 percent) moderate releases, and 32 (11 percent) major releases. There were no differences in the number of major, moderate, and minor releases among the four stands, so we pooled the data to simplify reporting.

There were significant differences in the mean number of major, moderate, and minor releases among and within time periods (fig. 1). Regardless of the period, the number of minor

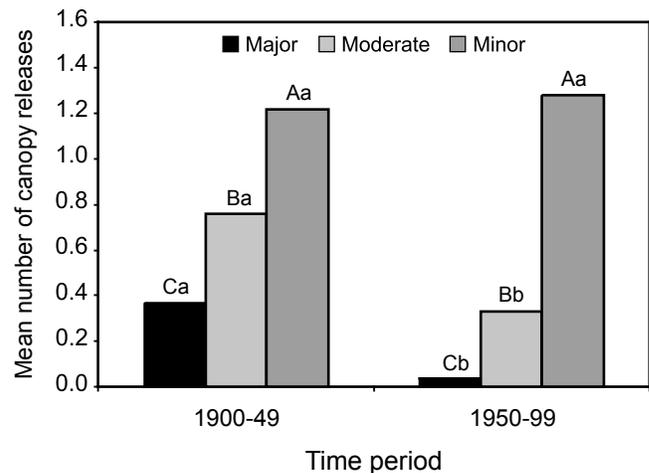


Figure 1—The mean number of major, moderate, and minor canopy releases for the time periods 1900-1949 and 1950-1999. Columns with different uppercase letters are statistically different within a time period at  $\alpha = 0.05$ . Columns with different lowercase letters are statistically different between time periods at  $\alpha = 0.05$ .

canopy releases always exceeded the number of moderate releases. Similarly, the number of moderate canopy releases was always greater than the number of major releases. The number of major and moderate releases decreased from the early 1900s to the late 1900s. The number of minor releases did not differ among time periods.

The frequency of major and moderate canopy releases in each time period did not differ by stand so these data were combined to simplify reporting (table 1). Events varied in frequency of occurrence during the early 1900s from 6.3 to 13.6 years depending on stand. Major and moderate canopy releases were too infrequent during the late 1900s for analysis. Minor canopy releases were much more frequent than major or moderate releases for both periods and all stands. Minor releases tended to increase in frequency from the early 1900s, but this change was not significant except at the GA stand.

The number and frequency of droughts, fires, and hurricanes in the southern Appalachian Mountains changed in a similar pattern during the 20<sup>th</sup> century (fig. 2). During the first half of the 20<sup>th</sup> century, 10 to 13 droughts occurred, and these were usually singular events except from 1925 to 1935. The numbers of droughts during 1950 to 1999 was the same as during the preceding period, but most were concentrated in the early 1950s and late 1980s. Detectable fires at each stand numbered two to six between 1900 and 1949 and one or two after 1950. Hurricanes showed the same numeric distribution as fires: four to seven from 1900 to 1950 and two after 1950.

## DISCUSSION

There have been dramatic changes in the disturbance regime of the southern Appalachian Mountains during the 20<sup>th</sup> century. Between 1900 and 1950, the occurrence of stand-level disturbances was 1 every 6 to 13 years, as was the case throughout the southern Appalachians (Yarnell 1998). These

**Table 1—The Weibull median return interval and confidence interval in years for major, moderate, and minor crown releases at the four study stands during 1900-49 and 1950-99 time periods**

Time period	Major/moderate crown releases <sup>a</sup>		Minor crown releases <sup>a</sup>	
	Median	CI	Median	CI
<b>GA</b>				
1900-49	13.6	5.5–26.6	5.2a	3.0 – 8.6
1950-99	na <sup>b</sup>	na	2.1b	1.2 – 3.0
<b>SCI</b>				
1900-49	6.3	1.0–12.9	1.4a	0.7 – 2.1
1950-99	na	na	1.5a	0.9 – 2.5
<b>SCII</b>				
1900-49	7.8	6.9–13.1	2.2a	0.9 – 3.8
1950-99	na	na	1.8a	1.1 – 4.2
<b>TN</b>				
1900-49	6.7	2.0–16.3	2.3a	0.9 – 4.4
1950-99	na	na	1.5a	0.8 – 2.4

<sup>a</sup> Medians with different lowercase letters are significantly different within that site at  $\alpha = 0.125$ .

<sup>b</sup> Insufficient number of releases for analysis.

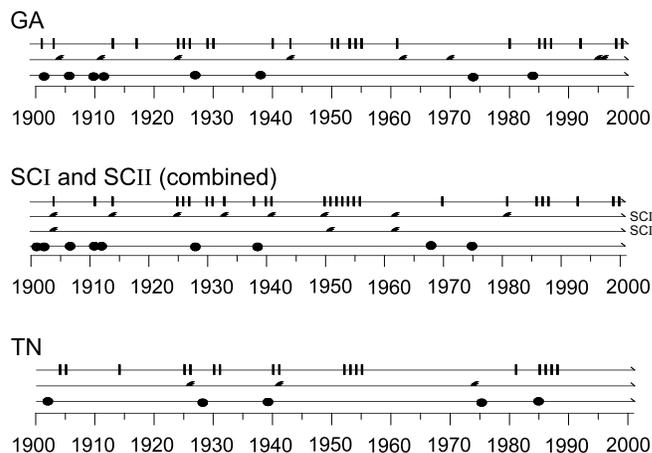


Figure 2—The number and temporal distribution of droughts, fires, and hurricanes in the GA, SCI, SCII, and TN study stands since 1900. Severe droughts (PDSI < -2.0) are denoted by short vertical bars, fires by diagonal slashes, and hurricanes by black dots.

major and moderate crown releases were most likely widespread fires, large-scale weather events, chestnut blight, and timber harvesting. From 1900 to 1950, at least 15 fires burned some or all of the 4 stands. Intermixed with the fires were 11 tropical storms. Chestnut blight moved through the region in the late 1920s (Keever 1953), and all stands had a significant chestnut component, especially GA. SCI and SCII experienced at least one logging operation.

There were several minor releases per decade during the first half of the 20<sup>th</sup> century. These events likely were lightning strikes, natural mortality of old trees, outbreaks of southern pine bark beetle (*Dendroctonus frontalis* Zimmermann), isolated fires, and thunderstorm downbursts.

Reoccurring droughts probably augmented the effects of all these disturbances. During the first half of the 20<sup>th</sup> century, 34 years were drier than average with 19 experiencing severe droughts. Fires occurring in drought years, e.g., the 1925 drought, and fires likely were more intense, severe, and widespread than those during non-drought years.

Since the mid-1950s, there have been virtually no major and moderate canopy releases while the frequency and number of minor releases have remained unchanged. Stand-level disturbances now are the exception. There were only four fires and six tropical storms. Logging occurred once at SCI and SCII and not at all at GA and TN. There have been no major disease epidemics like chestnut blight. Outbreaks of the bark beetle and minor weather events probably are the only disturbances that were similar in frequency between the first and second halves of the 20<sup>th</sup> century. The background disturbance of drought also was less common after the mid-1950s.

The tandem occurrence of tropical storms and surface fires may be a key event for perpetuating UYP stands. When a canopy-level disturbance occurs first, an ideal high-light environment is created for pine and oak regeneration. The stand also is predisposed to fire due to increasing fuel loads and insolation. A lightning strike or fire of human origin probably would burn more intensely in the aftermath of the preceding canopy disturbances than otherwise, opening sealed cones

and reducing hardwood competition. Table Mountain pine seedlings that established in the aftermath of the initial canopy disturbance would be killed but would be replaced rapidly by new germinants. Pitch and shortleaf pine seedlings would sprout from the root collar. After several years of initial slow height growth, pine seedlings grow quickly and overtake competing hardwoods to form a new pine-dominated stand.

If the disturbance order were reversed, i.e., the fire occurred first, understory hardwoods would be top-killed, and the sealed cones of Table Mountain pine would open. Although the canopy remains largely intact, there is sufficient sunlight for pine seedlings to survive. The following tropical storm, beetle infestation, or blight creates gaps in the canopy that ensure the young pines sufficient long-term light for some to eventually reach the canopy, ensuring perpetuation of a UYP community.

The intermixing of disturbances also means that no single disturbance need be catastrophic, that is, driving initial stand dynamics by itself. Canopy disturbances make low- and moderate-intensity fires more effective in controlling hardwoods and stimulating pine regeneration. It is easier for a surface fire in a partially-open stand to generate the necessary heat to girdle stems, consume leaf litter, and burn during the growing season than it is for a fire in a closed stand. Likewise, periodic fires keep the forest understory open, making the gaps that form more conducive to maintaining a pine component in a potentially hardwood-dominated stand. In the absence of the fire or canopy disturbance, continuous pine and oak recruitment ceases, as evidenced by the single fire and storm events after 1950. Additional research is needed on the effects of combined canopy and forest-floor disturbances on forest regeneration processes.

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## LITERATURE CITED

- Armbrister, M.R. 2002. Changes in fire regimes and the successional status of Table Mountain pine (*Pinus pungens* Lamb.) in the southern Appalachians, USA. Knoxville, TN: University of Tennessee. 51 p. Masters thesis.
- Carson, W.S.; Green, T.W. 1981. Soil survey of Rabun and Towns Counties, Georgia. Athens, GA: U.S. Department of Agriculture, Soil Conservation Service. 97 p.
- Cook, E.R.; Holmes, R.L.; Bosch, O. [and others]. 1997. International tree-ring data bank program library. Version 2.1. <http://www.ngdc.noaa.gov/paleo/treering.html> [Date accessed: unknown].
- Davis, H.A. 1993. Soil survey of Blount County, Tennessee. Knoxville, TN: U.S. Department of Agriculture, Soil Conservation Service. 121 p.
- Grissino-Mayer, H.D. 2004. FHx2 user's manual: software for analyzing temporal and spatial patterns in fire regimes from tree rings. Knoxville, TN: University of Tennessee. 101 p.
- Herren, E.C. 1985. Soil survey of Oconee County South Carolina. Columbia, SC: U.S. Department of Agriculture, Soil Conservation Service. 78 p.
- Holmes, R.L. 1999. Program JOLTS: finding growth surges or suppressions in trees. Tucson, AZ: The University of Arizona, Laboratory of Tree-Ring Research. 65 p.
- Keever, C. 1953. Present composition of some stands of the former oak-chestnut forest in the southern Blue Ridge Mountains. *Ecology*. 34: 44-55.
- Lorimer, C.G.; Frelich, L.E. 1989. A method for estimating canopy disturbance frequency and intensity in dense temperate forests. *Canadian Journal of Forest Research*. 19: 651-663.
- National Oceanic and Atmospheric Administration (NOAA). 2000. Temperature-precipitation data. [www.ncdc.noaa.gov/oa/climate/onlineprod/drought/](http://www.ncdc.noaa.gov/oa/climate/onlineprod/drought/). [Date accessed unknown].
- National Oceanic and Atmospheric Administration (NOAA). 2003. Historic hurricanes. [www.hurricane.csc.noaa.gov/hurricane/index.html](http://www.hurricane.csc.noaa.gov/hurricane/index.html). [Date accessed unknown].
- Nowacki, G.J.; Abrams, M.D. 1997. Radial growth averaging criteria for reconstructing disturbance histories from presettlement-origin oaks. *Ecological Monographs*. 67: 225-249.
- SAS Institute. 2002. User's guide. Cary, NC: SAS Institute. 754 p.
- Stokes, M.A.; Smiley, T.L. 1996. An introduction to tree-ring dating. Tucson, AZ: University of Arizona Press. 73 p.
- Waldrop, T.A.; Brose, P.H. 1999. A comparison of fire intensity levels for stand replacement of Table Mountain pine (*Pinus pungens* Lamb.). *Forest Ecology and Management*. 113: 155-166.
- Williams, C.E.; Johnson, W.C. 1990. Age structure and the maintenance of *Pinus pungens* in pine-oak forests of southwestern Virginia. *American Midland Naturalist*. 124: 130-141.
- Yarnell, S.L. 1998. The Southern Appalachians: a history of the landscape. Gen. Tech. Rep. SRS-18. Asheville, NC: U.S. Department of Agriculture, Forest Service. 45 p.
- Zobel, D.B. 1969. Factors affecting the distribution of *Pinus pungens*, an Appalachian endemic. *Ecological Monographs*. 39(3): 303-333.

# EARLY DYNAMICS OF TABLE MOUNTAIN PINE STANDS FOLLOWING STAND-REPLACEMENT PRESCRIBED FIRES OF VARYING INTENSITY

Thomas A. Waldrop, Helen H. Mohr, and Patrick H. Brose<sup>1</sup>

**Abstract**—Interest in using stand-replacement prescribed fires to regenerate stands of Table Mountain pine (*Pinus pungens* Lamb.) has increased in the past decade, but the type and intensity of fire needed to achieve success have been undefined. In an earlier paper, we concluded from first-year results that flames must reach into the crowns to kill most overstory trees and provide sunlight to the forest floor. In this paper, we show that lower-intensity flames will eventually achieve the same results. Overstory mortality continued throughout the 6-year measurement period, and pine numbers increased. Stand replacement was successful at all intensities measured.

## INTRODUCTION

Recent fire exclusion policies in the Southern Appalachian Mountains may have reduced plant community diversity (Van Lear and Waldrop 1989). Of concern is Table Mountain pine (*Pinus pungens* Lamb.), whose silvical characteristics, such as serotinous cones and shade intolerance, suggest that fire created stands of this species (Zobel 1969). Today, most stands are entering later seral stages, with oaks (*Quercus* spp.) replacing Table Mountain pines in the overstory and mountain laurel (*Kalmia latifolia* L.) replacing it in the shrub layer. Dendrochronology suggests that large-scale disturbances historically created these stands, and frequent low-intensity fires maintained them (Brose and others 2002, Sutherland and others 1995). As a result of changing species dominance and stand structure, the Southern Appalachian Assessment recognizes Table Mountain pine woodlands as one of 31 rare communities (Southern Appalachian Man and the Biosphere 1996).

Most research addressing the role of fire in Table Mountain pine stands has been limited to postwildfire studies, which suggest that high-intensity prescribed fires are needed to remove the forest canopy and expose mineral soil for successful regeneration (Williams and Johnson 1992, Zobel 1969). Williams (1998) suggested that Table Mountain pine stands are in decline as a result of fire exclusion and inadequate understanding of the species regeneration biology.

High-intensity, stand-replacement prescribed burning may reverse the decline. However, accomplishing these burns is difficult. Such prescriptions provide a narrow window of opportunity and raise questions about worker safety and smoke management. Waldrop and Brose (1999) examined four levels of fire intensity to determine which provided adequate levels of overstory mortality and pine regeneration for successful stand replacement. At the end of the first growing season after burning, they found that pine regeneration was abundant in plots burned at all fire intensities, but that overstory mortality was too low unless flames had reached into the crowns of overstory trees. In this paper, we examine the early dynamics of stands regenerated in that study and evaluate previous conclusions. Specifically, we will report on changes to overstory mortality, pine regeneration, and competing vegetation.

## METHODS

Measurement of study plots followed the methods of our previous study (Waldrop and Brose 1999). The study site is in the War Woman Wildlife Management Area of the Tallulah Ranger District in Rabun County, GA. We established study plots in three separate stands immediately south of Rabun Bald. All three stands were within the same 875-acre burn unit and had similar slope, aspect, and stocking of overstory hardwoods and Table Mountain pine. These areas were the only ones within the burn unit that had significant numbers of Table Mountain pine in the overstory. One stand occupies 44 acres at an elevation of 3,600 feet. The remaining stands are both 30 acres at elevations of 3,000 and 2,900 feet. All study areas cover sharp ridgetops and steep slopes with north-eastern or southwestern aspects.

All study stands were burned as one unit on April 4, 1997. The fire covered the entire burn unit including the northeastern and southwestern slopes. Backing fires were set by hand at upper elevations to secure fire lines. At 1030, a helicopter fired the interior portion of the burn unit using a plastic sphere dispenser. Fire intensity was generally high, with crowning in portions of the upper ridges and intermittent torching along the ridge. Other areas of the burn unit burned with high-intensity flames, but crowning was not observed.

Three months after burning, the entire burn unit was surveyed to select study areas exhibiting a range of fire intensity effects. Evidence of fire intensity included bark char height, mortality of overstory trees, portion of the crowns of living trees scorched, presence of scorched needles on the forest floor, soil exposure, insolation on the forest floor, presence of charred cones in the crowns of trees and on the forest floor, and the size of branches on trees and shrubs unconsumed by the fire (see Waldrop and Brose 1999). We placed 60 sample plots, 33 by 66 feet in size, throughout the 3 Table Mountain pine stands in areas burned at a range of intensity levels.

We subjectively described each sample plot by one of four intensity levels (low, medium low, medium high, or high) based on fire effects observed in the plot. Fire-intensity evidence suggested the following description of fire-intensity categories. Low-intensity flames were somewhat uniform in behavior and

<sup>1</sup> Research Forester and Forester, respectively, USDA Forest Service, Southern Research Station, 233 Lehotsky Hall, Clemson, SC 29634-0331; and Research Silviculturist, USDA Forest Service, Northeastern Research Station, P.O. Box 267, Irvine, PA 16329.

reached heights of 6 to 8 feet. Flames of this intensity would be considered as high intensity in most other studies. Medium-low intensity had slightly higher flames and one or more hot spots where localized flames reached into the lower limbs of the overstory trees. Medium-high intensity flames reached into the crowns of all trees within the plots but were not true crown fires where flames jumped from one tree crown to the next. High-intensity flames were true crown fires where flame height exceeded tree height, and flames carried from one crown to the next.

We measured sample plots at the end of the first (1997), second (1998), third (1999), and sixth (2002) growing seasons after burning. Measurements included overstory diameter at breast height (d.b.h.), species, and mortality; hardwood abundance; and species and size of pine regeneration. The study had an unbalanced completely random design with fire intensity as the independent variable. A more complete description of measurements appears in Waldrop and Brose (1999). Measurements in each sample year followed identical procedures. We compared treatment means for the fire-intensity levels by one-way analysis of variance with mean separation by linear contrast ( $\alpha = 0.05$ ). In analyses of pine seedling density, we used the number of cones on the ground and in the crowns of trees as a covariate to adjust for differences in seed source.

## RESULTS

### Overstory Mortality

During the first year after burning, high and medium-high intensities had killed almost all trees, including pines and hardwoods (fig. 1). Medium-low intensity resulted in the mortality of over half the basal area of the stands. Low-intensity flames reduced basal area by < 20 percent, and most of that mortality was within the smaller d.b.h. classes such as 6 and 8 inches.

Because of these results, our previous conclusion was that only fires of high and medium-high intensity would produce conditions of stand replacement. We assumed that stands with 65 to 100 square feet of basal area would produce too

much shade for seedling survival. That conclusion was probably premature, because both pine and hardwood overstory trees continued to die for several years after burning (fig. 1). At the end of the 1998 growing season, basal area remained the same in plots burned at medium-low intensity and above. However, additional mortality occurred in plots burned at low intensity. During that year, the basal areas of plots burned were not significantly different between the low (57.7 square feet per acre) and medium-low intensities (61.3 square feet per acre). By 2002, almost all overstory pines and hardwoods were dead in all study plots. Complete mortality may have occurred before 2002, but measurements were not taken between 1998 and 2002.

Delayed mortality of overstory trees was unexpected, particularly in plots burned at low intensity. Little literature exists on the relationship of fire intensity to hardwood mortality in the Southern Appalachian Mountains. Most studies suggest that low-intensity fires cause scars that eventually lead to disease and death. This study differs from previous ones, however, because fire intensities are higher. We designed the fire to kill hardwoods rather than to protect them. Two unpublished studies associated with the National Fire and Fire Surrogate Study show similar results with moderate fire intensities. Hardwoods in those studies died over a 3- to 4-year period. Causes of delayed mortality may include a combination of xeric site conditions, prolonged drought during the study period, and any root-borne pathogens that may have existed in the study area.

### Pine Regeneration

During the first year after burning, cones opened at all fire intensities, and regeneration was abundant (fig. 2). Even though pine numbers were highest at low and medium-low intensities, we previously concluded that there would be too much shade for seedlings to survive. In 1999, we found that this conclusion was partially true. Table Mountain pine numbers had decreased in all plots but most dramatically in the plots where overstory trees remained alive through that year. However, overstory trees were dying at this time, so not all seedlings were shaded. Pitch pine (*P. rigida* Mill.) seedlings began to appear between 1997 and 1999. We assume that these seedlings were from seed from adjacent stands,

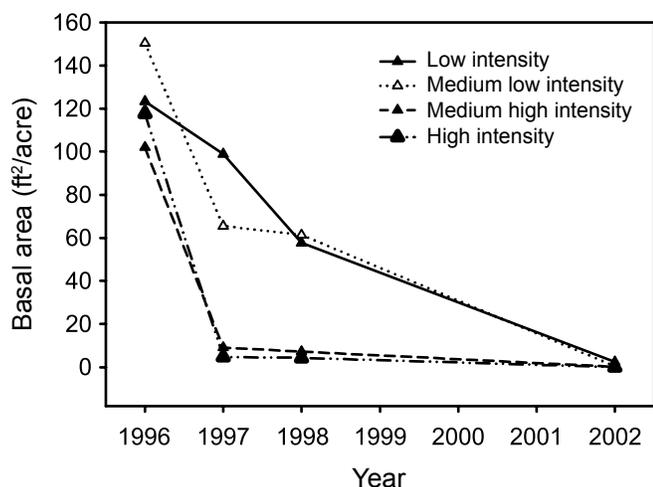


Figure 1—Basal area of surviving trees after prescribed burning by intensity and year.

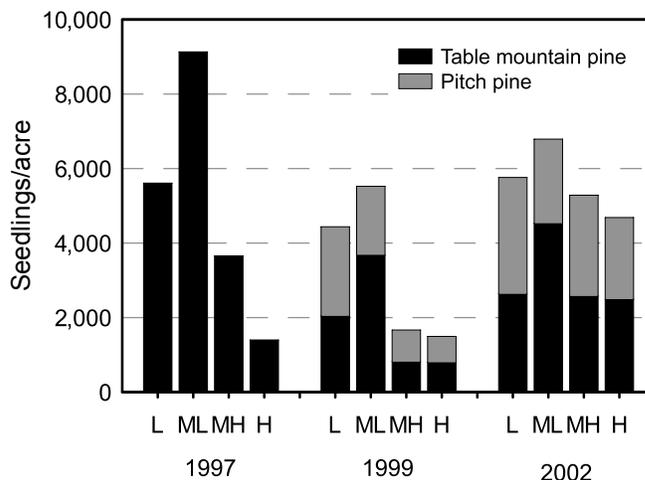


Figure 2—Pine regeneration by intensity and year.

because most overstory trees were dead, and the fire should have consumed the seed in place before burning.

Table Mountain pine seedlings increased in number between 1999 and 2002 in all plots. Pitch pine greatly increased in density between 1999 and 2002 to the point that it outnumbered Table Mountain pine in most plots, thus eliminating the treatment effect for all pines combined. After 6 years, plots burned at all intensities had abundant regeneration of both Table Mountain and pitch pines.

### Sprout Competition

A continuing concern for pine survival is competition from hardwood and shrub sprouts. These sprouts overtopped young pines during year one and have continued to be strong competitors (fig. 3). During the year immediately after the fire, there were large numbers of sprouts of all hardwood and shrub species. Common species were blackgum, oaks, and sassafras. Fire intensity had no impact on numbers of sprouts in 1997.

By the third year after burning, density of all species and species groups (oaks and other hardwoods) increased, and the total number of sprouts was significantly higher in plots burned at medium-high and high intensity. This should not be considered a treatment effect, however, because the difference was due to shrubs, particularly mountain laurel. These shrubs had heavy cover in these plots before burning, thus providing the vertical fuels to create the high intensity fires.

By 2002, mountain laurel sprouts were exceptionally dense in plots burned at medium-high and high intensities. Sprouts of all other species were dense but not significantly different in number among fire-intensity levels. Even though shrub and hardwood sprout density was high, competition did not seem to greatly impact pine survival.

Figure 4 compares the height of the various species groups at the most recent measurement. At all intensity levels, hardwood sprouts overtopped pines regardless of fire-intensity level. Hardwoods were approximately 8 feet tall, while Table Mountain pines were 4 to 5 feet tall and pitch pines were 3 to 4 feet tall. Table Mountain pine overtopped shrubs, and pitch pine should outgrow shrubs by the next growing season. Even

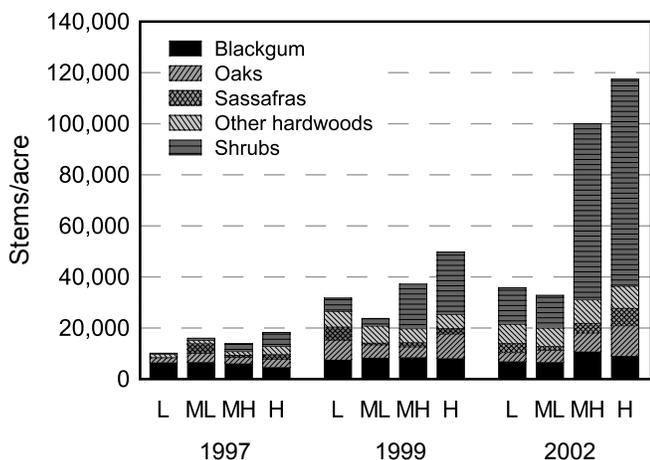


Figure 3—Number of hardwood and shrub sprouts by intensity and year.

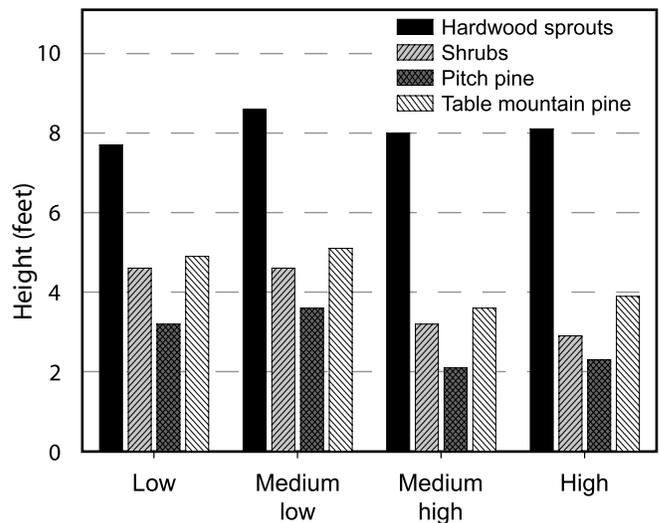


Figure 4—Relative height of pine regeneration and hardwood and shrub sprouts.

though hardwoods overtopped the pines, we do not expect the pines to be eliminated. Pines are numerous and continue to receive overhead sunlight. Previous work with pine-hardwood stands in the Piedmont showed that hardwoods overtopped pines for up to 7 years, but the pines eventually overtopped the hardwoods (Waldrop 1997). We expect a similar pattern here, although the time may be longer.

### CONCLUSIONS

Because we burned all study plots in a single unit, this project is a case study. Many variables may be confounded in our analyses. However, the study does provide some valuable insight into the types of fires needed to create conditions of stand replacement. Fires of all intensities killed essentially all overstory trees, but mortality was not immediate. Mortality occurred over a 3- to 6-year period. Therefore, our previous interpretation of results after only 1 year (Waldrop and Brose 1999) probably led to incorrect conclusions. Regardless of fire intensity, pine regeneration was abundant in all study plots after 6 years. Table Mountain and pitch pine numbers increased over time, suggesting the presence of an outside seed source. Fires of all intensities created heavy hardwood competition. Shrub density was very high in areas where it was present before burning. Pines remain overtopped by hardwoods but are expected to survive and may eventually outgrow the hardwoods.

The continuation of this study shows that our earlier conclusions were premature. Fires of all intensities tested created successful stand replacement of Table Mountain pine. Eventually, all overstory trees died, and pine regeneration increased in density over time. In our earlier publications, we thought that mortality only occurred when flames reached into the crowns of both hardwoods and pines. Therefore, we recommended medium-high flames as a target for managers. Our new results suggest that lower-intensity fires, such as those with flame heights of 6 to 8 feet, can be just as successful. These fires would be safer and easier to accomplish. This study also suggests that better information is needed to understand the relationship of hardwood mortality to fire intensity.

## ACKNOWLEDGEMENT

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## LITERATURE CITED

- Brose, P.H.; Tainter, F.; Waldrop, T.A. 2002. Regeneration history of Table Mountain/pitch pine stands in two locations in the southern Appalachians. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 296-301.
- Southern Appalachian Man and the Biosphere. 1996. The southern Appalachian assessment terrestrial technical report. Rep. 5. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region. 118 p.
- Sutherland, E.K.; Grissino-Mayer, H.; Woodhouse, G.A. [and others]. 1995. Two centuries of fire in a southwestern Virginia *Pinus pungens* community. In: Inventory and management techniques in the context of catastrophic events: altered states of the forest. Hypertext proceedings. University Park, PA: Pennsylvania State University, Center for Statistical Ecology and Environmental Statistics: 172-183.
- Van Lear, D.H.; Waldrop, T.A. 1989. History, use, and effects of fire in the Southern Appalachians. Gen. Tech. Rep. SE-54. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 20 p.
- Waldrop, T.A. 1997. Four site-preparation techniques for regenerating pine-hardwood mixtures in the Piedmont. Southern Journal of Applied Forestry. 21 (3): 116-122.
- Waldrop, T.A.; Brose, P.H. 1999. A comparison of fire intensity levels for stand replacement of Table Mountain pine (*Pinus pungens* Lamb.). Forest Ecology and Management. 113 (1999): 155-166.
- Williams, C.E. 1998. History and status of Table Mountain pine-pitch pine forests of the southern Appalachian Mountains (USA). Natural Areas Journal. 18: 81-90.
- Williams, C.E.; Johnson, W.C. 1992. Factors affecting recruitment of *Pinus pungens* in the southern Appalachian Mountains. Canadian Journal of Forest Research. 22: 878-887.
- Zobel, D.B. 1969. Factors affecting the distribution of *Pinus pungens*, an Appalachian endemic. Ecological Monographs. 39: 303-333.

# REMNANT FIRE DISTURBED MONTANE LONGLEAF PINE FOREST IN WEST CENTRAL GEORGIA

Robert Carter and Andrew J. Londo<sup>1</sup>

**Abstract**—Fire disturbed ecosystems are characteristic of the Southeastern Coastal Plain of the United States. Less well known are fire disturbed mountainous regions of the Piedmont and Appalachian region that support longleaf pine (*Pinus palustris* P. Mill.) ecosystems. The Pine Mountain Range in the Piedmont of west central Georgia has remnant longleaf pine ecosystems that occupy steep slopes with shallow soils. The montane longleaf ecosystems contain an unusual species composition of coastal plain (*Quercus margaretta* Ashe) and Appalachian (*Vaccinium pallidum* Ait.) species. Landscape scale analysis of vegetation and soils revealed four major ecosystems influenced by topography, soils, and fire history.

## INTRODUCTION

Montane longleaf pine (*Pinus palustris* P. Mill.) ecosystems are found in portions of northern Georgia and Alabama. Vegetation surveys have been conducted in areas such as Forest McClellan, AL (Maceina and others 2000) and Rome, GA (Lipps and Deselm 1969), but there have been no attempts to study the interrelationship between forest communities, soils, and landform variables. The objective of the study is to identify ecological land units in the montane longleaf pine forest of west central Georgia based on the discriminating vegetation, soils, and landform features of mature forest communities.

## SITES

The study area was Thunder Scout Reservation in Upson County, GA. The 2,200-acre area is owned by the Flint River Council, Boy Scouts of America and is managed for outdoor recreation. Upson County retains only 2,900 acres of montane ecosystems with 50 percent cover of *P. palustris* (Outcalt and Sheffield 1996). The Scout Reservation is within the Pine Mountain Range at the point where it is bisected by the Flint River. The elevation ranges from 61 m at the Flint River to 347 m above sea level. The area is characterized by steep rocky slopes.

## PROCEDURES

In the summer of 2003, 15 plots were established in suitable forested sites. The sites were free of recent disturbance with

the exception of fire. Tree, sapling, seedling, and herbaceous strata were sampled in a 20 x 50 m plot following the Carolina Vegetation Survey protocol (Peet and others 1998). Soil samples were collected by horizon from four locations within the plot to determine soil horizon depth and chemical and textural properties. Landform variables sampled included slope gradient, aspect, and landform index (LFI) (McNab 1990).

Ecological land units were delineated through ordination and cluster analysis of presence/absence data. The ordination programs employed were correspondence analysis, detrended correspondence analysis, principal components analysis, and nonmetric multidimensional scaling (McCune and Grace 2002). Cluster analysis was through PC-ORD using Jaccard, Euclidean, and Sorenson (Bray-Curtis) distance measures (McCune and Grace 2002). Environmental variables related to the ecological units were determined through stepwise discriminant analysis ( $p=0.10$ ) and discriminant functions tested through resubstitution (SPSS 1996).

## RESULTS AND DISCUSSION

Four landscape ecological land units were identified with a unique species assemblage and soil and landform characteristics (tables 1 and 2). Discriminant functions had a classification success rate of 100 percent, indicating a strong relationship between the ecosystems and environmental variables. Based on the characteristics of each community

**Table 1—Mean of diagnostic environmental variables for four communities in the Pine Mountain Region of west central Georgia ( $p=0.10$ )**

Community	Longleaf pine turkey oak goat's rue needle grass	Longleaf pine post oak blackseed flower	Mockernut hickory post oak yellow passion	Chestnut oak sand hickory Christmas fern
Landform index	20.58	11.68	6.44	31.5
A Horizon sand (%)	76.67	73.04	55.00	70.00
B Horizon Ca (%)	0.57	0.40	0.62	0.43
B Horizon P (kg/ha)	23.59	18.69	10.90	35.43
B Horizon Ca (kg/ha)	163.43	389.13	2,505.95	599.25
Elevation (m)	317.00	297.00	329.50	259.00

<sup>1</sup> Assistant Professor, Department of Biology, Jacksonville State University, Jacksonville, AL 36265; and Associate Extension Professor, Mississippi State University, Department of Forestry, Mississippi State, MS 39762, respectively.

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**Table 2—Community type, habitat, and diagnostic species for the Pine Mountain Region of west central Georgia**

Community	Longleaf pine, turkey oak, goat's rue	Longleaf pine, post oak, blackseed needlegrass	Mockernut hickory, post oak, yellow passion flower	Chestnut oak, sand hickory, Christmas fern
Habitat	Steep rocky upper slopes with low Ca	Mountain tops, side slopes with low Ca	Mountain tops, moist slopes with high Ca	Steep slopes bordering ephemeral streams
Diagnostic species	<i>Quercus laevis</i> <i>Tephrosia virginiana</i> <i>Pinus palustris</i> <i>Cnidioscolus stimulosus</i> <i>Quercus margaretta</i> <i>Hypoxis hirsuta</i> <i>Solidago odora</i> <i>Pteridium aquilinum</i>	<i>Quercus stellata</i> <i>Piptochaetium avenaceum</i> <i>Pinus palustris</i> <i>Euphorbia pubentissima</i> <i>Carya tomentosa</i> <i>Baptisia tinctoria</i> <i>Clitoria mariana</i> <i>Ipomoea pandurata</i> <i>Hexastylis shuttleworthii</i>	<i>Carya alba</i> <i>Quercus stellata</i> <i>Passiflora lutea</i> <i>Carya glabra</i> <i>Galium circaezans</i> <i>Ipomoea pandurata</i> <i>Aesculus pavia</i> <i>Lespedeza repens</i> <i>Pteridium aquilinum</i>	<i>Quercus prinus</i> <i>Polystichum acrostichoides</i> <i>Carya pallida</i> <i>Parthenocissus quinquefolia</i> <i>Quercus rubra</i> <i>Quercus nigra</i> <i>Acer rubrum</i> <i>Baptisia tinctoria</i> <i>Solidago odora</i>

identified, it was designated for recreation management as Leave No Trace, Primitive, Semi-primitive, or Group Camping. The management recommendations for each category are:

- (1) Leave No Trace—foot traffic only. Camping is not recommended.
- (2) Primitive—camping is permitted but no permanent structures with the exception of pit toilets and permanent fire pits. The establishment of foot and bike trails is permissible.
- (3) Semi-primitive—the same as Primitive areas but Appalachian Trail type shelters can be constructed
- (4) Group Camping—construction of permanent buildings, campsites, and trails is permissible.

### Plant Communities

A longleaf pine-turkey oak (*Quercus laevis* Walt.)-goat's rue [*Tephrosia virginiana* (L.) Pers.] type was found on steep rocky upper slopes with low calcium (Ca). Landform index averaged 20 percent with B-horizon Ca averaging 163 ppm (table 1). The relatively high landform index reflects the upper slope position and steep terrain. Species indicative of this site include *Carya pallida* (Ashe) Engl. & Graebn., *Cnidioscolus stimulosus* (Michx.) Engelm. & Gray, *Quercus margaretta* Ashe, *Q. marilandica* Muenchh., *Prunus umbellata* Ell., *Hypoxis hirsuta* (L.) Coville, *Pteridium aquilinum* (L.) Kuhn, *Hypericum hypericoides* (L.) Crantz, *Vaccinium pallidum*, and *Solidago odora* Ait. (table 2). Sites that support this community are too steep, rocky, and remote for the development of buildings or campsites. This is a Leave No Trace area.

A longleaf pine-post oak (*Quercus stellata* Wangenh.)-blackseed needle grass [*Piptochaetium avenaceum* (L.) Parodi] type was found on mountain tops and side slopes with low Ca. The landform index was lower at 11.68 reflecting positions on mountaintops. B-horizon Ca was slightly higher at 389 ppm (table 1). Species with affinity for these sites include *Carya pallida*, *C. alba* (L.) Nutt. ex Ell., *C. glabra* (P. Mill.) Sweet, *Quercus marilandica*, *Baptisia tinctoria* (L.) R. Br. ex Ait. f., *Clitoria mariana* L., *Euphorbia pubentissima* Michx., *Hypericum hypericoides*, *Hypoxis hirsuta*, *Ipomoea pandurata* (L.) G.F.W. Mey., *Pteridium aquilinum*, *Prunus umbellata* Ell., *Vaccinium pallidum*, *Smilax glauca* Walt., and *Solidago*

*odora* (table 2). This community is abundant and the sites are relatively flat. This is a Semi-primitive area.

A mockernut hickory (*Carya alba*)-post oak-yellow passion flower (*Passiflora lutea* L.) type was found on mountaintops and moist slopes with high Ca. The landform index was the lowest of the land units at 6.44. This reflects the mountaintop position on the landscape. The B-horizon Ca was very high at 2,505.95 kg/ha due to the parent material underlying the soil (table 1). Species common on this site were *Quercus prinus* L., *Quercus stellata*, *Galium circaezans* Michx., *Ipomoea pandurata*, *Aesculus pavia* L., and *Lespedeza repens* (L.) W. Bart. (table 2). This unusual community is found on relatively flat terrain that can support bike and hiking trails, campsites, and wilderness outposts. However, due to the unusual mix of plant species found on these sites, development should be kept to a minimum. This is a Primitive area.

A chestnut oak (*Quercus prinus*)-sand hickory (*Carya pallida*)-Christmas fern [*Polystichum acrostichoides* (Michx.) Schott] type was found on steep slopes bordering ephemeral streams. Landform index was the highest of the land units at 31.5 reflecting sites in protected valleys bordering streams. The Ca was relatively high at 599.25 kg/ha, reflecting the input and accumulation of Ca from upper slope sites (table 1). Species indicative of this site include *Parthenocissus quinquefolia* (L.) Planch., *Quercus rubra* L., *Quercus nigra* L., *Acer rubrum* L., *Hexastylis shuttleworthii* (Britten & Baker) Small, and *Baptisia tinctoria* (table 2). These sites are too steep to support recreation outside of hiking and bike trials. However, such uses should be kept to a minimum. These sites border streams and intermittent streams and should be protected to prevent erosion onto the streams. This is a Leave No Trace area.

### CONCLUSIONS

The montane longleaf pine forests of the Pine Mountain Range represent a unique ecosystem blending coastal and Piedmont/Appalachian species. The presence of longleaf pine on all sites indicates that fire played an historical role in determining plant species distribution. Although the land

units identified are unique and worthy of conservation, total preservation is not required. Recreational activities are compatible with the land units as long as the activities do not increase soil erosion. The steep slopes found in some land units are highly susceptible to erosion.

This study examined the major ecosystems found on Thunder Scout Reservation but did not address some unusual ecosystems such as canebrakes and mountain laurel thickets. Further research is needed to determine the species composition and presence of rare species in these ecosystems.

### **ACKNOWLEDGMENTS**

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### **LITERATURE CITED**

- Lipps, E.L.; Deselm H.R. 1969. The vascular flora of the Marshall Forest, Rome, Georgia. *Castanea*. 34: 414-432.
- Maceina, E.C.; Kush, J.S.; Meldahl, R.S. 2000. Vegetational survey of a montane longleaf pine community at Fort McClellan, Alabama. *Castanea*. 65: 147-154.
- McCune, B.; Grace, J.B. 2002. Analysis of ecological communities. Glenden Beach, OR: MjM Software Design. 300 p.
- McNab, W.H. 1990. Predicting forest type in Bent Creek Experimental Forest from topographic variables. In: Coleman, S.S.; Neary, D.G., comps. Proceedings of the sixth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 496-504.
- Outcalt, K.W.; Sheffield, R.M. 1996. The longleaf pine forest: trends and current conditions. Resour. Bull. SRS-9. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 25 p.
- Peet, R.K.; Wentworth, T.R.; White, P.S. 1998. A flexible multipurpose method for recording vegetation composition and structure. *Castanea*. 63: 262-274.
- SPSS. 1996. SYSTAT 6.0 for Windows. Chicago, IL: Prentice Hall. 147 p.

# EFFECTS OF PRESCRIBED FIRE ON PRODUCTION OF FOLIAGE BY SAPLING LONGLEAF PINE

Mary Anne Sword Sayer, J.C.G. Goelz, and James D. Haywood<sup>1</sup>

**Abstract**—We conducted an experiment that was designed to show how interaction between prescribed fire and branch phenology affects the growth of planted longleaf pine (*Pinus palustris* P. Mill.). Treatments were no control of vegetation, vegetation control by burning, and vegetation control by application of herbicides. In the plots burned in May 2003, > 50 percent of the foliage was scorched. In 2004, annual increments of biomass production were similar on the burned and herbicide plots and were greater on the burned plots than on the control plots. A larger proportion of leaf area occurred in the upper crown on the burned and herbicide plots than on the control plots, and a larger proportion of upper crown leaf area was second-flush foliage on the burned plots than on the control and herbicide plots. Results of this experiment suggest that newly established upper crown leaf area contributed to annual biomass production after burning.

## INTRODUCTION

The establishment of longleaf pine (*Pinus palustris* P. Mill.) ecosystems on cutover sites requires the control of competing vegetation by burning, herbicides, or mechanical treatments. Plant and animal species common to longleaf pine ecosystems are adapted to withstand fire (Brockway and Lewis 1997, Haywood and others 2001, Landers and others 1995, Outcalt 2000). Prescribed burning limits competing vegetation in longleaf pine stands, but the benefit of this control is not consistently reflected in production. Brockway and Lewis (1997), for example, reported that the growth of longleaf pine was not adversely affected by repeated fire in winter over a 40-year period. Boyer (1983, 1987), however, found that longleaf pine production was reduced by fire after 10 years of biennial burning in winter, spring, or summer.

Inconsistency in growth responses to fire may be caused by variation in fire intensity and branch phenology at the time of burning. Past research has established the close relationship between leaf area and stand production (Albaugh and others 1998, Colbert and others 1990, Sword Sayer and others 2004, Vose and Allen 1988). Thus, fire intensities that cause severe crown scorch reduce stemwood growth (Johansen and Wade 1987). When crown scorch is not severe, stand production may depend on branch phenology and amount of stored energy at the time of the fire.

Results of a study by Weise and others (1987), who removed up to 95 percent of the foliage from 4-year-old loblolly (*P. taeda* L.) and slash pine (*P. elliotii* Engelm.) at different times of the year, suggest that the response of stem growth to fire is mediated by branch phenology. Stem growth was unaffected by defoliation in January, July, or October. When saplings were defoliated in April, however, stem growth was reduced proportionally with the amount of foliage removed. Because southern pine buds do not begin expanding until after January, defoliation before this time could not affect new foliage (Chung and Barnes 1980, Tang and others 1999). By July and October, new foliage was well developed and had undergone several months of photosynthate production and export (Chung and Barnes 1980; Dickson 1989, 1991; Tang and others 1999). In

April, however, new foliage was expanding and may not have been mature enough to export photosynthate to other plant components. These results suggest that the impact of fire on stand production depends on the extent and season of foliage damage.

We hypothesize that annual production of longleaf pine is maintained after scorch where regrowth of foliage at least partly restores the potential for carbon fixation. In the present study, our objectives are to (1) quantify annual aboveground biomass production and distribution of foliage by crown level and age class of sapling longleaf pine and (2) evaluate relationships between these variables in response to prescribed burning in May 2003.

## MATERIALS AND METHODS

### Field Sites

The field sites are located on the Kisatchie National Forest in central Louisiana. Three replications, each containing three treatment plots, are at lat. 31°1' N, long. 92°37' W on a gently sloping (1 to 3 percent) Beauregard silt loam and Malbis fine sandy loam complex (site 1). The Beauregard soil forms the intermound and wetter portion of the site. The Malbis soil forms slightly elevated mima or pimple mounds. Two replications, each containing three treatment plots, are at lat. 31°6' N, long. 92°36' W on a Ruston fine sandy loam (fine-loamy, siliceous, thermic Typic Paleudult) with some Malbis fine sandy loam and Gore very fine sandy loam with a slope of 1 to 5 percent (site 2). A mixed pine-hardwood forest originally occupied both sites. Site 1 was clearcut harvested, sheared, and windrowed in 1991 and prescribed burned in 1993 and 1996. Site 2 was clearcut harvested in 1996 and roller-drum chopped and burned in August 1997.

At each location, treatment plots (22 by 22 m; 0.048 ha) were established, and blocks were delineated based on soil drainage and topography. Three vegetation management treatments were established: (1) control (C) - no management activities after planting, (2) prescribed burning (B) - plots were burned using the strip head fire method in late spring every 2

<sup>1</sup> Research Plant Physiologist, Research Forester, and Research Forester, respectively, USDA Forest Service, Southern Research Station, Pineville, LA 71360.

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or 3 years, and (3) herbicides (H) - herbicides were applied after planting for herbaceous and arborescent plant control. Specifically, the H plots at site 1 were rotary tilled in December 1996 before planting in March 1997. Sethoxydim was used for postplanting grass control, and hexazinone was used for general herbaceous plant control. In May 1997 and April 1998, sethoxydim and hexazinone in aqueous solution were applied in 0.9-m bands over the rows of unshielded longleaf pine seedlings. Within the 0.9-m bands, the rate of sethoxydim application was 0.37 kg active ingredient (ai)/ha, and for hexazinone the rate was 1.12 kg ai/ha. At site 2, no tillage was necessary, and only hexazinone was banded in April 1998 and 1999 because sparse occurrence of grasses did not warrant the use of sethoxydim. For both sites, triclopyr at 0.0048 kg acid equivalent/liter was tank mixed with surfactant and water and applied as a directed foliar spray to competing arborescent vegetation in April 1998 and May 1999. Recovering brush was cut by hand in February 2001. The B plots were burned by the strip head fire method in May 1998 at site 1 and in June 2000 and May 2003 at both sites. Container-grown longleaf pine seedlings from a genetically improved, Mississippi seed source (site 1) and a Louisiana seed source (site 2) were planted at a spacing of 1.8 by 1.8 m in March 1997 and November 1997, respectively. Treatment plots contained 12 rows of 12 seedlings each. The measurement plots contained only the innermost eight rows of eight seedlings in each treatment plot.

### Measurements

Fire intensity was evaluated by examining three saplings that were randomly chosen from those within 10 percent of mean height on each plot. For each of these saplings, the height of crown scorch and total tree height were measured 1 month after burning, and scorched height as a percentage of total height was estimated. Scorched height was rated 0, 1, 2, or 3 (0 = no crown scorch, 1 = < 50 percent of total height scorched, 2 = from 50 percent to < 100 percent of total height scorched, 3 = 100 percent of total height scorched).

Stand production was quantified in two ways. First, groundline diameter and total height were measured for all saplings in January 2003 and February 2004, and groundline basal area (GBA) per sapling and per ha were calculated. Second, the stem, branch, and foliage biomass per ha in January 2003 and February 2004 and annual biomass production during this period were predicted. Predictions were based on equations developed from data obtained by destructive sampling of three saplings from the outer two rows of each treatment plot in August 2003.

The three destructively sampled saplings per plot were randomly chosen from each of the three one-third percentiles of sapling total tree height on the plot. The groundline diameter and total height of each sampled sapling were measured, each sapling was felled at the groundline, and the length and midpoint of each sapling's live crown were determined. The live crown midpoint marked the point of division between the upper and lower crown sections. Branches were cut, and foliage was pulled from the stems.

Subsequently, branch foliage from the upper crown was separated from that of the lower crown. Foliage from each crown level was partitioned into four categories: (1) stem foliage and branch foliage produced in 2002, (2) first-flush

foliage produced in 2003, (3) second-flush foliage produced in 2003, and (4) foliage from the third and subsequent flushes produced in 2003. Foliage, branches, and stems were dried to equilibrium at 70 °C and weighed.

Upper and lower crown peak total leaf area (TLA) were also predicted. These predictions represented peak TLA because they were based on data collected in August when leaf area was maximum. From each sample of 2002 foliage and 2003 first-flush foliage, five fascicles were subsampled. Their total or all-sided surface areas were quantified by volume displacement (Johnson 1984), and dry weights were determined after drying to equilibrium at 70 °C. For each set of 15 samples per crown level and treatment, linear equations were developed to predict peak TLA from dry weight. Equations associated with the 2002 foliage were applied to all 2002 foliage samples, and equations associated with the 2003 first-flush foliage were applied to all 2003 foliage samples. This resulted in predictions of peak TLA in the upper and lower crown for all 45 destructively sampled saplings.

Data for the destructively sampled trees were used to construct regression equations to predict stem, branch, and foliage biomass and peak TLA as functions of groundline diameter and total height. Each regression equation was developed independently of the others. To stabilize variance, a natural logarithm (ln) transformation was applied to each side of each equation. Thus, the equation form was  $\ln(Y) = b_0 + b_1 \ln(D) + b_2 \ln(H) + e$ , where  $e$  represents a normal error term,  $D$  is groundline diameter,  $H$  is total height,  $Y$  is one of the biomass or peak TLA dependent variables, and the  $b_i$  are parameters to be estimated. Nested models were fitted where the parameters were common among treatments and where parameters were allowed to vary among treatments, and standard F-tests were used to compare full and reduced models and achieve a final model. Only variables that were significant at the  $P = 0.05$  level were retained. The nested models were implemented by using dummy variables representing the different treatments (Weisburg 1985, p. 169-185). Potentially, one of the parameters could vary while the others were common across treatments. For some dependent variables, a common relationship was used for all treatments, and for other dependent variables, parameters were unique for each treatment.

These equations were used to predict stem and branch biomass, upper and lower crown foliage biomass, and peak TLA in 2003 and 2004 for all saplings in the measurement plots. Stem, branch, and foliage biomass were expressed as megagrams (Mg) per ha, and peak TLA was expressed as m<sup>2</sup> of leaf area per m<sup>2</sup> of measurement plot area. Foliage biomass in the upper and lower crown was summed. Annual stem, branch, and foliage biomass production was calculated as the difference between plot-level values in January 2003 and February 2004.

### Statistical Analysis

Values of GBA (m<sup>2</sup>/ha); annual production of stem, branch, and foliage biomass (Mg/ha per year); and upper and lower crown peak TLA (m<sup>2</sup>/m<sup>2</sup>) were transformed to their natural logarithms (ln) to establish normality. Transformed values of GBA in January 2003 and February 2004 were evaluated by analysis of variance (ANOVA) using a randomized complete block design with five blocks. With ln (GBA) in 2003 as a

covariate, transformed values of annual stem, branch, and foliage biomass production and upper and lower crown peak TLA were evaluated by analysis of covariance (ANCOVA) with five blocks. Also, percentages of peak TLA in the upper and lower crown were analyzed by ANCOVA, and percentages of upper crown peak TLA in each of four age classes were evaluated by ANOVA. Mean groundline diameter was the covariate. Total leaf area data for the 45 saplings that were sampled destructively in August 2003 were used in this analysis. Main and interaction effects were considered significant at  $P \leq 0.10$ . Means were compared by the least significant difference test and considered significantly different at  $P \leq 0.10$ .

## RESULTS

Prescribed burning in May 2003 resulted in a crown scorch rating of  $1.5 \pm 1.1$  (standard deviation). This value indicates that the mean percentage of scorched sapling height was from 50 percent to < 100 percent with considerable variation.

Vegetation management treatment significantly affected GBA (table 1). In 2003 and 2004, GBA was greater in the H plots than in the C and B plots, and GBA in the C plots was similar to that in the B plots (fig. 1). Annual stem biomass and foliage biomass production, adjusted by GBA in 2003, were significantly affected by vegetation management treatment. Small but significant differences were found between adjusted annual stem production on the B plots and that on the H plots, and between adjusted annual foliage production on the C and B plots and that on the H plots. In each case, the production adjusted by the covariate was less on the H plots than on the C and B plots. Clearly, however, the H plots did not grow less stem or foliage biomass than the C and B plots (figs. 2A and 2B). Adjusted annual production of stem biomass on the B plots was similar to that on the C plots, and adjusted annual production of foliage biomass on the B plots was similar to that on the C plots (fig. 2C). Vegetation management treat-

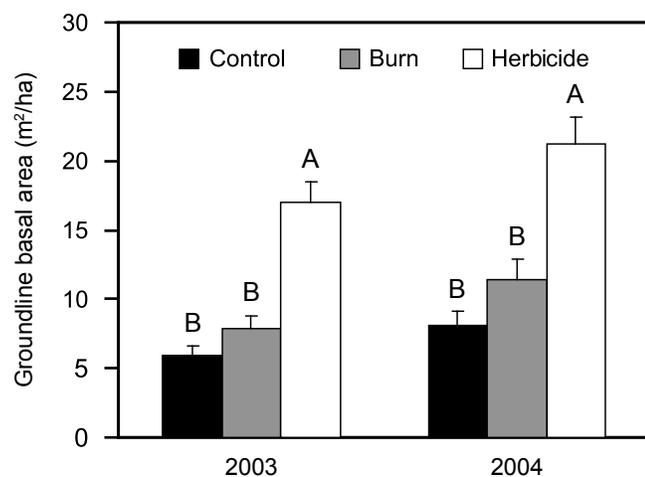


Figure 1—Groundline basal area of sapling longleaf pine in January 2003 and February 2004 in response to no vegetation management (Control), vegetation management with prescribed fire in June 2000 and May 2003 (Burn), and vegetation management by herbicide application (Herbicide). Bars represent one standard error of the mean. Means within a year associated with different upper case letters are significantly different at  $P \leq 0.10$ .

ment did not affect adjusted annual production of branch biomass (fig. 2C).

Upper crown peak TLA, adjusted by GBA in 2003, was significantly affected by vegetation management treatment in 2004 but not in 2003 (table 1). Adjusted upper crown peak TLA in 2003 was not significantly affected by vegetation management treatment, but there was a small but significant difference between adjusted upper crown peak TLA for B plots and that for H plots in 2004 (figs. 3A and 3B). Adjusted lower crown peak TLA was significantly affected by vegetation management treatment in 2003 and 2004. In both years, the B and H plots averaged less adjusted peak TLA in the lower crown than did the C plots (fig. 3C and 3D).

The distribution of peak TLA, adjusted by groundline diameter, between the upper and lower crown of saplings destructively sampled in August 2003 was significantly affected by vegetation management treatment (table 2). A larger percentage of

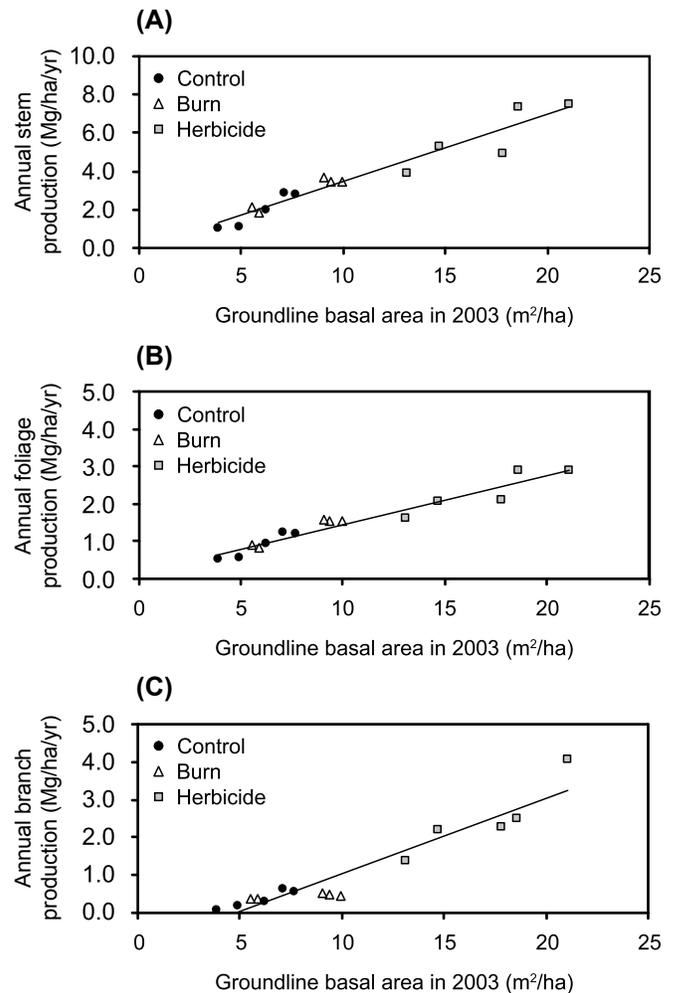


Figure 2—Relationship between groundline basal area in January 2003 and predicted annual production of stem (A), foliage (B), and branch (C) biomass between January 2003 and February 2004 of sapling longleaf pine in response to no vegetation management (Control), vegetation management with prescribed fire in June 2000 and May 2003 (Burn), and vegetation management by herbicide application (Herbicide). Lines represent regression relationships among all treatments.

**Table 1—Analysis of variance of mean groundline basal area, analyses of covariance of mean annual production of stem, branch, and foliage biomass, and upper and lower crown peak total leaf area of sapling longleaf pine in response to vegetation management treatment**

Variable	Source of variation	df	SS	MS	F-value	Pr > F
GBA, 2003 <sup>a</sup> (m <sup>2</sup> /ha)	Block	4	0.3205	0.0801	1.48	0.2937
	Treatment <sup>b</sup>	2	3.0581	1.5291	28.31	0.0002
	Error	8		0.0540		
GBA, 2004 <sup>a</sup> (m <sup>2</sup> /ha)	Block	4	0.5053	0.1263	2.14	0.1675
	Treatment	2	2.4962	1.2481	21.12	0.0006
	Error	8		0.0591		
Stem biomass production <sup>a</sup> (Mg/ha/yr)	Covariate <sup>c</sup>	1	0.8279	0.8279	53.17	0.0002
	Block	4	0.1260	0.0315	2.02	0.1953
	Treatment	2	0.1077	0.0539	3.46	0.0902
	Error	7		0.0156		
Branch biomass production <sup>a</sup> (Mg/ha/yr)	Covariate	1	2.1419	2.1419	29.76	0.0010
	Block	4	0.6943	0.1736	2.41	0.1460
	Treatment	2	0.0427	0.0213	0.30	0.7522
	Error	7		0.0720		
Foliage biomass production <sup>a</sup> (Mg/ha/yr)	Covariate	1	0.6547	0.6547	72.02	0.0001
	Block	4	0.0700	0.0175	1.92	0.2112
	Treatment	2	0.0939	0.0470	5.17	0.0419
	Error	7		0.0091		
Upper crown TLA, 2003 <sup>a</sup> (m <sup>2</sup> /m <sup>2</sup> )	Covariate	1	0.8032	0.8032	342.28	0.0001
	Block	4	0.0628	0.0157	6.69	0.0153
	Treatment	2	0.0064	0.0032	1.37	0.3141
	Error	7		0.0023		
Lower crown TLA, 2003 <sup>a</sup> (m <sup>2</sup> /m <sup>2</sup> )	Covariate	1	1.3823	1.3823	127.33	0.0001
	Block	4	0.3658	0.0915	8.42	0.0082
	Treatment	2	3.2503	1.6251	149.71	0.0001
	Error	7		0.0109		
Upper crown TLA, 2004 <sup>a</sup> (m <sup>2</sup> /m <sup>2</sup> )	Covariate	1	0.6935	0.6935	320.62	0.0001
	Block	4	0.0330	0.0083	3.82	0.0593
	Treatment	2	0.0297	0.0143	6.86	0.0224
	Error	7		0.0022		
Lower crown TLA, 2004 <sup>a</sup> (m <sup>2</sup> /m <sup>2</sup> )	Covariate	1	1.1291	1.1291	103.45	0.0001
	Block	4	0.1890	0.0472	4.33	0.0447
	Treatment	2	2.6059	1.3030	119.38	0.0001
	Error	7		0.0109		

df = degrees of freedom; SS = sum of squares; MS = mean square; Pr > F = probability of a greater F-value; GBA = groundline basal area; TLA = total leaf area.

<sup>a</sup> Analyses were conducted with data transformed to their natural logarithms.

<sup>b</sup> Treatments were no vegetation management (C), vegetation management with prescribed fire (B), and vegetation management by herbicide application (H).

<sup>c</sup> The covariate was groundline basal area in January 2003.

adjusted peak TLA was found in the upper crown of saplings on the B and H plots than in the upper crown of those on the C plots (fig. 4A). Consequently, a smaller percentage of adjusted peak TLA occurred in the lower crown of saplings on the B and H plots than in the lower crown of those on the C plots. Vegetation management treatment significantly

affected the percentage of upper crown peak TLA that was produced in 2002, in the second flush of 2003, and in the third and subsequent flushes of 2003 (fig. 4B). Foliage produced in 2002 made up 13 percent more of peak TLA in the H plots than it did in the B and C plots. Foliage produced in the third and subsequent flushes of 2003 made up 11 percent

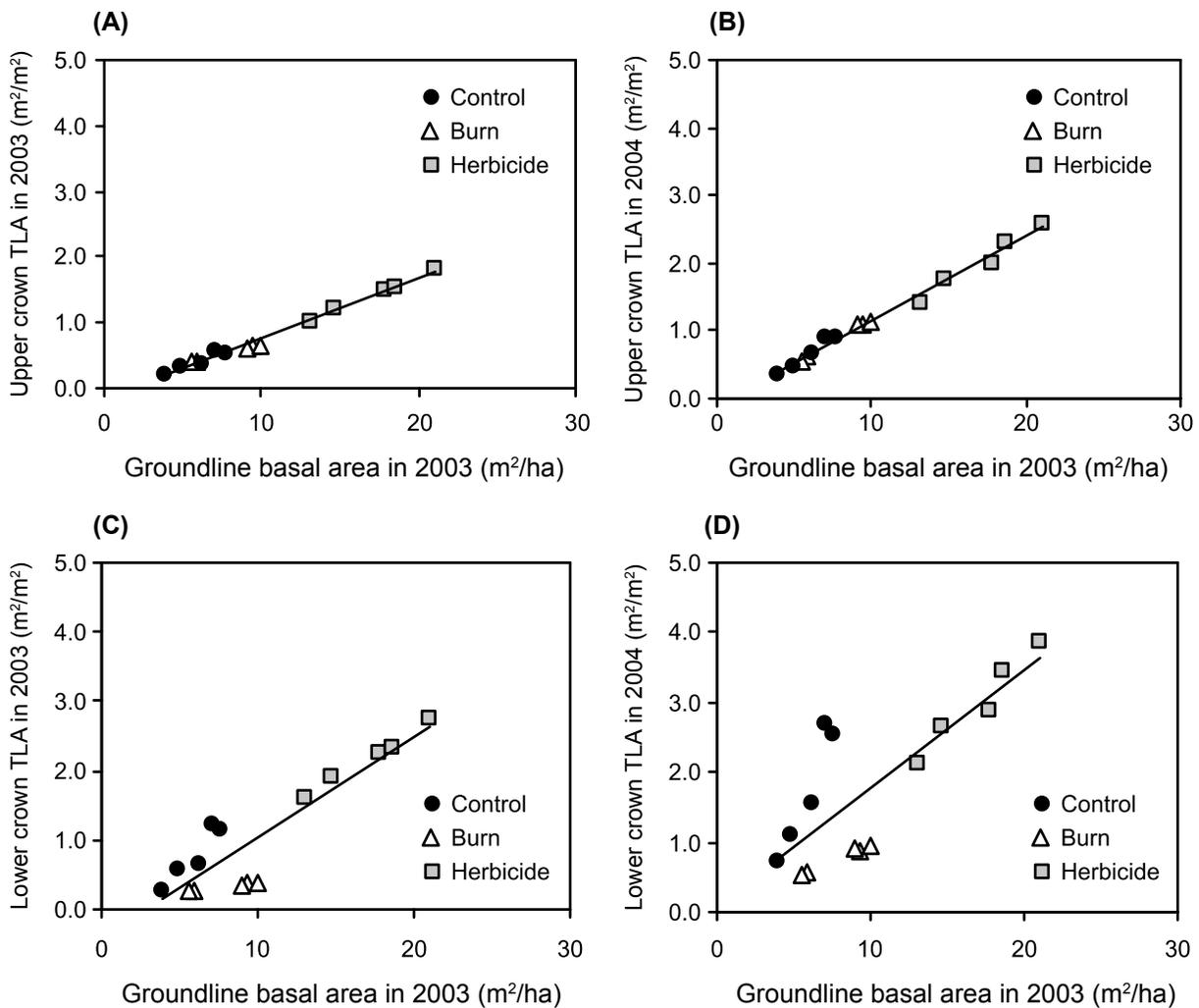


Figure 3—Relationship between groundline basal area in January 2003 and predicted peak total leaf area in the upper crown in August 2003 (A) and August 2004 (B) and in the lower crown in August 2003 (C) and August 2004 (D) of sapling longleaf pine in response to no vegetation management (Control), vegetation management with prescribed fire in June 2000 and May 2003 (Burn), and vegetation management by herbicide application (Herbicide). Lines represent simple linear regressions of all treatments combined. TLA = total leaf area.

less of peak TLA in the H plots than it did in the B and C plots. Foliage produced in the second flush of 2003 made up 10 percent more of peak TLA in the B plots than it did in the H and C plots.

## DISCUSSION

Carbohydrate for the production of southern pine foliage originates from different sources. The expanding first flush is supplied with energy derived from starch stored in living parenchyma cells of branches, roots, needles, and the stem as well as current photosynthate from foliage produced in the previous year (Dickson 1989, 1991). As fascicles of the first flush reach maturity, they become a source of energy for the growth of the second flush, and surplus carbohydrate is redirected to the stem and roots. This pattern is repeated as successive flushes or cohorts of foliage develop.

The allocation of current photosynthate to growth and stored energy changes seasonally with the progression of the phenological cycle. Under normal environmental conditions, for

example, current photosynthate allocated to the root system of loblolly and longleaf pine yields a pulse of fine-root production during April through July. During this time, starch reserves in the root system are mobilized to the point of near-depletion and allocated to the stem and crown (Dickson 1989, 1991; Kuehler and others 1999; Ludovici and others 2002; Sword Sayer and Haywood 2006; Sword Sayer and Tang 2004). By November, current photosynthate translocated to the root system is allocated to stored starch rather than fine-root production (Kuehler and others 1999, Ludovici and others 2002).

We suggest that both the retention of residual foliage in the crown after fire and the phenological stage of crown development at the time of fire influence postfire sapling growth. Scorch damages the lower crown more than it damages the upper crown. Thus, branch phenology in the upper crown alone may be closely tied to sapling responses to fire. Bud formation and expansion, the source-sink status of current-year fascicles, and the amount of readily accessible stored energy in longleaf pine vary seasonally (Dickson 1989, 1991; Sheffield and others 2003; Sword Sayer and Haywood 2006).

**Table 2—Analyses of covariance of percentages of peak total leaf area (TLA) per sapling in the upper and lower crown, and analyses of variance of percentages of upper crown peak TLA in each of four age classes of sapling longleaf pine in August 2003 in response vegetation management treatment**

Variable	Source of variation	df	SS	MS	F-value	Pr > F
Upper crown TLA (%)	Covariate <sup>a</sup>	1	0.0243	0.0243	10.08	0.0156
	Block	4	0.0398	0.0100	4.12	0.0499
	Treatment <sup>b</sup>	2	0.0350	0.0175	7.26	0.0197
	Error	7		0.0024		
Lower crown TLA (%)	Covariate	1	0.0243	0.0243	10.08	0.0156
	Block	4	0.0398	0.0100	4.12	0.0499
	Treatment	2	0.0350	0.0175	7.26	0.0197
	Error	7		0.0024		
2002-up <sup>c</sup> TLA (%)	Block	4	0.0037	0.0009	0.70	0.6126
	Treatment	2	0.0579	0.0289	21.97	0.0006
	Error	8		0.0013		
2003-1-up TLA (%)	Block	4	0.0118	0.0030	0.64	0.6511
	Treatment	2	0.2266	0.0113	2.43	0.1494
	Error	8		0.0047		
2003-2-up TLA (%)	Block	4	0.0033	0.0008	0.45	0.7695
	Treatment	2	0.0302	0.0151	8.16	0.0117
	Error	8		0.0019		
2003-3-up TLA (%)	Block	4	0.0138	0.0034	1.66	0.2513
	Treatment	2	0.0444	0.0222	10.65	0.0056
	Error	8		0.0021		

df = degrees of freedom; SS = sum of squares; MS = mean square; Pr > F = probability of a greater F-value; TLA = total leaf area.

<sup>a</sup> The covariate was mean groundline diameter in August 2003.

<sup>b</sup> Treatments were no vegetation management (C), vegetation management with prescribed fire (B), and vegetation management by herbicide application (H).

<sup>c</sup> 2002-up = upper crown foliage produced in 2002; 2003-1-up = upper crown first flush foliage produced in 2003; 2003-2-up = upper crown second flush foliage produced in 2003; 2003-3-up = upper crown third and subsequent flush foliage produced in 2003.

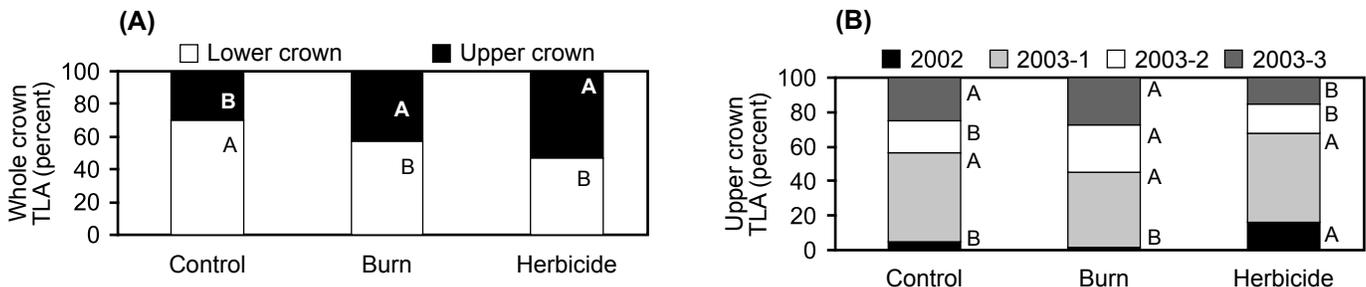


Figure 4—Distribution of predicted peak total leaf area (TLA), adjusted by groundline diameter, between the upper and lower crown (A) and distribution of TLA in the upper crown among four cohorts of foliage (B) of sapling longleaf pine in response to no vegetation management (Control), vegetation management with prescribed fire in June 2000 and May 2003 (Burn), and vegetation management by herbicide application (Herbicide). Cohorts of foliage are 2002 (stem foliage and branch foliage produced in 2002), 2003-1 (first-flush foliage produced in 2003), 2003-2 (second-flush foliage produced in 2003), and 2003-3 (foliage from the third and subsequent flushes produced in 2003). Bars represent one standard error of the mean. Means within a crown level or cohort of foliage with different upper case letters are significantly different at  $P \leq 0.10$ .

It is understandable, therefore, that the effects of crown scorch on stand production also vary seasonally.

Weise and others (1987) simulated crown scorch at different times of the year by removing 0, 33, 66, 95, and 100 percent of the foliage from sapling loblolly and slash pine in January, April, July, and October. When 100 percent of the foliage was removed, stemwood growth was consistently reduced regardless of month of defoliation. With 33 to 95 percent defoliation, stemwood growth was reduced only by the April defoliation. Defoliation in January did not affect new foliage because terminal buds had not yet expanded (Stenberg and others 1994). In July and October, at least two cohorts of foliage were mature or nearly mature and had been producing photosynthate and exporting it to growth and stored energy for several months (Dickson 1989, 1991; Stenberg and others 1994). It is possible that both the first and second cohorts of foliage were in the process of expanding in April and that they had not yet exported a significant amount of photosynthate (Chung and Barnes 1980; Dickson 1989, 1991; Stenberg and others 1994; Tang and others 1999). All of this work suggests that stemwood growth is more a function of sapling phenology as the growing season progresses than just a function of month of defoliation.

At our field site, prescribed fire in late May 2003 defoliated > 50 percent of the live crown length but did not reduce the annual production of stem, branch, or foliage biomass. On the basis of branch phenological measurements in June 2003 (data not shown), we estimate that upper crown first-flush internodes were fully expanded with 40 percent fascicle expansion and that second-flush internodes were 25 percent expanded with no fascicle expansion when prescribed burning took place. Unlike the first cohort of foliage, the second cohort of foliage had not begun to expand by late May and was not vulnerable to scorch.

Even though part of the upper crown was scorched in May 2003 on the B plots, upper crown peak TLA in August 2003 was similar among the B, C, and H plots. Apparently, saplings on the B plots readily re-established the upper crown leaf area that was destroyed by scorch. The contribution to upper crown peak TLA made by the second cohort of foliage was greater on the B plots than on the C and H plots, so that by August 2003, the combined contribution of the first and second cohorts of foliage to upper crown peak TLA was similar among the B, C, and H plots. Past research has shown that stored carbohydrates are used for the re-growth of leaves after defoliation (Dickson 1989, 1991). It is not surprising, therefore, that at our study site Kuehler and others (this proceedings) found a 35 percent decrease in longleaf pine root starch concentration approximately 1 month after burning on the B plots but no comparable starch drop on the C and H plots. We speculate that burning before the onset of fascicle expansion by the second cohort of needles and the availability of stored energy in roots accelerated the growth of second cohort foliage.

The retention of living foliage in the upper crown after burning, and favorable conditions of branch development and root starch concentration at the time of burning, were associated with the reestablishment of upper crown peak TLA within 3 months of scorch and no loss of annual aboveground biomass production. Because branch development and the allocation

of photosynthate to starch change seasonally, similar peak TLA and annual production responses may not have occurred with burning at other times of the year. For example, peak TLA may have been more vulnerable to fire damage after fascicles of the second cohort started to expand. This vulnerability could have been increased by suboptimal starch storage in roots.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Albaugh, T.J.; Allen, H.L.; Dougherty, P.M. [and others]. 1998. Leaf area and above- and belowground growth responses of loblolly pine to nutrient and water additions. *Forest Science*. 44: 317-328.
- Boyer, W.D. 1983. Growth of young longleaf pine as affected by biennial burns plus chemical or mechanical treatments for competition control. In: Jones, E.P., Jr., ed. Proceedings of the second biennial southern silvicultural research conference. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 62-65.
- Boyer, W.D. 1987. Volume growth loss: a hidden cost of periodic prescribed burning in longleaf pine? *Southern Journal of Applied Forestry*. 11: 154-157.
- Brockway, D.G.; Lewis, C.E. 1997. Long-term effects of dormant-season prescribed fire on plant community diversity, structure and productivity in a longleaf pine wiregrass ecosystem. *Forest Ecology and Management*. 96: 167-183.
- Chung, H.; Barnes, R.L. 1980. Photosynthate allocation in *Pinus taeda*. II. Seasonal aspects of photosynthate allocation to different biochemical fractions in shoots. *Canadian Journal of Forest Research*. 10: 338-347.
- Colbert, S.R.; Jokela, E.J.; Neary, D.G. 1990. Effects of annual fertilization and sustained weed control on dry matter partitioning, leaf area, and growth efficiency of juvenile loblolly and slash pine. *Forest Science*. 36: 995-1014.
- Dickson, R.E. 1989. Carbon and nitrogen allocation in trees. In: Dreyer, E.; Aussenac, G.; Bonnett-Masimbert, M. [and others], eds., *Forest tree physiology*. Paris: Elsevier/INRA: 631s-647s. *Annales des Sciences Forestieres*. 46 supplement.
- Dickson, R.E. 1991. Assimilate distribution and storage. In: Raghavendra, A.S., ed. *Physiology of trees*. New York: John Wiley: 51-85.
- Haywood, J.D.; Harris, F.L.; Grelen, H.E.; Pearson, H.A. 2001. Vegetative response to 37 years of seasonal burning on a Louisiana longleaf pine site. *Southern Journal of Applied Forestry*. 25: 122-130.
- Johansen, R.W.; Wade, D.D. 1987. Effect of crown scorch on survival and diameter growth of slash pines. *Southern Journal of Applied Forestry*. 11: 180-184.
- Johnson, J.D. 1984. A rapid technique for estimating total surface area of pine needles. *Forest Science*. 30: 913-921.
- Kuehler, E.A.; Sword, M.A.; Andries, C.D. 1999. Seasonal fine-root carbohydrate and growth relations of plantation loblolly pine after thinning and fertilization. In: Haywood, J.D., ed., Proceedings of the 10<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 420-425.
- Kuehler, E.A.; Sword Sayer, M.A.; Andries, C.D. 2006. How does fire affect longleaf pine root carbohydrates, foliar nutrients, and sapling growth? In: Connor, K.F., ed., Proceedings of the 13<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 98-101.
- Landers, J.L.; Van Lear, D.H.; Boyer, W.D. 1995. The longleaf pine forests of the southeast: requiem or renaissance? *Journal of Forestry*. 93: 39-44.

- Ludovici, K.H.; Allen, H.L.; Albaugh, T.J.; Dougherty, P.M. 2002. The influence of nutrient and water availability on carbohydrate storage in loblolly pine. *Forest Ecology and Management*. 159: 261-270.
- Outcalt, K.W. 2000. The longleaf pine ecosystem of the south. *Native Plants Journal*. 1: 42-53.
- Sheffield, M.C.; Gagnon, J.L.; Jack, S.B.; McConville, D.J. 2003. Phenological patterns of mature longleaf pine (*Pinus palustris* Miller) under two different soil moisture regimes. *Forest Ecology and Management*. 179: 157-167.
- Stenberg, P.; Kuuluvainen, T.; Kellomäki, S. [and others]. 1994. Crown structure, light interception and productivity of pine trees and stands. *Ecological Bulletin*. 43: 20-34.
- Sword Sayer, M.A.; Goetz, J.C.G.; Chambers, J.L. [and others]. 2004. Long-term trends in loblolly pine productivity and stand characteristics in response to thinning and fertilization in the West Gulf Region. *Forest Ecology and Management*. 192: 71-96.
- Sword Sayer, M.A.; Haywood, J.D. 2006. Seasonal fine root production and carbohydrate concentrations of mature longleaf pine—consequence of season of prescribed fire and drought. *Trees* 20: 165-175.
- Sword Sayer, M.A.; Tang, Z. 2004. Long-term root growth response to thinning, fertilization, and water deficit in plantation loblolly pine. In: Connor, K.F., ed. *Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 458-464.
- Tang, Z.; Chambers, J.L.; Guddanti, S. [and others]. 1999. Seasonal shoot and needle growth of loblolly pine responds to thinning, fertilization, and crown position. *Forest Ecology and Management*. 120: 117-130.
- Vose, J.M.; Allen, H.L. 1988. Leaf area, stemwood growth, and nutrition relationships in loblolly pine. *Forest Science*. 34: 547-563.
- Weisburg, S. 1985. *Applied linear regression*. 2<sup>nd</sup> ed. New York: John Wiley. 324 p.
- Weise, D.R.; Johansen, R.W.; Wade, D.D. 1987. Effects of spring defoliation on first-year growth of young loblolly and slash pines. Res. Note SE-347. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 4 p.

# COMMUNITY ANALYSIS OF PITCHER PLANT BOGS OF THE LITTLE RIVER CANYON NATIONAL PRESERVE, ALABAMA

Robert Carter, Terry Boyer, Heather McCoy, and Andrew J. Londo<sup>1</sup>

**Abstract**—Pitcher plant bogs of the Little River Canyon National Preserve in northern Alabama contain the federally endangered green pitcher plant [*Sarracenia oreophila* (Kearney) Wherry]. Multivariate analysis of the bog vegetation and environmental variables revealed three communities with unique species compositions and soil characteristics. The significant soil characteristics were percent A-horizon sand and A-horizon depth. A blackgum (*Nyssa sylvatica* Marsh.)-yellow poplar (*Liriodendron tulipifera* L.)-azalea [*Rhododendron canescens* (Michx.) Sweet] type was found on sites bisected by ephemeral streams with a closed canopy. A scarlet oak (*Quercus coccinea* Muenchh.) -flowering dogwood (*Cornus florida* L.) -sweet goldenrod [*Solidago speciosa* Nutt. var. *erecta* (Pursh) MacM.] type was found on upland sites close to the canyon rim and along perennial streams sites. A smooth yellow false foxglove [*Aureolaria flava* (L.) Farw.]-pale-spike lobelia (*Lobelia spicata* Lam.)- violet lespedeza [*Lespedeza violacea* (L.) Pers.] type was found on relatively flat sites away from the canyon rim.

## INTRODUCTION

Populations of the federally-endangered green pitcher plant are found in scattered moist upland bogs in northern Alabama, northern Georgia, and western North Carolina. According to green pitcher plant habitat descriptions, populations are typically found on moist upland and sandy riverbank sites. The U.S. Fish and Wildlife Service (1994) indicated that there were differences in soil characteristics of moist upland areas supporting green pitcher plant populations but provided only a general habitat categorization as mixed oak, seepage bog types, and streamside habitats. McDaniel (1971) indicated that the species often occurs in heavily wooded areas. According to Schnell (1980), the best habitats for green pitcher plants are on gently sloping open bogs adjacent to small branches or ponds. The soil was usually a silt-clay-sand mixture. According to Folkerts (1977), green pitcher plants occurred on sites bordering streams, mesic woodlands, and open or shaded depressions. Patrick and others (1995) reported that green pitcher plants were found in poorly drained oak-pine flatwoods and red maple-blackgum swamps.

Previous green pitcher plant habitat research has primarily involved the description of the vegetation with no attempts to measure vegetation, soil, and landform variables to identify ecological communities. The objective of this study was to examine differences in bog vegetation structure and relate the differences to soil and landform variables.

## SITES

The Little River Canyon National Preserve near Fort Payne, AL, has eight bogs with populations of green pitcher plants. The Little River Canyon is located entirely on Lookout Mountain in the Cumberland Mountain-Plateau Province of north-east Alabama (Hodgkins and others 1979). The canyon has been carved into the top of Lookout Mountain by the Little River. Most of the eight pitcher plant bogs are located near the rim of the canyon where the water table is at or near the soil surface.

## PROCEDURES

In the summer of 2003, a 10 x 30 m plot was placed in each of the 8 bogs. Plots were located near the center of the bogs and away from roads and power lines. Tree, sapling, seedling, and herbaceous strata were sampled following the Carolina Vegetation Survey protocol (Peet and others 1998). Tree (>11.4 cm d.b.h.) and sapling (>5 cm d.b.h.) diameters were measured throughout the plot while seedling (<5 cm d.b.h.) and herbaceous cover were estimated in 2 10 x 10 m subplots. Vines were recorded as part of the herbaceous strata. Soil samples were collected by horizon (A and B) from four locations within the plot to determine soil horizon depth. The soil was retained for texture analysis and chemical analysis including pH, percent N and C, and total P, K, CA, and Mg (tons per acre). Landform variables sampled included slope gradient, aspect, terrain shape index (TSI), and landform index (LFI) (McNab 1989, 1992).

Plant communities were delineated through ordination and cluster analysis of vegetation and environmental data. Species occurring in more than one stratum (e.g., red maple as a tree, sapling, and seedling) were considered separate species. Importance values (IVs) were calculated and used in the initial analysis. Detection of communities was difficult with IVs, thus they were replaced with presence/absence data. The mere presence or absence of a species proved to be more important than its relative IV for community classification. The ordination methods employed were Canonical correspondence analysis (CCA) and Detrended correspondence analysis (DCA). Two-way indicator species analysis (TWINSPAN) (Hill 1979) was the cluster analysis employed.

In order to characterize the species composition of each community, constancy and IVs were calculated for each community. Constancy for a single species was calculated by dividing the number of plots of occurrence by the total number of plots within the community, expressed as a percentile. Species with a constancy of  $\geq 50$  percent were considered to be diagnostic for a community. Species with the highest constancy and IV were used to give each community a name (e.g., longleaf pine-shiny blueberry-wiregrass type).

<sup>1</sup> Assistant Professor, Graduate Student, and Undergraduate Student, respectively, Jacksonville State University, Department of Biology, Jacksonville, AL 36265; and Associate Extension Professor, Mississippi State University, Department of Forestry, Mississippi State, MS 39762.

The environmental variables significantly ( $p = 0.20$ ) related to the communities were determined by stepwise discriminant analysis with SYSTAT (2004). Discriminant functions were created for each community with the significant environmental variables and tested by resubstitution and cross-validation to determine their predictive efficacy.

## RESULTS AND DISCUSSION

Three green pitcher plant communities were identified. One community only contained one plot but was accepted because of its unique structure and species composition. Discriminant analysis revealed that percent A horizon sand and depth of the A horizon were significantly ( $p=0.20$ ) related to the plant communities. These variables were used to create discriminant functions for each community. Resubstitution analysis of the discriminant functions revealed that the classification success rate using only the environmental variables was 100 percent for each community. Classification success with cross-validation analysis was 63 percent.

### Green Pitcher Plant Communities

All pitcher plant bogs shared certain species in common including *Sarracenia oreophila* (Kearney) Wherry, *Acer rubrum* L., *Liquidambar styraciflua* L., *Oxydendrum arboretum* (L.) DC., *Pinus taeda* L., *Quercus falcata* Michx., *Vaccinium arboreum* Marsh., *Smilax rotundifolia* L., *Smilax glauca* Walt., and *Vitis rotundifolia* Michx. Most tree species were sapling size, although *O. arboretum*, *P. taeda*, and *Q. falcata* were tree sized.

A blackgum-yellow poplar-azalea type was found in broad swales bisected by an ephemeral stream with a mean slope of 3 percent. The mean percent A-horizon sand was 46.25 while the A horizon depth was 22.78 cm (table 1). The community had experienced prescribed fires, but a closed canopy still persisted. The fire intensity likely was too low due to the

ephemeral streams to reduce the canopy cover. It had the lowest number of trees/ha (190), but the trees were larger in diameter and height than those of other communities. The sapling density was 4,940 stems/ha. The overstory was dominated by *A. rubrum*, *Nyssa sylvatica* Marsh., and *Liriodendron tulipifera* L. The sapling stratum was characterized by *Liriodendron tulipifera* and *Rhododendron canescens* Michx., while the seedling stratum was primarily *Liriodendron tulipifera*, *P. taeda*, and *Ilex verticillata* (L.) Gray. Common herbaceous species included *Hexastylis shuttleworthii* (Britten & Baker) Small and *Solidago erecta* Pursh (table 2). *Sarracenia oreophila* density was 5.81 stems/m<sup>2</sup>.

A scarlet oak-flowering dogwood-sweet goldenrod type was found on upland seepage bogs close to the canyon rim and along perennial streams. The mean slope was 7.5, and these sites were the most concave (TSI = 8.5) of all communities. The mean percent A-horizon sand was 24.73 and the A-horizon depth was 27.73 cm (table 1). This community had an open tree canopy (386 stems/ha); however, little sunlight reached the ground due to a dense midstory of saplings (5,040 stems/ha). Prescribed fire was likely intense enough to reduce the overstory but not intense enough to prevent the development of a dense midstory. *Q. coccinea* Münchh. was found in the overstory while the sapling stratum was characterized by *Q. coccinea*, *Q. velutina* Lam., *Cornus florida* L., *Castanea pumila* (L.) P. Mill., *Rhus glabra* L., and *Sassafras albidum* (Nutt.) Nees. Common seedling species were *Rhus glabra*, *Rhus copallina* L., and *Castanea pumila*. The herbaceous stratum was characterized by *Rubus argutus* Link, *Solidago odora* Ait., and *Arundinaria gigantea* (Walt.) Muhl. ssp. *tecta* (Walt.) McClure (table 2). *Sarracenia oreophila* density was 7.76 stems/m<sup>2</sup>.

A smooth yellow false foxglove-pale-spike lobelia-violet lespedeza type was found on convex sites with a slope of 4.25 percent and TSI of -1.875 (table 1). The tree density was still

**Table 1—Mean and range (in parentheses) of environmental variables of green pitcher plant bogs of the Little River Canyon National Preserve**

Variable	Community type		
	Blackgum yellow-poplar azalea	Scarlet oak flowering dogwood sweet goldenrod	Smooth yellow false foxglove pale-spike lobelia violet lespedeza
LFI	11.92 (10.75-11.38)	12.29 (8.12-13.88)	9.12 (9.12)
TSI	2.83 (1.63-4.63)	8.5 (0.13-10.25)	-1.18 (-1.18)
% slope	12.00 (3-28)	6.00 (3-11)	4.25 (4.25)
A-horizon depth (cm) <sup>a</sup>	22.78 (12.5-28.5)	24.73 (11.33-38.25)	15.00 (15.00)
B-horizon depth (cm)	79.58 (46.5-111.00)	62.22 (53.00-81.00)	75.37 (75.37)
A-horizon % sand <sup>a</sup>	46.25 (43.75-46.25)	55.31 (50-61.25)	38.75 (38.75)
B-horizon % sand	51.25 (42.5-58.75)	55.00 (46.25-57.5)	41.25 (41.25)

<sup>a</sup>Statistically significant ( $p=0.20$ )

**Table 2—Constancy and mean importance value [constancy (%): importance value] of diagnostic species in green pitcher plant bogs of the Little River Canyon National Preserve**

Species <sup>a</sup>	Community type		
	Blackgum yellow-poplar azalea	Scarlet oak flowering dogwood sweet goldenrod	Smooth yellow false foxglove pale-spike lobelia violet lespedeza
<i>Sarracenia oreophila</i> 4	100:10.94	100:5.12	100:0
<i>Nyssa sylvatica</i> 1	100:3		
<i>Liriodendron tulipifera</i> 3	66:2		
<i>Rhododendron canescens</i> 1,2	66:10		
<i>Rhododendron canescens</i> 3	00:6	100:4	
<i>Hexastylis shuttleworthii</i> 4	66:7		
<i>Solidago speciosa</i> var. <i>erecta</i> 4	66:7	25:2	
<i>Ilex verticillata</i> 3	66:4	25:5	
<i>Sassafras albidum</i> 2	33:12	75:2	
<i>Arundinaria gigantea</i> 4	33:7	75:10	
<i>Rubus argutus</i> 4	33:4	75:6	
<i>Rhus copallina</i> 3	33:3	100:6	
<i>Cornus florida</i> 2		75:3	
<i>Solidago odora</i> 4		100:5	
<i>Quercus velutina</i> 2		75:2	100:2.35
<i>Quercus coccinea</i> 2		75:2	100:9
<i>Rhus copallina</i> 2		75:7	100:15
<i>Quercus stellata</i> 2		50:2	100:3
<i>Lobelia spicata</i> 4			100:9
<i>Aureolaria flava</i> 4			100:14
<i>Hieracium gronovii</i> 4			100:6
<i>Ludwigia alternifolia</i> 4			100:4
<i>Lespedeza violacea</i> 4			100:11

<sup>a</sup> 1, 2, 3, and 4 following species names indicates tree, sapling, seedling, and herb, respectively.

relatively high (240 stems/ha), but the sapling density was the lowest of the communities (2,280 stems/ha). Fire intensity was great enough to reduce the overstory and midstory density permitting many herbaceous species to become established. This community lacked many woody species common in the other two communities. The A-horizon sand was 15 percent while the A-horizon depth was 38.75 cm (table 1). *Q. stellata* Wang. and *Q. velutina* were found in the overstory while common sapling species included *Q. stellata*, *Q. velutina*, *Q. alba* L., *Vaccinium arboreum*, *P. taeda*, and *Carya tomentosa* (Poir. in Lam.) Nutt. The seedling stratum was characterized by *Q. stellata*, *Q. coccinea*, and *Sassafras albidum*. The herbaceous stratum included *Lobelia spicata* Lam., *Aureolaria flava* (L.) Farw., *Ludwigia alternifolia* L., and *Hieracium gronovii* L. (table 2). *Sarracenia oreophila* was present in the plot but absent from the herbaceous subplot; thus, it does not have an IV. *Sarracenia oreophila* density was 20.46 stems/m<sup>2</sup>.

### Relationship to Previous Studies

The bogs of the Little River Canyon seem to be similar to the poorly-drained oak-pine flatwoods and red maple black swamps of Patrick and others (1995) or seepage bogs noted by Schnell (1980). The seepage bogs were reported to be located on moderately to steeply sloping sites with low density canopies. The smooth yellow false foxglove-pale-spike lobelia-violet lespedeza type seems to fit Schnell's seepage bog description. Patrick and others (1995) reported that green

pitcher plants were found in poorly drained oak-pine flatwoods and red maple-blackgum swamps. The blackgum-yellow-poplar-azalea type and scarlet oak-flowering dogwood seem to fit communities described by Patrick.

No previous research has quantitatively examined soil and landform properties and vegetative structure of green pitcher plant bogs and attempted to classify communities. The inclusion of soil and landform properties into community classification provides a more ecologically-based classification. Possible sites for restoration can then be located based on soil and landform properties. It also reduces the possibility of a classification being a reflection of successional communities. The communities identified in this research each have unique soil properties that have influenced the vegetation. This is reflected in dry site species such as *Q. coccinea* in the scarlet oak-flowering dogwood-sweet goldenrod type and moister site species such as *Liriodendron tulipifera* in the blackgum-yellow-poplar-azalea type.

### Fire and Fire Suppression

The sites in the Little River Canyon National Preserve are suffering from overstory encroachment due to infrequent fire. If a more frequent fire regime is restored, the fire could interact with environmental variables to change the species composition. Sites experiencing fire suppression consistently have lower species richness (Walker and Peet 1983).

Research is needed to access the influence of fire on the communities and the green pitcher plant populations. Each community is likely to respond to fire differently and may require unique management regimes.

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## LITERATURE CITED

- Folkerts, G.W. 1977. Endangered and threatened carnivorous plants of North America. In: Prance, G.; Elisa, T., eds. Extinction is forever. New York, NY: New York Botanical Garden: 301-313.
- Hill, M.O. 1979. TWINSPAN: A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ithaca, NY: Cornell University, Department of Ecology and Systematics. 90 p.
- Hodgkins E.J.; Golden, M.S.; Miller, W.F. 1979. Forest habitat regions and types on a photomorphic-physiographic basis: a guide to forest site classification in Alabama-Mississippi. Southern Cooperative Series Number 210. Auburn, AL: Alabama Agricultural Experiment Station, Auburn University. 64 p.
- McDaniel, S.T. 1971. The genus *Sarracenia* (Sarraceniaceae). Bulletin of the Tall Timbers Research Station. 9: 1-36.
- McNab, W.H. 1989. Terrain shape index: quantifying effect of minor landforms on tree height. Forest Science. 35: 91-104.
- McNab, W.H. 1992. A topographic index to quantify the effect of mesoscale and form on site productivity. Canadian Journal of Forest Research. 23: 1100-1107.
- Patrick, T.S.; Allison, J.R.; Krakow, G.A. 1995. Protected plants of Georgia. Social Circle, GA: Georgia Department of Natural Resources. 248 p.
- Peet, R.K.; Wentworth, T.R.; White, P.S. 1998. A flexible multipurpose method for recording vegetation composition and structure. Castanea. 63: 262-274.
- Schnell, D.E. 1980. Notes on the biology of *Sarracenia oreophila* (Kearney) Wherry. Castanea. 45: 166-170.
- SYSTAT. 2004. SYSTAT 11.0 for Windows. Richmond, CA: SYSTAT Software.
- U.S. Fish and Wildlife Service. 1994. Green pitcher plant recovery plan. Jackson, MS: U.S. Fish and Wildlife Service. 23 p.
- Walker, J.; Peet, R.K. 1983. Composition and species diversity of pine-wiregrass savannas of the Green Swamp, North Carolina. Vegetatio. 55: 163-179.

# SHORT-TERM EFFECTS OF SPRINGTIME PRESCRIBED FIRES ON ADULT POPULATIONS OF SOIL-EMERGING WEEVILS IN CENTRAL APPALACHIAN HARDWOOD STANDS

David P. McCann, David W. McGill, Thomas M. Schuler, and W. Mark Ford<sup>1</sup>

**Abstract**—Numerous biotic and abiotic factors interact to affect oak regeneration in the central Appalachians. Fire, white-tailed deer, rodents, other vertebrate seed predators, invasive plants, insects, fungi, climate, and tree physiology contribute singularly or additively to oak regeneration problems. Moreover, fire suppression has significantly enhanced the deleterious impacts of several of these biotic influences. The relationship between fire and acorn weevils is unknown, but acorn weevils are significant contributors to regeneration problems in some oak stands and may be vulnerable to fire at certain life stages. As part of a broader investigation of fire use as a silvicultural tool, we examined prescribed fire impacts on acorn weevils (genera: *Curculio* and *Conotrachelus*) that inhibit oak (*Quercus* spp.) regeneration by larval consumption of embryonic or newly dropped acorns. We prescribe burned two stands on the Fernow Experimental Forest in north-central West Virginia: One was burned April, 2002, and the other April, 2003. We placed soil emergence traps under oak and other tree species on five plots within each burn treatment and four adjacent unburned plots. Arthropod samples were collected April to October in 2003 and 2004. We collected 233 weevils representing 11 species from 9 genera. *Curculio* and *Cyrtopistomus* species predominated; *Conotrachelus* species were notable. Our preliminary data indicates that acorn weevil emergence may not be reduced following a single spring fire. Herein, we describe the pattern and intensity of acorn weevil emergence during the first 2 years of our study.

## INTRODUCTION

Successful oak regeneration in the central Appalachians is currently hindered by many biotic and abiotic factors such as an absence of fire, white-tailed deer herbivory, seed predation by rodents and other vertebrates, insects, invasive plants, fungi, climate, and tree physiology. These factors probably work in both additively and synergistically, presenting managers with almost insurmountable challenges. Historical evidence suggests lack of fire is an important factor accelerating the shift from oak-dominated stands to those dominated by shade-tolerant species such as red maple, *Acer rubrum* L., and sugar maple, *A. saccharum* Marsh. (Gribko and others 2002, Oak 1998). It has been hypothesized that fire suppression has allowed acorn weevils and other insects to become a greater impediment to oak establishment and regeneration than would have occurred otherwise (Gribko and others 2002, Oak 1998, Riccardi and others 2004).

Within the central Appalachian landscape, Native Americans and European settlers routinely used fire to clear land, flush game, and increase soft fruit and forage production (Van Lear and Harlow 2002). These anthropogenic efforts aided oak establishment and maintenance, particularly in forest systems where shade-tolerant mesic species would otherwise predominate. Local and regional extirpation of white-tailed deer, black bear, and wild turkey might have somewhat ameliorated the impacts of the early fire suppression era (circa 1920). However, several decades of restocking, conservation, and hunting regulation has led to tremendous population increases of game animals—particularly deer—that impact oak through seed consumption and plant herbivory (Horsley and others 2003).

Red oaks (*Erythrobalanus*) and white oaks (*Leucobalanus*) are temporally distinct in germination. Red oaks drop acorns

in early fall and need a period of dormancy interrupted by 4 to 6 weeks of cool, moist conditions to germinate, whereas white oaks drop and germinate in the same fall season (Gribko and others 2002, Olson and Boyce 1971). Accordingly, white oaks germinate during peak litter depths, whereas red oaks germinate more often on bare soils (Gribko and others 2002). Furthermore, acorns from red oaks have significantly higher tannin concentrations than white oak acorns and in some cases have been reported to have less weevil predation (Brezner 1960, Weckerly and others 1989).

Once germinated, seedling growth is dictated by several factors. Stored food reserves in the form of endosperm and cotyledon health are crucial determinates of seedling survival (Gribko and others 2002, Oliver and Chapin 1984), but sufficient soil moisture also is necessary for root development. Light becomes limiting once the carbohydrate reserves in the cotyledons, which remain below ground, are consumed (Kramer and Kozlowski 1979). Ultimately, long-term seedling success depends on competition for growing space. Seedlings must outcompete herb and shrub layers to become advance regeneration.

Insects and vertebrates inhibit acorn production and oak regeneration at all levels, from flower development through sapling survival. Vertebrates prey on acorns in the tree and on the ground (Brooks 1910, Marquis and others 1976); treehoppers (Family: Membracidae) retard flower development (Beck 1993, Gribko and others 2002); and a litany of primary and secondary insects injure acorns and shoots at all stages of development.

Deer and rodents are among the primary vertebrate acorn predators, although their impact is hard to evaluate because

<sup>1</sup> Graduate Research Assistant and Extension Specialist, respectively, West Virginia University, Division of Forestry, Percival Hall, Morgantown WV 26506; and Research Forester and Research Wildlife Biologist, respectively, USDA Forest Service, Northeastern Research Station, Parsons, WV 26287.

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they often remove or completely consume acorns. Gray and fox squirrels and eastern chipmunks cache acorns whole or consume enough endosperm to prevent germination and radicle growth, particularly in the presence of secondary organisms such as fungi, bacteria, and insects (Edwards and others 2003, Galford and others 1988, Gribko and others 2002, Marquis and others 1976, Steiner 1995, Tryon and Carvell 1962). Any estimates of vertebrate predation will necessarily be underestimations because of missing acorns that cannot be counted.

Numerous acorn-damaging insects from various families are primary predators; they penetrate sound, undamaged acorns (Galford and others 1988, Gibson 1971, Gibson 1972, Gribko and others 2002, Murtfeldt 1894, Steiner 1995). Secondary insects and other pests only enter acorns through damage incurred physically or from primary predators feeding on acorns and developing seedlings (Galford and others 1991, Galford and others 1988, Gibson 1972, Gibson 1982, Murtfeldt 1894, Oak 1992, Winston 1956).

The most significant primary insect predators are the acorn weevils of the genus *Curculio* (Coleoptera); the filbertworm (*Melissopus latiferreanus* Wals.: Lepidoptera) and Cynipid wasps (*Callirhytis* spp.: Hymenoptera) are also notable, but their damage is insignificant relative to *Curculio* spp. (Galford and others 1991, Gibson 1971, Gibson 1972, Gibson 1982, Gribko and others 2002, Murtfeldt 1894, Oak 1992, Oliver and Chapin 1984, Olson and Boyce 1971, Steiner 1995, Tryon and Carvell 1962, Winston 1956). The most prominent secondary insect predators are weevils of the genus *Conotrachelus* (Coleoptera)—a seedling weevil, *Barypeithes pellucidus* Boh. (Coleoptera), the acorn moth (*Valentinia glandulella* Ril.: Lepidoptera), and a nitidulid beetle, *Stelidota octomaculata* Say (Coleoptera) (Galford and others 1991, Galford and others 1988, Gibson 1964, Gribko and others 2002, Murtfeldt 1894, Oak 1992). Other scavenging insects from the order Diptera are commonly found in damaged acorns; they often are attracted by secondary fungal organisms (Winston 1956).

Adult *Curculios* emerge from the soil from spring to fall following pupation; they then oviposit eggs in acorns on the tree or ground where larvae feed on endosperm or embryo tissue before exiting to overwinter in the soil for 1 to several years prior to pupation during the growing season (Brooks 1910, Gibson 1971, Gibson 1972). *Conotrachelus* spp. adults also emerge from the soil from spring to fall, but they only oviposit in previously-damaged acorns or in the oviposition holes of *Curculios* (Brooks 1910, Gibson 1964). *Conotrachelus* larvae feed on acorn contents, exit in the fall, and pupate before overwintering in leaf litter (Brooks 1910, Gibson 1964); *Conotrachelus posticatus* Boh. may spend its first winter as a larva, pupate the following spring, and overwinter as an adult during its second winter (Brezner 1960, Brooks 1910, Gibson 1964).

*Cyrtopistomus castanea* Roel. and *Barypeithes pellucidus* typically do not enter acorns but feed on leaves, shoots, roots, and, more significantly, radicles of oak seedlings (Evans 1959, Ferguson and others 1991, Ferguson and others 1992, Galford 1986, Galford 1987, Triplehorn 1955). Secondary insects other than weevils also will feed on embryos, endosperm, and radicles (Galford and others 1988, Gribko and others 2002, Murtfeldt 1894). Insect infestation is not always an absolute mortality agent if cotyledons and endosperm are

still somewhat intact. However, if the radicle is damaged, then acorn germination is unlikely. Furthermore, if reserves for seedling survival are diminished enough to affect seedling health, survival rates of seedlings are lowered.

Damaged portions of the acorn crop vary but generally indicate significant insect activity. Gibson (1972, 1982) reported 100 percent insect damage in stands of white oak and up to 96 percent in red oak stands. Tryon and Carvell (1962) noted approximately 30 percent damage from all insects. *Curculio* spp. can be responsible for nearly all of insect damage to acorns (Gibson 1971, Riccardi and others 2004). *Conotrachelus* spp. can infest up to 38 percent of sampled acorns (Gibson 1964, 1972) or as few as 2.8 percent (Gibson 1971).

Our knowledge on the limiting factors and controls on weevil infestations in oaks is lacking, especially about fire-weevil interactions and ecology. By sampling acorns and adult emergence, Riccardi and others (2004) found spring prescribed fires in Ohio resulted in improved acorn crops and lower weevil predation rates in the second season after burning. However, there were insignificant differences in weevil emergence among thinning and burn treatments. Wright (1987) found spring fires reduced populations of *Conotrachelus* weevils in Ohio. In Washington, growing season fires have been shown to impact ground-dwelling arthropod numbers (Rickard 1970) and in Minnesota, Wisconsin, and Michigan, spring and fall fires significantly reduced red pine cone beetle, *Conophthorus resinosae* Hopkins (Miller 1978).

Fire was an historical component in the central Appalachians and might have had a role in controlling weevil populations when it occurred at opportune times during weevil life cycles. Therefore, the objective of our study was to evaluate the impacts of spring prescribed fire on soil-emerging adult populations of weevils known to prey on acorns and oak seedlings in the central Appalachians.

## SITES

Our study sites were located on the Fernow Experimental Forest (39.03° N, 79.67° W) in north-central West Virginia. The Fernow is a 1,900-ha Experimental Forest within the Monongahela National Forest administered by the Northeastern Research Station, U.S. Forest Service. The ecological land type of the Fernow is referred to as within the Allegheny Mountains of the Central Appalachian Broadleaf Forest as designated by McNab and Avers (1994). The draft landtype association is the Allegheny Front Sideslopes (DeMeo and others 1995) and is representative of over 40,000 ha on the Monongahela National Forest alone. The vegetation of the Fernow ranges from mixed mesophytic to northern hardwoods depending on elevation, aspect, and site quality.

Spring burning occurred in the Stonelick and Sugarcamp Run drainages and included both a flat ridgetop (47 acres; 2,400 to 2,600 feet asl) and a lower slope (30 acres; 2,000 to 2,200 feet asl) site. The lower site had a western aspect, and both the upper and lower sites have inclusions of cove-like conditions. Study site soils were characterized by a Calvin series that were well-drained and strongly acid, moderately deep, and moderately permeable. Overall, the site index was approximately 70 for northern red oak (*Quercus rubra* L.). Overstory species in the study area include northern red oak, chestnut oak (*Q. prinus* L.), and white oak (*Q. alba* L.) in descending

order of dominance as measured by basal area. Other over-story species include red maple, sugar maple, yellow-poplar (*Liriodendron tulipifera* L.), and sweet birch (*Betula lenta* L.).

## METHODS

A total of 24 experimental plots were established (12 on each site, 2 of which were controls receiving no treatments) on which the effects of shelterwood harvests and accompanying fires will be evaluated. Prescribed fire was applied to the lower site in April, 2002, and the upper site in April, 2003 (excluding control plots on both sites). Shelterwood regeneration cuts have not yet been completed.

We sampled emerging adult weevils using 1 m<sup>2</sup> soil emergence traps placed under oak and non-oak species on 5 plots of both the upper and lower sites and the 4 control plots. In all, 60 traps were used in burned plots, 15 traps under oaks and 15 under non-oaks on each site. Additionally, 31 traps were used on control plots, 15 under oaks and 16 under non-oaks.

We collected samples from March through October in 2003 and 2004; contents were placed in plastic bags and kept frozen until examined for weevils. We examined contents ocularly and with a stereoscope to determine the number and genus of emerging weevils. Weevils trapped in 2003 were pinned by staff from the West Virginia University Entomology Department and sent to R.S. Anderson in Canada for species identification. This collection served as the source for identification of future-trapped weevils to genus.

## RESULTS AND DISCUSSION

### Species and Relative Frequency

Overall, we collected 233 weevils, 53 in 2003 and 180 in 2004, representing 11 species from 9 genera (table 1). Most genera occurred in negligible numbers. Three species/genera

**Table 1—Species and abundance of trapped adult weevils in the central Appalachians in West Virginia in 2003 and 2004**

Species	2003	2004	Total
<i>Cyrtepistomus castanea</i> Roel.	14	121	135
<i>Curculio pardalis</i> Chitt.	11	56	67
<i>Conotrachelus posticatus</i> Boh.	11	1	12
<i>Conotrachelus naso</i> Lec.	1	0	1
<i>Conotrachelus anaglypticus</i> Say	2	0	2
<i>Acalles carinatus</i> Lec.	7	1	8
<i>Eubulus bisignatus</i> Say	2	0	2
<i>Ithycerus noveboracense</i> Forster	2	1	3
<i>Epacalles inflatus</i> Blat.	1	0	1
<i>Cophes fallax</i> Lec.	1	0	1
<i>Lepidophorus setiger</i> Ham.	1	0	1
Totals	53	180	233

dominated collections: *Curculio pardalis* Chitt. was the most commonly collected nut weevil; *Conotrachelus* spp. occurred less frequently; *Cyrtepistomus castanea*, an exotic root/seedling weevil, accounted for the majority of collections (fig. 1). As noted above, *Curculio* spp. have been observed to be responsible for the majority of acorn infestations, and *Conotrachelus* spp. significantly added to infestations or may be primarily responsible at times. While the genera *Curculio* and *Conotrachelus* were the main subjects of this study, the predominance of *Cyrtepistomus castanea* is clear (table 1; figs. 1, 2, and 3), and the species must be considered when evaluating detriments to oak regeneration. Trap locations under oak versus non-oak species did not have any influence on our results.

*Cyrtepistomus castanea*, the Asiatic oak weevil, is a univoltine, broad-snouted weevil that as an adult feeds on leaves

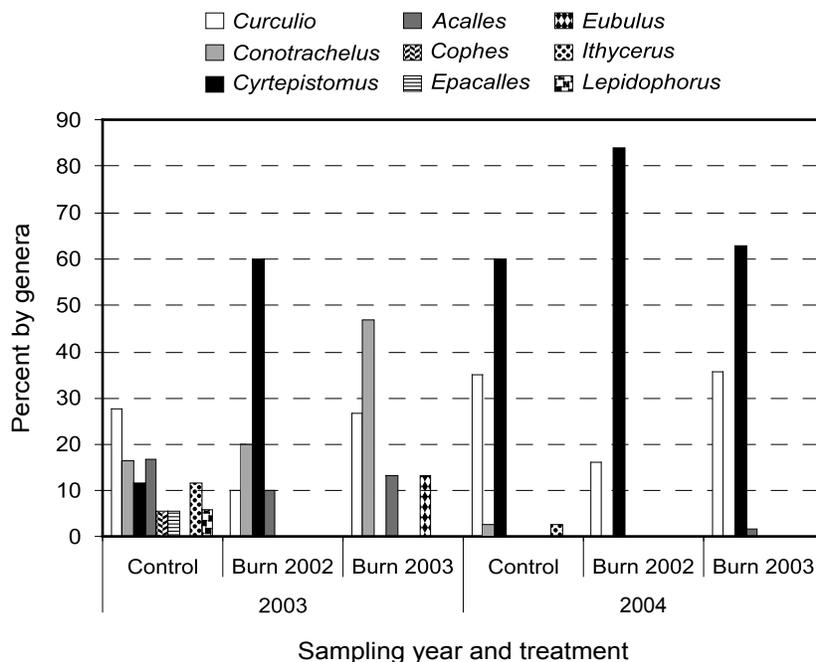


Figure 1—Proportion of weevils by genera, treatment, and sampling year.

(of seedlings most importantly) and emerging radicles. Larvae reside and overwinter in soil, feeding on roots. Pupation occurs in the summer shortly before adult emergence in the summer and fall (Evans 1959, Ferguson and others 1991, Ferguson and others 1992, Triplehorn 1955). The Asiatic oak weevil uses almost any oak species as food. The habits of this weevil and its abundance in the sampled area also indicate its potential importance as a factor affecting oak regeneration in the central Appalachians.

### Emergence and Population Sizes

Emergence patterns of the three dominant genera of this study confirm findings of previous studies: *Curculio* and *Conotrachelus* adults emerge predominantly from April to July, and *Cyrtepistomus castanea* adults emerge from July to October (fig. 2). Data from our study also suggest population sizes

vary substantially from year to year (figs. 2 and 3). Population sizes, as estimated from emergence, also vary from control to burn plots (fig. 3).

In 2003, more *Curculio* weevils emerged in control plots than in plots burned that year or in the previous year (2002). *Conotrachelus* weevil emergence increased in both the same year and 1-year-old burn plots, and *Cyrtepistomus castanea* emergence increased in the same year, even more so in 1-year-old burn plots relative to control plots (fig. 3). In 2004, *Curculio* weevil emergence increased in all three treatment areas (control, burn 2002, burn 2003), suggesting a secondary environmental signal, but the fewest *Curculios* appeared in the treatment area burned in 2002 (fig. 3). It may be noteworthy that this area burned more completely and with higher average temperatures than the other burn area (Schuler

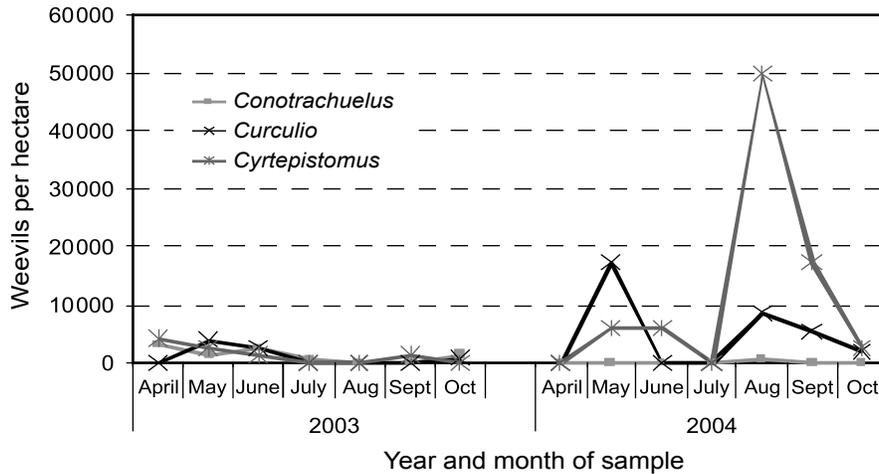


Figure 2—Emergence patterns of adult weevils of the three prominent genera collected in the central Appalachians in 2003 and 2004.

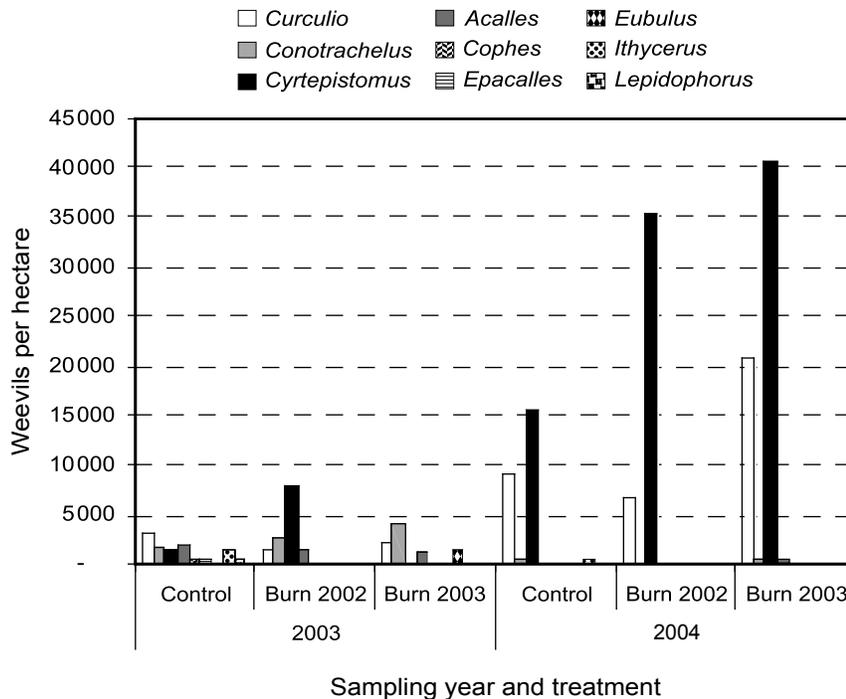


Figure 3—Number of weevils per hectare by species, treatment, and sampling year.

unpublished data). *Cyrtopistomus castanea* was the most abundant weevil in all three areas in 2004; fire either had no effect or possibly favored this species.

Overall, our results suggest spring burns do not directly reduce emerging populations of adult acorn and seedling weevils in the short term. Conversely, burning may somehow stimulate larger-than-normal emergence populations. In most comparisons, emergence on burned plots exceeded that on control plots in terms of absolute numbers and per unit area (figs. 1 and 3).

Wright (1987) obtained similar results from collections of *Conotrachelus* weevils in pitfall traps over 2 years of sampling following a spring fire. However, the use of pitfall traps could have skewed data by gathering weevils in an area greater than their emergence zone. Wright (1987) concluded that *Conotrachelus* weevil emergence was consistently reduced by spring fires when sampling from litter rather than with pitfall traps. Conversely, Riccardi and others (2004) found no difference in adult weevil emergence following fire in Ohio.

Future studies should perhaps utilize fall fires that might effectively impact insects in forest litter (Miller 1978, Wright 1987) or target late-emerging adults (fig. 2), any resident adults in litter, larvae recently emerging from acorns that have not yet burrowed into the soil, or larvae still in acorns that have dropped to the ground. *Cyrtopistomus castanea* populations in particular could be controlled more effectively with fall fires when late-season, active adults are present and larvae are preparing to overwinter. Repeated fires have not yet been assessed but may also contribute to significantly different weevil population dynamics, more so than a single prescribed fire.

Although our study suggests emerging weevil populations might be enhanced by spring fire, the increase in emergence in the short term may retard emergence in subsequent years. In figure 3, *Curculio* weevil emergence 2 years following burning is reduced on burned plots; similarly, Riccardi and others (2004) found acorn infestations 2 years after spring burns were reduced.

One of the strategies insects employ for species survival that could possibly account for variable populations from year to year (figs. 2 and 3) is diapause: Some larvae may overwinter 2 or more years, supplementing future populations. These larvae may in some cases develop more slowly and need more time to mature to where they can be significant contributors to reproduction.

If fire stimulates the emergence of weevils that would have emerged later or are not fully developed for reproduction, subsequent weevil populations might exhibit less overall fitness and survival, which could reduce numbers over the long term. To evaluate these possibilities, continuous sampling over several years to identify the long-term effects of prescribed fires (spring or fall) on weevil populations will be necessary. In addition to sampling emerging populations, acorn infestation and reproductive fitness (as determined by adult dissections) should be measured and correlated with emerging populations from previous years to investigate the long-term effects of fire on weevil populations.

Our study continues, and in the spring of 2005 all of the previously burned areas were successfully burned again. Through

continued monitoring and periodic prescribed fires, we hope to gain a better understanding of how fire may have changed acorn weevil populations in the past, and whether fire has any management potential for controlling problematic weevil populations in the present.

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## LITERATURE CITED

- Beck, D.E. 1993. Acorns and oak regeneration. In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: serious problems, practical recommendations. Symposium proceedings. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 96-104.
- Brezner, J. 1960. Biology, ecology, and taxonomy of insects infesting acorns. Research Bulletin 726. Columbia, MO: Missouri Agricultural Experiment Station. 40 p.
- Brooks, F.E. 1910. Snout beetles that injure nuts. Bulletin 128. Morgantown, WV: West Virginia Agricultural Experiment Station: 148-185.
- DeMeo, T.; Tracy, L.; Wright, L. 1995. Landtype associations of the Monongahela National Forest. 1:250,000; UTM map projection. Elkins, WV: U.S. Department of Agriculture, Forest Service, Monongahela National Forest.
- Edwards, J.W.; Ford, W.M.; Guynn, D.C. 2003. Fox and gray squirrels. In: Feldhammer, G.A.; Thompson, B.C.; Chapman, J.A., eds. Wild mammals of North America, second edition. Baltimore, MD: John Hopkins University Press: 248-267.
- Evans, R. 1959. Notes on the biology of the Asiatic oak weevil in Maryland. Journal of Economic Entomology. 52: 177.
- Ferguson, C.S.; Linit, M.J.; Krause, G. 1991. Host plant preference of the Asiatic oak weevil (Coleoptera: Curculionidae). Environmental Entomology. 20: 1427-1432.
- Ferguson, C.S.; Linit, M.J.; Krause, G. 1992. Dispersion and density of Asiatic oak weevil (Coleoptera: Curculionidae) relative to oak density. Environmental Entomology. 21: 247-252.
- Galford, J.R. 1986. The weevil *Barypeithes pellucidus* (Coleoptera: Curculionidae) feeds on northern red oak, *Quercus rubra*, seedlings. Entomological News. 97(3): 113-114.
- Galford, J.R. 1987. Feeding habits of the weevil *Barypeithes pellucidus* (Coleoptera: Curculionidae). Entomological News. 98(4): 163-164.
- Galford, J.R.; Auchmoody, L.R.; Smith, H.C.; Walters, R.S. 1991. Insects affecting establishment of northern red oak seedlings in central Pennsylvania. In: McCormick, L.H.; Gottschalk, K.W., eds. Proceedings of the eighth central hardwood forest conference. Gen. Tech. Rep. NE-148. Parsons, WV: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 271-280.
- Galford, J.R.; Peacock, J.W.; Wright, S.L. 1988. Insects and other pests affecting oak regeneration. In: Smith, H.C.; Perkey, A.W.; Kidd, W.E., eds. Proceedings: guidelines for regenerating Appalachian hardwood stands. Publication 88-03. Bethesda, MD: Society of American Foresters: 219-225.
- Gibson, L.P. 1964. Biology and life history of acorn-infesting weevils on the genus *Conotrachelus* (Coleoptera: Curculionidae). Annals of the Entomological Society of America. 57: 521-526.
- Gibson, L.P. 1971. Insects of bur oak acorns. Annals of the Entomological Society of America. 64: 232-234.

- Gibson, L.P. 1972. Insects that damage white oak acorns. Res. Pap. NE-220. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.
- Gibson, L.P. 1982. Insects that damage northern red oak acorns. Res. Pap. NE-492. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.
- Gribko, L.S.; Schuler, T.S.; Ford, W.M. 2002. Biotic and abiotic mechanisms in the establishment of northern red oak seedlings: a review. Gen. Tech. Rep. NE-295. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 18 p.
- Horsley, S.B.; Stout, S.L.; DeCalesta, D.S. 2003. White-tailed deer impact on the vegetation dynamics of a northern hardwood forest. *Ecological Applications*. 13(1): 98-118.
- Kramer, P.J.; Kozlowski, T.T. 1979. *Physiology of woody plants*. New York: Academic Press. 811 p.
- Marquis, D.A.; Eckert, P.L.; Roach, B.A. 1976. Acorn weevils, rodents, and deer all contribute to oak-regeneration difficulties in Pennsylvania. Res. Pap. NE-356. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 5 p.
- McNab, W.H.; Avers, P.E. 1994. Ecological subregions of the United States: section descriptions. Publication WO-WSA5. Washington, DC: U.S. Department of Agriculture, Forest Service. 218 p.
- Miller, W.E. 1978. Use of prescribed burning in seed production areas to control red pine cone beetle. *Environmental Entomology*. 7(5): 698-702.
- Murtfeldt, M.E. 1894. Acorn insects, primary and secondary. Washington, DC: U.S. Department of Agriculture, Division of Entomology. *Insect Life*. 6: 318-324.
- Oak, S.W. 1992. Insects and diseases affecting oak regeneration success. In: Loftis, D.L.; McGee, C.E., eds. Symposium proceedings: oak regeneration; serious problems, practical recommendations. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 105-111.
- Oak, S.W. 1998. Insects and pathogens in eastern wilderness and natural areas. In: Kulhavy, D.L.; Legg, M.H., eds. *Wilderness and natural areas in eastern North America: research, management and planning*. Nacogdoches, TX: Stephen F. Austin University: 71-75.
- Oliver, A.D.; Chapin, J.B. 1984. *Curculio fulvus* (Coleoptera: Curculionidae) and its effects on acorns of live oaks, *Quercus virginiana* Miller. *Environmental Entomology*. 13(6): 1507-1510
- Olson, D.F.; Boyce, S.G. 1971. Factors affecting oak production and germination and early growth of seedlings and seedling sprouts. In: White, D.E.; Roach B.A., co-chairs. *Oak symposium proceedings*. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Northeast Forest Experiment Station: 44-48.
- Riccardi, C.L.; McCarthy, B.C.; Long, R.P. 2004. Oak seed production, weevil (Coleoptera: Curculionidae) populations, and predation rates in mixed-oak forests of Southeast Ohio. In: Yaussy, D.A.; Hix, D.M.; Long, R.P.; Goebel, P.C., eds. *Proceedings of the 14<sup>th</sup> central hardwood forest conference*. Gen. Tech. Rep. NE-316. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 10-20.
- Rickard, W.H. 1970. Ground dwelling beetles in burned and unburned vegetation. *Journal of Range Management*. 29: 293-294.
- Steiner, K.C. 1995. Autumn predation of northern red oak seed crops. In: Gottschalk, K.W.; Fosbroke, S.L., eds. *Proceedings of the 10<sup>th</sup> central hardwood forest conference*. Gen. Tech. Rep. NE-197. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 489-494.
- Triplehorn, C.A. 1955. The Asiatic oak weevil in Delaware. *Journal of Economic Entomology*. 48: 289-293.
- Tryon, E.H.; Carvell, K.L. 1962. Acorn production and damage. West Virginia University Agricultural Experiment Station Bulletin 466T. 14 p.
- Van Lear, D.H.; Harlow, R.F. 2002. Fire in the eastern United States: influences on wildlife habitat. In: Ford, W.M.; Russell, K.R.; Moorman, C.E., eds. *The role of fire in nongame wildlife management and community restoration: traditional uses and new directions*. Proceedings of a special workshop. Gen. Tech. Rep. NE-288. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 2-10.
- Weckerly, F.W.; Sugg, D.W.; Semlitsch, R.D. 1989. Germination success of acorns (*Quercus*): insect predation and tannins. *Canadian Journal of Forest Research*. 19: 811-815.
- Winston, P.W. 1956. The acorn microsera, with special reference to arthropods. *Ecology*. 37(1): 120-132.
- Wright, S.L. 1987. Managing insects affecting oak regeneration by prescribed burning. In: *Current topics in forest research: emphasis on contributions by women scientists*. Proceedings of a national symposium. Gen. Tech. Rep. SE-46. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 186-192.

# THE EFFECT OF FIRE ON FLOWERING DOGWOOD STAND DYNAMICS IN GREAT SMOKY MOUNTAINS NATIONAL PARK

Eric J. Holzmüller, Shibu Jose, and Michael A. Jenkins<sup>1</sup>

**Abstract**—Flowering dogwood (*Cornus florida* L.) survival is threatened across most of its range in forests of the eastern United States by dogwood anthracnose, a disease caused by the fungus *Discula destructiva* Redlin. Where anthracnose is present, mortality of dogwood has been severe. Currently, no management techniques exist to reduce impacts of the disease on populations of dogwood. This study examined dogwood in burned and unburned oak-hickory forests in Great Smoky Mountains National Park (GSMNP) to determine if past burning has favored dogwood survival. Stand composition and structure of areas that burned in the 1970s and 1980s were compared to those in unburned areas to determine if dogwood stem density was affected by fire. Heavy dogwood mortality has occurred in unburned areas in western GSMNP over the past two decades. However, dogwood density was greater in areas that burned during the 1970s ( $232 \pm 64$  stems/ha) than in unburned areas ( $54 \pm 72$  stems/ha;  $P=0.08$ ). The increase in dogwood stem density in burned plots is likely a result of increased stump sprouting following the fire and the favorable conditions for survival from dogwood anthracnose fire creates. Our results suggest fire may play an important role in dogwood survival from dogwood anthracnose in GSMNP and other areas in the Eastern United States.

## INTRODUCTION

*Cornus florida* L. (flowering dogwood), a common understory species in the Eastern United States, is found in a variety of forest types ranging from mesic cove hardwood stands to xeric oak-pine woodlands. Dogwood is shade tolerant but can grow in full sunlight. Dogwood trees produce a calcium-rich fruit during the fall that is consumed by many bird and small game species. Leaves of dogwood trees also contain high amounts of calcium (2.0-3.0 percent, oven dry weight), which makes dogwood an important factor in calcium cycling in eastern hardwood forests (Thomas 1969).

*Discula destructiva* Redlin, the fungus that causes a disease known as 'dogwood anthracnose', is decimating dogwood populations across the Eastern United States. The fungus is believed to be an exotic from Asia brought over on contaminated nursery stock (Britton 1994). Dogwood anthracnose causes leaf blight and twig dieback. In smaller trees, this can lead to death 1 to 3 years after infection. Larger trees usually tolerate the leaf blight and twig dieback longer, but eventually the disease moves into the stem where cankers develop that girdle the tree. Dogwood anthracnose was first observed in New York City in 1978 (Pirone 1980) and moved rapidly down the Appalachian Mountains over the next decade. The disease is now present throughout most of the Northeastern United States and Appalachian Mountain region, as well as in some scattered pockets in the Midwest.

In areas where the disease has been found, dogwood trees have experienced high rates of mortality. Anagnostakis and Ward (1996) reported an 86 percent mortality rate in dogwood density from 1977 to 1987 in Connecticut, while Hiers and Evans (1997) observed a 91 percent decline between 1983 and 1995 in Tennessee. In Great Smoky Mountains National Park (GSMNP), Jenkins and White (2002) observed similar trends in dogwood decline. Between the late 1970s and 2000, dogwood decline ranged from 92 percent in alluvial forests to 80 percent in oak-hickory forests and 69 percent in oak-pine

forests. In an oak-dominated area that burned in 1976, however, dogwood density increased 200 percent (fig. 1).

This research was conducted to determine if similar increases in density occurred in other areas of the park that burned during the 1970s and 1980s. We hypothesize that stands burned during the 1970s and 1980s will have greater dogwood densities than unburned stands.

## STUDY AREA

Established in 1934, GSMNP is located in the heart of the southern Appalachian Mountains in eastern Tennessee and western North Carolina. The Park is over 200,000 ha, and its flora is among most diverse in eastern North America. Mean annual temperature in Gatlinburg, TN (440 m a.s.l.) is 12.9 °C; mean annual precipitation is 142 cm. Although the highest point in the Park is over 2,000 m, our study sites ranged

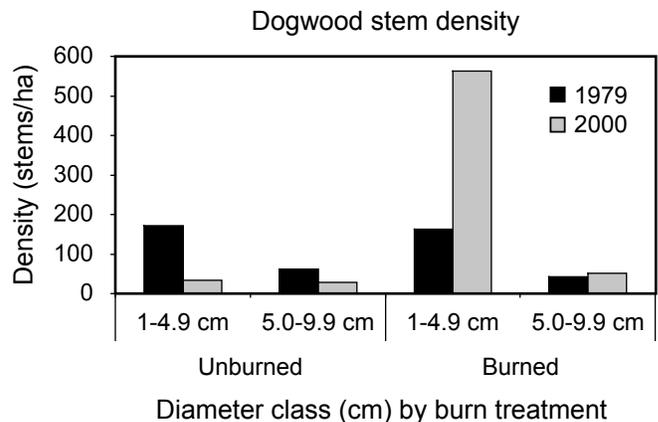


Figure 1—Dogwood stem density in Great Smoky Mountains National Park on burned and unburned plots for two size classes sampled in 1979 and 2000.

<sup>1</sup> Research Assistant, University of Florida, Gainesville, FL 32611; Associate Professor, University of Florida, Gainesville, FL 32611; and Ecologist, Great Smoky Mountains National Park, Gatlinburg, TN 37738, respectively.

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between 287 to 975 m, which represents the pre-anthrachnose elevation range of dogwood.

We used historic Park maps and fire history records to select burned areas for sampling. We established 29 0.04-ha plots in 7 areas that burned in the 1970s or 1980s. A minimum of three plots were established in each burn. All burns selected were at least 10 ha in size. We randomly selected plot locations within each burn by placing a 50 m buffer within the perimeter of each burn and randomly selecting coordinates. All plots were located in oak-hickory forest stands. In addition, 23 reference plots were sampled in unburned stands. These unburned reference plots had similar slope, aspect, elevation, and vegetation as the burned plots.

Data were collected from 52 plots from 2001 to 2004 during the months of June, July, and August. Diameter at breast height (d.b.h.) of all living overstory stems (>10 cm) was measured to the nearest 0.1 cm and recorded by species. We also measured the d.b.h. of all living dogwood stems, including trees < 10 cm d.b.h., to the nearest 0.1 cm. Understory stems ( $\leq 10$  cm d.b.h.) of all other species were tallied into 4 diameter classes: 0 to 1.0 cm, 1.1 to 2.5 cm, 2.6 to 5.0 cm, and 5.1 to 10.0 cm.

## DATA ANALYSIS

We used mixed procedure analysis of variance (ANOVA) to compare dogwood stem densities among burned and unburned stands. Separate analyses were conducted for each of the 3 diameter classes (0 to 5.0 cm, 5.1 to 10.0 cm, and >10.0 cm) and total density (SAS 2002). The mixed model was made up of two factors: sampling category, which was fixed, and burn area, which was random and nested within sampling category. When analysis revealed a significant difference between the sampling categories, we used orthogonal contrasts to determine the differences between the means of the sampling categories. We used the same technique to compare overstory and understory stem density and basal area.

## RESULTS AND DISCUSSION

### Dogwood Stem Density

Total dogwood stem density was greater on burned plots than on unburned plots (232 stems/ha versus 54 stems/ha,  $P=0.08$ ; fig. 2). We observed the greatest differences in stem

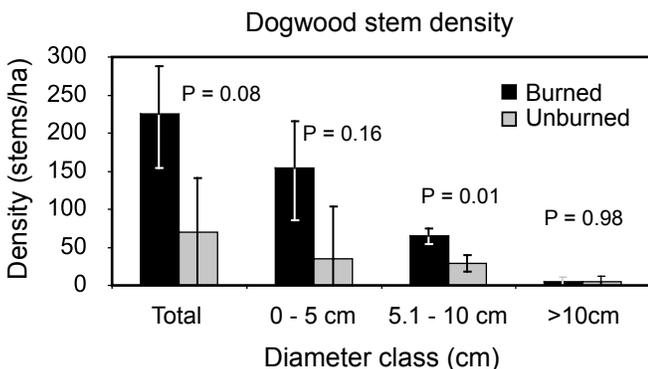


Figure 2— Dogwood density on burned and unburned plots for three diameter classes and all classes combined (total). P-values listed are for contrasts in mean stem density for each diameter class.

density within in the 0 to 5 cm size class: 159 stems/ha on burned plots compared to 21 stems/ha on unburned plots ( $P=0.16$ ). Since smaller dogwoods are more susceptible to dogwood anthracnose and usually die before larger trees (Hiers and Evans 1997, Mielke and Langdon 1986), it is not surprising that the greatest difference in stem density was in the smallest size class. In the 5.1 to 10 cm class, the difference was smaller but statistically significant: 67 stems/ha on burned plots versus 27 stems/ha on unburned plots ( $P=0.01$ ). The >10 cm size class, however, showed no difference in stem density; we observed 5 stems/ha on both burned and unburned plots. The stem density in this size class is comparable to pre-anthrachnose levels of dogwood observed in GSMNP by Jenkins and White (2002).

### Stand Structure

Overstory basal area was similar for the two sampling categories: 21.7  $m^2/ha$  in burned stands versus 23.3  $m^2/ha$  in unburned stands ( $P=0.31$ ; table 1). Understory basal area was also similar between categories: 7.1  $m^2/ha$  in burned stands versus 7.4  $m^2/ha$  in unburned stands ( $P=0.83$ ). Overstory stem density was greater on unburned plots (572 stems/ha) compared to burned plots (435 stems/ha;  $P=0.009$ ). Decreased overstory stem density likely resulted in reduced shading on burned plots. Reduced shading has been shown to reduce moisture levels in stands, which increases dogwood survival by lessening the virulence of anthracnose (Chellemi and Britton 1992). The understory stem density, however, did not differ between burned (3,217 stems/ha) and unburned (2,250 stems/ha) plots ( $P=0.46$ ).

## CONCLUSIONS

Overall, burning appears to increase the survival of dogwood trees in anthracnose-infected stands. Dogwood stem density was greater in burned plots compared to unburned plots. Smaller dogwood size classes benefited from burning more than larger size classes. The increase in dogwood stem density in burned areas compared to unburned areas is likely a result of stump sprouting and reduced shading that created a favorable microclimate for dogwood survival from anthracnose. Although dogwood occurs in a variety of forest types, these results are most applicable in oak-dominated forest types where burning is part of the historic fire regime. Since we

Table 1—Understory and overstory basal area and stem density means for burned and unburned sampling categories. Value of one standard error is in parentheses. P-values listed are for comparison of means between two sampling categories

	Basal area	Density
	$m^2/ha$	stems/ha
Understory		
Single burn	7.1 (0.7)	3,217 (600)
Unburned	7.4 (0.8)	2,550 (654)
P-value	0.83	0.46
Overstory		
Single burn	21.7 (0.9)	435 (31)
Unburned	23.3 (1.0)	572 (34)
P-value	0.31	0.009

observed anthracnose on both burned and unburned plots, additional monitoring is needed to determine how long the effect of burning lasts. However, our results suggest that the positive effects of burning on dogwood survival may last for decades. Based upon our results, prescribed burning may offer a viable tool for maintaining dogwood populations in forests of GSMNP and other areas in the eastern United States.

#### LITERATURE CITED

- Anagnostakis, S.L.; Ward, J.S. 1996. The status of flowering dogwood in five long-term forest plots in Connecticut. *Plant Disease*. 80: 1403-1405.
- Britton, K. 1994. *Cornus florida* anthracnose. In: Ferguson, C.; Bowman, P., eds. Threats to forest health in the Southern Appalachians. Gatlinburg, TN: Southern Appalachian Man and the Biosphere Cooperative: 17-20.
- Chellemi, D.O.; Britton, K.O. 1992. Influence of canopy microclimate on incidence and severity of dogwood anthracnose. *Canadian Journal of Botany*. 70: 1093-1096.
- Hiers, J.K.; Evans, J.P. 1997. Effects of anthracnose on dogwood mortality and forest composition of the Cumberland Plateau (U.S.A.) *Conservation Biology*. 11: 1430-1435.
- Jenkins, M.A.; White, P.S. 2002. *Cornus florida* L. mortality and understory composition changes in western Great Smoky Mountains National Park. *Journal of the Torrey Botanical Society*. 129: 194-206.
- Mielke, M.; Langdon, K. 1986. Dogwood anthracnose fungus threatens Catoctin Mountain Park. Corvallis, OR/Seattle, WA: U.S. Department of the Interior, National Park Service. *Park Science*. 6: 6-8.
- Pirone, P.P. 1980. Parasitic fungus affects the region's dogwood. *New York Times*. Feb. 24: 34, 37.
- SAS Institute Inc. 2002. Edition 9.0. Cary, NC: SAS Institute Inc.
- Thomas, W.A. 1969. Accumulation and cycling of calcium by dogwood trees. *Ecological Monographs*. 39: 101-120.

# PERFORMANCE OF MIXED PINE-HARDWOOD STANDS 16 YEARS AFTER FELL-AND-BURN TREATMENTS

Elizabeth M. Blizzard, David H. Van Lear, G. Geoff Wang, and Thomas A. Waldrop<sup>1</sup>

**Abstract**—Four variations of the fell-and-burn technique were compared for height and volume production on dry Piedmont sites. A two-factorial randomized complete block design of winter versus spring felling, with and without a summer burn, was implemented, followed by planting of loblolly pine (*Pinus taeda* L.) at 15 x 15 foot spacing. After 16 growing seasons, the winter fell with summer burn treatment resulted in greater planted pine volume (1,087.1 ± 72.8 cubic feet per acre) than either unburned treatment (652.4 ± 89.2 cubic feet per acre). The winter fell with no burn treatment resulted in greater oak volume (373.5 ± 71.3 cubic feet per acre) than did either burn treatment (108.7 ± 58.3 cubic feet per acre). Modifications of the fell-and-burn treatment can be used to alter the dominance of pine or hardwood components in developing mixed pine-hardwood stands. Stands should be monitored for further effects of canopy closure, self-thinning, and growth of oaks into micro-canopy gaps.

## INTRODUCTION

Forest owners may be left with low-quality hardwoods after a pine overstory is removed (Wear and Greis 2002). While owners may not wish to return to predominately pine stands, they are willing to manage their forests for desired characteristics (Hull and others 2004). The fell-and-burn technique (Abercrombie and Sims 1986) was used in the 1980s and early 1990s to regenerate mixed pine-hardwood stands in the southern Appalachians. This technique, along with its three variations, was tested for suitability on drier Piedmont sites in order to provide landowners with the option of adding pines while improving hardwood quality (Waldrop 1997, Waldrop and others 1989). The treatments were: winter fell with no burn, spring fell with no burn, winter fell with summer burn, and spring fell with summer burn.

Growing season felling was proposed to reduce hardwood sprout vigor, which would allow planted pines to become established (Zedaker and others 1989). Moving felling from growing season to dormant season was proposed to improve hardwood competitiveness on drier Piedmont sites (Newcomer and others 1986, Zedaker and others 1989).

Not burning was also proposed to increase hardwood competitiveness, although burning provides a larger proportion of better quality sprouts (Augspurger and others 1986). Not burning saves landowners money and simplifies the regeneration process, but logging slash remains on site, and there is a greater proportion of stool sprouts versus more desirable basal sprouts (Augspurger and others 1986). Basal sprouts occur closer to the root collar and generally produce healthier, better quality boles. Burning kills the cambium above the root collar, leading to a higher proportion of basal sprouts.

Spacing of planted pines affects hardwood competitiveness after the pines overtop the hardwoods and canopy structure develops. Pines planted too closely may force hardwoods to bend and become misshapen. An ideal spacing allows room for oaks to grow in micro-gaps between the pines and encourages the pines to self-prune some. Although pine spacing used in other studies ranged from 6.6 x 6.6 feet to 10 x 10 feet

(McGee 1989, Nix and others 1989, Zedaker and others 1989), a larger pine spacing of 15 x 15 feet was used to improve the competitiveness of hardwoods when testing the fell-and-burn technique on drier Piedmont sites.

The objectives of our study were (1) to determine if pines survive beyond crown closure when planted among hardwood sprouts on drier Piedmont sites and (2) to compare pine and oak volumes in 16-year-old pine-hardwood stands as impacted by four site preparation treatments (table 1).

## METHODS

The study sites are located in northeast South Carolina on the Clemson Experimental Forest. Soils are Typic Halpudults, with 7 to 10 percent slope and southern exposure (Waldrop 1997). Plant communities were classified as xeric and sub-xeric. The subxeric sites contained, for example, post oak, black oak, and lowbush blueberry. Xeric sites contained species such as white oak, scarlet oak, and deerberry (Jones 1989, Waldrop and others 1989).

The treatment design was a two-factorial randomized complete block with winter fell with no burn, spring fell with no burn, winter fell with summer burn, and spring fell with summer burn treatments. Complete descriptions of the treatments were given by Waldrop and others (1989) and Waldrop (1995,

**Table 1—Oak and planted pine species on study sites**

Common name	Scientific name
Black oak	<i>Quercus velutina</i> Lam.
Blackjack oak	<i>Q. marilandica</i> Muenchh.
Chestnut	<i>Q. prinus</i> L.
Loblolly pine	<i>Pinus taeda</i> L.
Post oak	<i>Q. stellata</i> Wangenh.
Scarlet oak	<i>Q. coccinea</i> Muenchh.
Southern red oak	<i>Q. falcata</i> Michx.
Water oak	<i>Q. nigra</i> L.
White oak	<i>Q. alba</i> L.

<sup>1</sup> Forestry Technician, Bowen Professor, and Associate Professor, respectively, Clemson University, Department of Forestry and Natural Resources, Clemson, SC 29634; and Research Forester, USDA Forest Service, Southern Research Station, Clemson, SC 29634.

1997). Heights and diameters of all stems 6 feet high or greater were measured on planted pines within 1/20 acre plots and on oaks within nested 1/40 acre plots after 16 growing seasons. Height data reported by Waldrop (1997) through the 6<sup>th</sup> growing season were combined with data collected after the 11<sup>th</sup> growing season to diagram change in heights over time. Heights collected after 11 growing seasons were of the dominate sprout within a clump. Mean separation was performed using pair-wise comparisons of least square means ( $\alpha = 0.05$ ).

## RESULTS AND DISCUSSION

Waldrop (1997) concluded after six growing seasons that planted pines overtopped hardwoods on each treatment, indicating that season of felling and the use of a summer burn

were not factors in planted pine success on drier Piedmont sites. This trend continued through the 16<sup>th</sup> growing season (fig. 1); however, significant differences in treatments became apparent after canopy structure developed and impacted tree growth. Volumes of planted pines and oaks synthesize these treatment affects over time. Affects of treatments are discussed below.

The winter fell with summer burn treatment resulted in greater planted pine volume ( $1,087.1 \pm 72.8$  cubic feet per acre) than either unburned treatment ( $652.4 \pm 89.2$  cubic feet per acre) (tables 2 and 3). Results for the spring fell with summer burn treatment ( $990.6 \pm 75.5$  cubic feet per acre) are inconclusive. With only two replications there is an increased risk of declaring an insignificant difference when there is a significant difference. In a few years, spring fell/summer burn treatments may

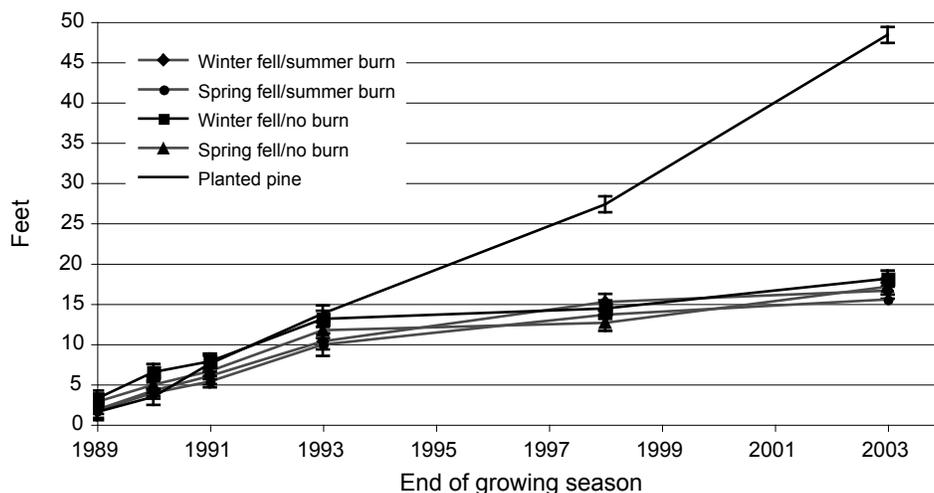


Figure 1—Effects of silvicultural treatments on planted pine and hardwood heights over time. Planted pine heights are averaged across treatments. Hardwood heights include all hardwoods and are represented by treatment.

**Table 2—Mean planted pine and oak volume (cubic feet per acre) ( $\bar{X} \pm SE$ ) by species group and treatment after 16 growing seasons**

Treatments	Planted pine <sup>a</sup>	Oak <sup>b</sup>
	----- cubic feet per acre -----	
Winter fell/ no burn	658.4a ( $\pm 90.7$ ) <sup>c</sup>	373.5a ( $\pm 71.3$ )
Spring fell/ no burn	646.3a ( $\pm 87.7$ )	203.6ab ( $\pm 69.0$ )
Winter fell/ summer burn	1,087.1b ( $\pm 72.8$ )	116.3b ( $\pm 57.2$ )
Spring fell/ summer burn	990.6ab ( $\pm 75.5$ )	101.1b ( $\pm 59.4$ )

<sup>a</sup> Pine volume includes stemwood to a 4 inch top, based upon d.b.h. and total-tree height for 5 inches d.b.h. and up.

<sup>b</sup> Oak volume consists of above-stump total tree wood for 2 inch d.b.h. and up. Oak species found were scarlet, southern red, white, post, black, chestnut, water, and blackjack.

<sup>c</sup> Least square means with the same letter within a column are not significantly different at  $\alpha = 0.05$ . Standard error means are in parentheses.

**Table 3—Planted pine volume t-statistics<sup>a</sup>**

	Spring fell/ burn	Spring fell/ no burn	Winter fell/ burn	Winter fell/ no burn
Spring fell/ burn		0.0588	0.4252	0.0670
Spring fell/ no burn	0.0588		0.0306	0.9298
Winter fell/ burn	0.4252	0.0306		0.0346
Winter fell/ no burn	0.0670	0.9298	0.0346	

<sup>a</sup> Probability of a t-statistic greater than the absolute value of t for the null hypothesis that the least square mean of treatment i equals the least square mean of treatment j.

**Table 4—Oak volume t-statistics<sup>a</sup>**

	Spring fell/ burn	Spring fell/ no burn	Winter fell/ burn	Winter fell/ no burn
Spring fell/ burn		0.1302	0.9321	0.0254
Spring fell/ no burn	0.1302		0.1371	0.1418
Winter fell/ burn	0.9321	0.1371		0.0258
Winter fell/ no burn	0.0254	0.1418	0.0258	

<sup>a</sup> probability of a t-statistic greater than the absolute value of t for the null hypothesis that the least square mean of treatment i equals the least square mean of treatment j, based upon analysis of ranks.

also have significantly greater volume than unburned treatments at  $\alpha = 0.05$ .

The winter fell with no burn treatment resulted in greater oak volume ( $373.5 \pm 71.3$  cubic feet per acre) than did either burn treatment ( $108.7 \pm 58.3$  cubic feet per acre) (tables 2 and 4). Burning negates the advantage of winter felling by killing all sprouts and shortening the initial growing season. The spring fell with no burn treatment ( $203.6 \pm 69.0$  cubic feet per acre) was not significantly different from other treatments. The volumes were based upon oaks with d.b.h.  $\geq 2$  inches; further treatment effects may be detected as the stands continue to self-thin and shorter oaks enter micro-gaps in the main canopy.

### SUMMARY AND CONCLUSIONS

While height growth is a good early indicator of successful tree establishment, longer-term treatment effects may not become apparent until canopy structure develops and impacts tree growth. Results after six growing seasons suggested that planted pine survival and growth on unburned treatments was similar to burned treatments (Waldrop 1997). The current results suggest that burning does improve planted pine volume. Oaks were taller on unburned treatments after 6 growing seasons, but only the winter felled with no burn treatment had greater volume than the winter felled and burned treatment after 16 growing seasons. Based upon these results, a landowner wishing to grow mixed stands of pines and hardwoods should use a summer site preparation burn to improve pine volume or avoid burning to improve oak volume.

### ACKNOWLEDGMENTS

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### LITERATURE CITED

- Abercrombie, J.A., Jr.; Sims, D.H. 1986. Fell and burn for low-cost site preparation. *Forest Farmer*. 46(1): 14-17.
- Augsburger, M.K.; Van Lear, D.H.; Cox, S.K.; Phillips, D.R. 1986. Regeneration of hardwood coppice following clearcutting with and without prescribed fire. In: Phillips, D.R., ed. Proceedings of the fourth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 89-92.
- Hull, R.B.; Robertson, D.P.; Buhyoff, G.J. 2004. "Boutique" forestry: new forest practices in urbanizing landscapes. *Journal of Forestry*. 102 (1): 14-19.
- Jones, S.M. 1989. Application of landscape ecosystem classification in identifying productive potential of pine-hardwood stands. In: Proceedings of pine-hardwood mixtures: a symposium on management and ecology of the type. Gen. Tech. Rep. SE-58. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 64-69.
- McGee, C.E. 1989. Converting low-quality hardwood stands to pine-hardwood mixtures. In: Proceedings of pine-hardwood mixtures: a symposium on management and ecology of the type. Gen. Tech. Rep. SE-58. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 107-111.
- Newcomer, K.P.; Zedaker, S.M.; Smith, D.W.; Kreh, R.E. 1986. Even-aged regeneration alternatives for low quality mixed hardwood forests in the Virginia Piedmont. In: Phillips, D.R., ed. Proceedings of the fourth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 169-175.
- Nix, L.E.; Ruckelshaus, T.F.; Jones, S.M. 1989. Early crop tree presence in upland pine-hardwood stands related to site quality and preharvest stand composition. In: Proceedings of pine-hardwood mixtures: a symposium on management and ecology of the type. Gen. Tech. Rep. SE-58. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 112-116.
- Waldrop, T.A. 1995. Variations in the fell-and-burn system to regenerate pine-hardwood mixtures in the piedmont. In: Edwards, M.B., comp. Proceedings of the eighth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service Southern Research Station: 401-405.
- Waldrop, T.A. 1997. Four site-preparation techniques for regenerating pine-hardwood mixtures in the piedmont. *Southern Journal of Applied Forestry*. 21(3): 116-122.
- Waldrop, T.A.; Lloyd, F.T.; Abercrombie, J.A., Jr. 1989. Fell and burn to regenerate mixed pine-hardwood stands: an overview of research on stand development. In: Proceedings of pine-hardwood mixtures: a symposium on management and ecology of the type. Gen. Tech. Rep. SE-58. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 75-82.
- Wear, D.N.; Greis, J.G. 2002. The southern forest resource assessment summary report. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 635 p.
- Zedaker, S.M.; Smith, D.W.; Kreh, R.E.; Fredericksen, T.S. 1989. The development of five-year-old mixed upland hardwood pine stands. In: Proceedings of pine-hardwood mixtures: A symposium on management and ecology of the type. Gen. Tech. Rep. SE-58. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 100-106.

# LOBLOLLY PINE GROWTH RESPONSE TO MID-ROTATIONAL TREATMENTS IN AN EASTERN TEXAS PLANTATION

Mohammad M. Bataineh, Amanda L. Bataineh, Brian P. Oswald,  
Kenneth W. Farrish, and Hans M. Williams<sup>1</sup>

**Abstract**—The effects of mid-rotational treatments (herbicide, prescribed burn, combination of herbicide and burn, and fertilization) on growth of loblolly pine were evaluated. Five replicates were established in a split-plot experimental design with fertilizer treatments as the whole-plot factor and competition control treatments as the sub-plot factor. Growth response was measured (as change in diameter, total height, and volume) at 8 months and again 4 years after treatments were applied. Mid-rotational treatments failed to enhance diameter, height, and volume growth of loblolly pine. However, a small positive response of diameter growth to fertilization was detected. Height growth was not significantly affected by any treatment 8 months after application date, while it was slightly negatively affected by herbicide and the combination of herbicide and prescribed burning 4 years after application of treatments. In this study, no substantial positive growth response to mid-rotational treatments was detected. However, loblolly growth response may vary from site to site based on differences in soil type, soil condition, and competition level. In addition, associated factors such as seedling quality and planting method may greatly influence loblolly growth response to mid-rotational treatments.

## INTRODUCTION

Ideal growth potential of most southern pine plantations is not achieved. This may be attributed to low capital investments in silvicultural practices and to the uncertainty associated with future market and land ownership (Allen and others 1990). Annual volume increments of 34 m<sup>3</sup>ha<sup>-1</sup>yr<sup>-1</sup> have been reported for loblolly pine (*Pinus taeda* L.) (Borders and Bailey 2001). Such annual increments were achieved using a highly intensive management approach in which complete control of competing vegetation and annual fertilization were applied throughout the study. A less intensive approach in which complete competition control was applied at mid-rotation of slash pine (*Pinus elliotii* Engelm.) plantations resulted in an increase in volume growth by 7 m<sup>3</sup>ha<sup>-1</sup> 4 years after treatment (Pienaar and others 1983).

Silvicultural practices that aim to improve availability, allocation, and amount of water and nutrients to crop trees in established-stands at mid-rotation are referred to as mid-rotational treatments. These treatments may have the potential of increasing annual volume growth and thus productivity of loblolly pine plantations. In addition, these treatments may be less capital demanding and therefore more applicable on operational management levels than complete control of competing vegetation and annual fertilization throughout the rotation. Mid-rotational treatments may include fertilization, chemical and/or mechanical herbaceous and woody competition control, prescribed burning, and thinning.

Several studies have examined the effect of fertilization and competition control on loblolly pine growth. Borders and others (2004) reported significantly greater height and diameter growth in response to fertilization and competition control. The greatest growth response was observed on the combination (fertilization and competition control) treated plots. In an earlier study, Borders and Bailey (2001) reported exceptional growth rates with mean annual increments for the combination treatments ranging between 22.6 and 34 m<sup>3</sup>ha<sup>-1</sup>.

Jokela and others (2000) combined data from 21 regional experiments to examine loblolly and slash pine response to fertilization and understory competition control. The authors reported significant growth response of loblolly pine to fertilization and understory competition control as well as an additive effect of combining both treatments. In addition, Jokela and others (2000) emphasized the importance of mid-rotational fertilization to maintain growth increments that were obtained due to silvicultural treatments at establishment. Loblolly height gains in response to herbaceous control alone or woody control alone were identical in magnitude and greater than the untreated plots 11 years after treatment application (Zutter and Miller 1998). Although these studies have reported loblolly growth response to fertilization and competition control, the treatments in these studies were either applied to young loblolly stands or were applied annually throughout the study.

In 1999, a study to evaluate growth response of loblolly pine to mid-rotational treatments was established in Cherokee County, eastern Texas. Initial growth response was reported by Marino and others (2002) and Barnett and others (2002). Physiological response was reported by Goodwin and others (2004), and the effects on soil physical and chemical characteristics were reported by Wilson and others (2002). The objectives of this paper were to report loblolly pine growth response to mid-rotational treatments in the form of prescribed burning, herbicide application, combination of herbicide and prescribed burning, and fertilization 4 years after application of treatments and to compare loblolly response to data collected (from the same site) 8 months after application of treatments.

## MATERIALS AND METHODS

### Study Site

The study site was located within an 80 ha plantation in Cherokee County, TX (31°35' N, 94° 58' W). The site was

<sup>1</sup> Graduate Research Assistant, Graduate Research Assistant, and Professors of Forestry, respectively, Stephen F. Austin State University, Arthur Temple College of Forestry, SFA Station, Nacogdoches, TX 75962.

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hand-planted with improved loblolly pine seedlings (from two families: 3-050-013-CC22L2 and 172-TFS ODHM2) in 1985 at 1.8 x 3.1 m spacing. In 1998, the site was thinned to a basal area of 13 m<sup>2</sup> ha<sup>-1</sup> and density of 465 trees ha<sup>-1</sup>. Soils of the study site are of the Darco (Grossarenic Paleudult), Tenaha (Arenic Hapludult), and Osier (Typic Psammaquent) series. Mean annual precipitation is approximately 114 cm, and mean annual temperature is 18 °C.

### Experimental Design and Treatments

In 1999, five replications were established in a split-plot experimental design. Fertilizer treatment (fertilizer, no fertilizer) served as the whole-plot factor, and competition control treatments (herbicide application, prescribed burning, combination of herbicide and prescribed burning, and untreated control) served as the sub-plot factor. Fertilizer and competition control treatments were randomly assigned to their corresponding plots. A 10 m buffer zone surrounded each sub-plot (0.1 ha in area). Sampling plots of 0.04 ha each were centered within each sub-plot. Herbicide was applied in October 1999 as a mixture of imazapyr (Chopper®, 4.5 L ha<sup>-1</sup>), glyphosate (Accord®, 2.2 L ha<sup>-1</sup>), nonionic surfactant (Sun-It II®, 11.2 L ha<sup>-1</sup>), and water (76.7 L ha<sup>-1</sup>) using backpack sprayers. Woody vegetation > 3.7 m in height was injected with imazapyr (Arsenal®, 34 percent solution in water). Prescribed burning was accomplished in March 2000 using strip backfires. Fire temperature, relative humidity, and scorch height were measured for each burn sub-plot. In April 2000, fertilizer treatments were applied as urea and diammonium phosphate (224 kg ha<sup>-1</sup> N and 28 kg ha<sup>-1</sup> P) using a crank spreader.

### Measurements and Statistical Analysis

The parameters evaluated included diameter at breast height (d.b.h.; 1.3 m), total height, and volume. Volume was estimated using Lenhart and others' (1987) stem content prediction model (wood and bark to upper stem). Total height was measured to the nearest 0.5 m, and d.b.h. was measured to the nearest 0.1 cm. Pre-treatment measurements were accomplished in July 1999. Post-treatment measurements were obtained in December 2000 (8 months after treatments completion) and in December 2003 (approximately 4 years after treatments completion). The two data sets were analyzed separately. In addition, height, d.b.h., and volume data were analyzed separately for each sampling period. The effects of the fixed factors (fertilizer and competition control treatments) were tested using a split-plot analysis in PROC MIXED (SAS Institute Inc. 1999). When significant interaction was revealed, multiple one-way ANOVAs were performed to test for the effect of competition control treatments (*Trt.*) at each fixed level of fertilization (*Fert.*) (Lehman 1995). In one-way ANOVAs, mean square error from the original split-plot analysis was used to obtain the *F*-statistic. In addition, Bonferroni adjustment was used to control inflation of type I error that is associated with multiple one-way ANOVAs. As a result, the effect of competition control treatments on diameter and volume growth 8 months after application of treatments was tested at an  $\alpha=0.025$  level. When no significant interaction was present, an  $\alpha=0.05$  level was used. Tukey's multiple comparison procedure was used to separate *Trt.* means whenever significant *Trt.* effect was found. A significance level of 0.05 was used to separate *Trt.* means. Mean separation output in PROC Mixed was converted to letter groupings using PDMIX800 macro (Saxton 1998).

## RESULTS AND DISCUSSION

### Diameter Growth Response

Eight months after application of treatments, a significant interaction between fertilizer and competition control treatments was revealed ( $P = 0.031$ ). Therefore, the effects of competition control treatments were confounded by the fertilization level (fig. 1). One-way ANOVA, however, indicated a highly significant effect ( $P = 0.0002$ ) of competition control treatments for the unfertilized plots at the  $\alpha = 0.025$  level. Mean d.b.h. growth was significantly lower for the prescribed burning treatment than for the untreated control and herbicide application (table 1). Marino (2002) quantified the scorch damage associated with prescribed burning on these plots. Lillieholm and Hu (1987) reported a short-term negative effect of crown scorch on diameter growth. Stress in the form of needle loss due to crown scorching may explain the lower diameter growth for the prescribed burned plots. Diameter growth for the untreated control was similar to that of herbicide application plots. The effects of competition control treatments on d.b.h. growth were not significantly different for the fertilized plots ( $P = 0.306$ ) at the  $\alpha=0.025$  level. Goodwin and others (2004) reported lower photosynthetic rates, stomatal conductance, and transpiration for the fertilized plots as compared to the unfertilized plots. This lower physiological activity of fertilized plots may explain the masking effect of fertilization on competition control treatments.

Approximately 4 years after application of treatments, means of fertilizer treatments ( $P = 0.022$ ) were significantly different at the  $\alpha=0.05$  level. Means of competition control treatments ( $P = 0.002$ ) were significantly different at the same significance level. In addition, differences in mean d.b.h. growth among competition control treatments were independent of fertilization ( $P = 0.282$ ). Fertilizer treatment resulted in greater d.b.h. growth than the non-fertilizer treatment (table 2). The positive response of loblolly pine to fertilization is widely reported (Borders and others 2004, Jokela and others 2000, Williams and Farrish 2000). However, diameter growth difference between fertilizer and non-fertilizer treatments was only 0.5 cm. Significantly greater diameter growth was achieved with herbicide application than with prescribed burning, suggesting a residual effect of crown scorching on diameter growth. The effect of the combination treatment (herbicide application and prescribed burning) resulted in diameter growth similar to that of prescribed burning which may suggest an advantage of using herbicide over prescribed burning as a

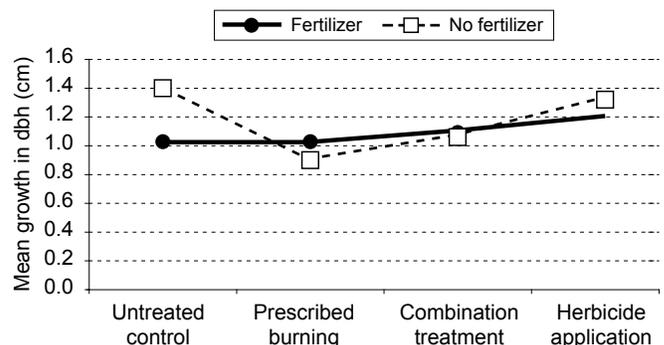


Figure 1—The confounding effect of fertilizer treatment on competition control treatments (significant interaction  $P = 0.031$ ).

**Table 1—Mean growth in d.b.h. (cm), height (m), and volume (m<sup>3</sup>) of loblolly pine in response to mid-rotational treatments in the form of herbicide application, prescribed burning, combination of herbicide and prescribed burning, untreated control, and fertilization 8 months after application of treatments**

Treatment	Difference in d.b.h. --- cm <sup>b, c</sup> ---	Difference in height --- m <sup>d</sup> ---	Difference in volume --- m <sup>3 b, c</sup> ---
Fertilized	1.1 (0.03) <sup>a</sup>	0.9 (0.04) <sup>a</sup>	0.039 (0.001)
Untreated control	1.0 (0.04) <sup>A</sup>	0.8 (0.06) <sup>a</sup>	0.033 (0.002) <sup>A</sup>
Prescribed burning	1.0 (0.07) <sup>A</sup>	1.0 (0.10) <sup>a</sup>	0.038 (0.003) <sup>A</sup>
Combination treatment <sup>e</sup>	1.1 (0.09) <sup>A</sup>	0.9 (0.08) <sup>a</sup>	0.043 (0.003) <sup>A</sup>
Herbicide application	1.2 (0.06) <sup>A</sup>	0.9 (0.08) <sup>a</sup>	0.043 (0.003) <sup>A</sup>
Unfertilized	1.2 (0.05)	0.9 (0.04) <sup>a</sup>	0.045 (0.002)
Untreated control	1.4 (0.15) <sup>a</sup>	1.0 (0.09) <sup>a</sup>	0.054 (0.005) <sup>a</sup>
Prescribed burning	0.9 (0.05) <sup>b</sup>	0.9 (0.08) <sup>a</sup>	0.036 (0.002) <sup>b</sup>
Combination treatment	1.1 (0.10) <sup>ab</sup>	1.0 (0.10) <sup>a</sup>	0.044 (0.004) <sup>ab</sup>
Herbicide application	1.3 (0.07) <sup>a</sup>	0.9 (0.07) <sup>a</sup>	0.051 (0.004) <sup>a</sup>

<sup>a</sup> Standard error in parenthesis.

<sup>b</sup> Means followed by the same capital letter within a partitioned column are not significantly different at the 0.025 level.

<sup>c</sup> Means followed by the same small letter within a partitioned column are not significantly different at the 0.025 level.

<sup>d</sup> Means followed by the same small letter within a column are not significantly different at the 0.05 level.

<sup>e</sup> Combination treatment = herbicide application and prescribed burning.

**Table 2—Mean growth in d.b.h. (cm), height (m), and volume (m<sup>3</sup>) of loblolly pine in response to mid-rotational treatments in the form of herbicide application, prescribed burning, combination of herbicide and prescribed burning, untreated control, and fertilization four years after application of treatments**

Treatment	Difference in d.b.h. --- cm ---	Difference in height --- m ---	Difference in volume --- m <sup>3 b, c</sup> ---
Fertilized	4.6 (0.08) <sup>a A b</sup>	3.3 (0.06) <sup>A</sup>	0.193 (0.005) <sup>A</sup>
Unfertilized	4.1 (0.07) <sup>B</sup>	3.1 (0.05) <sup>A</sup>	0.178 (0.004) <sup>A</sup>
Untreated control	4.4 (0.10) <sup>ab c</sup>	3.6 (0.09) <sup>a</sup>	0.192 (0.006) <sup>a</sup>
Prescribed burning	4.1 (0.10) <sup>b</sup>	3.4 (0.07) <sup>a</sup>	0.176 (0.005) <sup>a</sup>
Combination treatment <sup>d</sup>	4.3 (0.13) <sup>b</sup>	2.8 (0.07) <sup>b</sup>	0.181 (0.007) <sup>a</sup>
Herbicide application	4.7 (0.10) <sup>a</sup>	3.1 (0.07) <sup>b</sup>	0.193 (0.006) <sup>a</sup>

<sup>a</sup> Standard error in parenthesis.

<sup>b</sup> Means followed by the same capital letter within a partitioned column are not significantly different at the 0.05 level.

<sup>c</sup> Means followed by the same small letter within a partitioned column are not significantly different at the 0.05 level.

<sup>d</sup> Combination treatment = herbicide application and prescribed burning.

mid-rotational treatment. However, variations in fire intensity, duration, and timing of prescribed burning may produce different results. In addition, mean difference between herbicide application and prescribed burning was only 0.6 cm.

### Height Growth Response

Fertilizer and competition height control treatments had no significant effect on loblolly height growth 8 months after applica-

tion of treatments ( $P = 0.790$ ,  $P = 0.946$  respectively) (table 1), and no significant interaction was found between competition control treatments and fertilizer ( $P = 0.117$ ) at the  $\alpha=0.05$  level. Four years after application of treatments, means of fertilizer treatments ( $P = 0.131$ ) were not significantly different, whereas means of competition control treatments were highly significant ( $P < 0.0001$ ) at the  $\alpha=0.05$  level. Differences in mean height growth among competition control treatments

were independent of fertilization ( $P = 0.968$ ). Mean height growth for prescribed burning was not different from the untreated control, and herbicide application was not different from combination treatment (table 2). However, herbicide application and combination treatment resulted in lower mean height growth than prescribed burning and untreated control. These results are in disagreement with Zutter and Miller (1998) who reported increases in loblolly height growth with herbaceous and woody control. Bacon and Zedaker (1987) reported no significant effect of herbicide application on height growth of young loblolly stands (3 years old). Also, no significant height growth was reported for slash pine 2 years after mechanical and herbicide treatment, but greater height growth was reported 4 years after treatment (Pienaar and others 1983). Although lower height growth was reported for the herbicide and combination treatment than for the untreated control, mean differences between these treatments and untreated control were small (0.5 and 0.8 m, respectively).

### Volume Growth Response

A significant interaction between fertilizer and competition control treatments was revealed 8 months after application of treatments ( $P = 0.0004$ ). Differences in mean volume growth ( $m^3$ ) among competition control treatments were not significantly different at the  $\alpha=0.025$  level for fertilized plots ( $P = 0.044$ ), whereas differences in mean volume growth among competition control treatments were significantly different for unfertilized plots ( $P = 0.0001$ ). Mean volume growth was significantly lower for the prescribed burning treatment than for the untreated control and herbicide application (table 1). Volume growth for the untreated control was similar to that of herbicide application plots. These results are a reflection of the effect of competition control and fertilizer treatments on diameter growth. This is not surprising since that volume estimates are a combination of diameter and height measurements.

Approximately 4 years after application of treatments, means of fertilizer treatments ( $P = 0.143$ ) and means of competition control treatments ( $P = 0.155$ ) were not significantly different at the  $\alpha=0.05$  level (table 2). In addition, differences in mean volume growth among competition control treatments were independent of fertilization ( $P = 0.113$ ). Thus, the small differences that were detected using d.b.h. and total height separately were not recognized when the two variables were combined in one variable (volume). This reinforces that differences in growth response among competition control treatments and fertilizer treatments were minute.

### CONCLUSIONS

Short-term (8 months) loblolly pine diameter growth was affected negatively by prescribed burning. However, lower physiological activity (i.e., photosynthetic rate, stomatal conductance, and transpiration) due to fertilization has compensated for the negative effect of prescribed burning. A residual effect of prescribed burning on diameter growth and a small positive effect of fertilization were detected 4 years after treatment application. Height growth was not significantly affected by any treatment 8 months after application date, while it was slightly negatively affected by herbicide and the combination of herbicide and prescribed burning 4 years after application of treatments. Volume growth 8 months after application of treatments reflected the differences in diameter growth. Small

differences in diameter and height growth among fertilizer and competition control treatments were concealed by the use of volume estimates 4 years after application of treatments.

No substantial positive growth response to mid-rotational treatments was detected. However, loblolly growth response may vary from site to site based on differences in soil type, soil condition, and competition level. In addition, planting associated factors such as seedling quality and planting method may greatly influence loblolly growth response to mid-rotational treatments. Mid-rotational treatments alone may not have the potential of increasing annual volume growth and thus productivity of loblolly pine plantations in eastern Texas. Other intensive approaches in which complete competition control and annual fertilization would be applied throughout the rotation might be the key for increasing productivity. However, such treatments may have a negative impact on wood quality (Borders and others 2004).

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### LITERATURE CITED

- Allen, H.L.; Dougherty, P.M.; Campbell, R.G. 1990. Manipulation of water and nutrients—practice and opportunity in Southern U.S. pine forests. *Forest Ecology and Management*. 30: 437-453.
- Bacon, C.G.; Zedaker, S.M. 1987. Third-year growth response of loblolly pine to eight levels of competition control. *Southern Journal of Applied Forestry*. 11(2): 91-95.
- Barnett, M.M.; Rideout, S.; Oswald, B.P. [and others]. 2002. Growth response from herbicide, prescribed fire, and fertilizer treatments in midrotational loblolly pine: first-year response. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 143-146.
- Borders, E.B.; Bailey, R.L. 2001. Loblolly pine—pushing the limits of growth. *Southern Journal of Applied Forestry*. 25 (2): 69-74.
- Borders, B.E.; Will, R.E.; Markewitz, D. [and others]. 2004. Effect of complete control and annual fertilization on stem growth and canopy relations for a chronosequence of loblolly pine plantations in the lower coastal plain of Georgia. *Forest Ecology and Management*. 192: 21-37.
- Goodwin, E.J.; Marino, L.M.; Williams, H.M. [and others]. 2004. Physiological and growth responses of midrotation loblolly pine to treatments of fire, herbicide, and fertilizer. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 48-53.
- Jokela, E.J.; Wilson, D.S.; Allen, J.E. 2000. Early growth response of slash and loblolly pine following fertilization and herbaceous weed control treatments at establishment. *Southern Journal of Applied Forestry*. 24(1): 23-30.
- Lenhart, J.D.; Hackett, T.L.; Laman, C.J. [and others]. 1987. Tree content and taper functions for loblolly and slash pine trees planted on non-old-fields in east Texas. *Southern Journal of Applied Forestry*. 11(3): 147-151.
- Lehman, R.S. 1995. Statistics in the behavioral sciences: a conceptual introduction. Pacific Grove, CA: Brooks/Cole Publishing Company. 538 p.

- Lilieholm, R.J.; Hu, S.C. 1987. Effect of crown scorch on mortality and diameter growth of 19-year-old loblolly pine. *Southern Journal of Applied Forestry*. 11(4): 209-211.
- Marino, L.M. 2002. Growth response of mid-rotational loblolly pine (*Pinus taeda* L.) to treatments of fire, herbicide, and fertilizer: possible role of canopy and area potentially available. Ph.D. Dissertation. Nacogdoches, TX: Stephen F. Austin State University. 94 p.
- Marino, L.M.; Oswald, B.P.; Farrish, K.W. [and others]. 2002. Growth response of loblolly pine to intermediate treatment of fire, herbicide, and fertilizer: preliminary results. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 31-34.
- Piñaar, L.V.; Rheney, J.W.; Shiver, B.D. 1983. Response to control of competing vegetation in site-prepared slash pine plantations. *Southern Journal of Applied Forestry*. 7: 38-45.
- SAS Institute Inc. 1999. The SAS system for Windows. Release 8.20. Cary, NC: SAS Institute Inc.
- Saxton, A.M. 1998. A macro for converting mean separation output to letter groupings in Proc Mixed. In: Proc 23<sup>rd</sup> SAS Users Group Intl., SAS Institute. Cary, NC: U.S.: 1243-1246.
- Williams, R.A.; Farrish, K.W. 2000. Response of loblolly pine plantations to late-rotation fertilization and herbicide application in north Louisiana. *Southern Journal of Applied Forestry*. 24(3): 166-175.
- Wilson, S.A.; Farrish, K.W.; Oswald, B.P. [and others]. 2002. Effects of midrotation intensive silviculture on forest soils in east Texas: first-year results. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 35-37.
- Zutter, B.R.; Miller, J.H. 1998. Eleventh-year response of loblolly pine and competing vegetation to woody and herbaceous plant control on a Georgia flatwood site. *Southern Journal of Applied Forestry*. 22(2): 88-95.

# A SIMULATION OF WILDFIRE BEHAVIOR IN PIEDMONT FORESTS

Helen H. Mohr and Thomas A. Waldrop<sup>1</sup>

**Abstract**—Decades of fire exclusion have increased the need for fuel reduction in U.S. forests. The buildup of excessive fuels has led to uncharacteristically severe fires in areas with historically short-interval, low to moderate intensity fire regimes. The National Fire and Fire Surrogate Study compares the impacts of three fuel reduction treatments on numerous response variables. At a National Fire and Fire Surrogate Study research site in the South Carolina Piedmont, fuels were altered by burning, thinning, and a combination of burning and thinning. Each treatment produced a unique fuel complex and altered microclimate for surface fuels by opening the stands to wind and light. We designed the fuel-reduction treatments to minimize damage if a wildfire were to occur, but we found fire behavior in each treatment area difficult to predict. We evaluate wildfire behavior after the fuel-reduction treatments using the BehavePlus2 fire modeling system. Custom fuel models for each treatment were developed from inventories of the litter layer, dead woody fuels, and live fuels. Microclimate variables affected by each treatment, such as crown closure, temperature, relative humidity, and wind speed, were collected over four fire seasons and used as model input. Simulation results will help determine the value of fuel reduction treatments.

## INTRODUCTION

Over the past several decades fire suppression has caused excessive amounts of forest fuel accumulations throughout the United States. Increased fuel loadings can exacerbate wildfire control, cause smoke management problems, and threaten firefighter and public safety. Annually, South Carolina suppresses about 5,000 to 6,000 wildfires that burn a total of 30,000 acres.

Two studies about how fuel treatment affects on wildfire behavior in the West by van Wagtenonk (1996) and Stephens (1998) found that prescribed fire reduced severe fire behavior more than thinning. Stephens (1998) also found that thinning followed by prescribed burning would not produce extreme fire behavior at 95<sup>th</sup>-percentile weather conditions. Van Wagtenonk (1996) suggested that managing forests using a combination of fuel treatments is critical in reducing the size and intensity of wildfires. A study in Portugal by Fernandes and others (1999) found that fuel treatments consisting of any physical fuel elimination, such as prescribed burning and mechanical treatment with slash disposal, were effective short-term solutions for reducing wildfire behavior. In a similar study, Brose and Wade (2002) found that prescribed fire was the most effective treatment for immediate fuel reduction. Thinning was less effective than prescribed burning but more effective than herbicide application due to disruption of fuel continuity. Herbicide treatments resulted in no decrease in fire behavior during the first year but dramatically decreased it the second year. Brose and Wade (2002) suggested combining treatments for the most effective reduction of hazardous fuels and maintaining ecosystem health.

Fuel-reduction treatments on a South Carolina Piedmont site followed National Fire and Fire Surrogate Study (NFFS) protocols and included three replications of four treatments: control, prescribed burning, thinning, and a combination of thinning and burning. Treatments altered the fuel complex and microsite climate differently, which could produce different wildfire intensities and severities. Using measured

fuel data from the treatments and extreme fire-weather as variables in our model, we estimated wildfire behavior to determine if fuel reduction treatments adequately protect forests from wildfire.

## National Fire and Fire Surrogate Study

This national study compares ecological and economic impacts of fuel reduction treatments. This study consists of 13 sites across the United States where fire has played a historical role. These areas currently have excessive fuel buildup and are considered to be at risk of wildfire. Eight sites are located in the Western United States, with the remainder in the Eastern United States. Each site follows the same protocols for treatments and data collection to allow for a national database of core variables.

## Location

The Piedmont NFFS study is located on the Clemson Experimental Forest in northwest South Carolina. The research sites are in second- or third-growth forest with loblolly pine (*Pinus taeda* L.) and shortleaf pine (*P. echinata* Mill.) as the dominant species. The fire-return interval ranges from 1 to 30 years.

## METHODS

The Piedmont NFFS site consists of three replications of four treatments. Treatments used were burn only, thin only, thin and burn, and control. Within each treatment, 40 grid points were established on 50- by 50-m spacing. At each grid point, fuel data were collected on three fuel transects using the Brown's Planar Intersect Method (Brown 1974). We inventoried 1-, 10-, and 100-hour fuels and measured fuel height on each transect. We used the data to develop custom fuel models in the BehavePlus2 fire modeling system (Andrews and others 2002).

HOBO® data loggers and HOBO® micro stations were placed in a central location within each treatment area to compare treatment microsite differences. At 10-minute intervals we

<sup>1</sup> Forester and Research Forester, respectively, USDA Forest Service, Southern Research Station, 233 Lehotsky Hall, Clemson, SC 29634.

used the HOBO® data logger to record temperature and relative humidity and the HOBO® micro stations to collect wind speed data. Four additional RainWise MK3 weather stations were located in open fields on the Clemson Forest also to collect temperature, relative humidity, wind speed, and wind direction at 10-minute intervals. Weather data were downloaded monthly using a palm device or laptop computer.

We analyzed the data with the Statistical Analysis System using PROC GLM procedure (Littell and others 1996). Significance was determined at the  $\alpha = 0.05$  level. We developed regression equations to predict stand weather conditions based on weather reported in open areas. Those equations estimated the high temperature, low relative humidity, and high midflame wind speed that would occur in each treatment on an 80<sup>th</sup>-percentile day during the fire season. Using estimated weather variables, BehavePlus2 simulated fire behavior in each treatment.

## RESULTS

### Fuel Loads

Thin-only treatments increased 1-, 10-, and 100-hour fuels, with 100-hour fuels increasing the most (fig. 1). Burn only reduced 1- and 10-hour fuels and increased 100-hour fuels. Thin and burn reduced 1-hour fuels but increased 10- and 100-hour fuels.

### Weather Conditions

Ambient temperatures were lowest in the control and burn-only treatments (fig. 2). The thin-and-burn treatments had the highest ambient temperatures, which were significantly higher than the thin-only treatments. Relative humidity was lowest in the thin-and-burn treatments (fig. 3). There was no

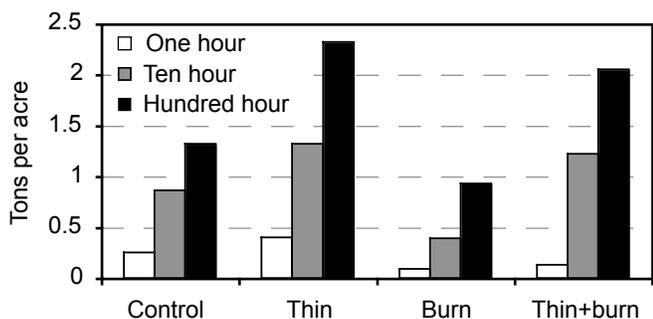


Figure 1—Average fine woody fuels in tons per acre on all treatments posttreatment.

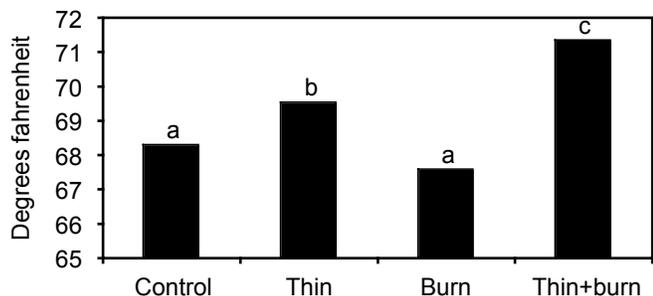


Figure 2—Maximum ambient temperature in degrees Fahrenheit posttreatment.

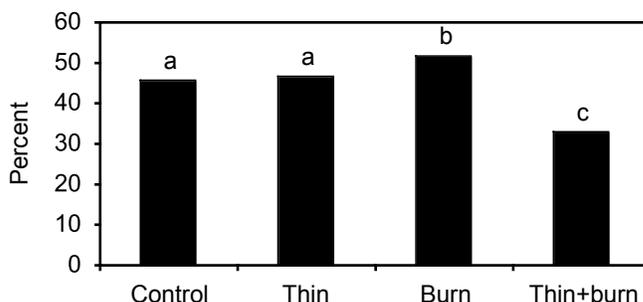


Figure 3—Lowest percent relative humidity posttreatment.

difference in the thin-only and control treatments. The burn-only treatments had significantly higher relative humidity than all other treatments. Thin-and-burn and thin-only treatments had average wind speeds around 1.75 miles per hour with no significant difference between the two (fig. 4). The control and burn-only treatments had significantly higher wind speeds, just below 2.5 miles per hour. Increased hardwood sprouting in the thin-and-burn and the thin-only treatments may be a factor in the low wind speed in these treatments.

### Wildfire Behavior

BehavePlus2 (Andrews and others 2002) predicted that wildfire flame lengths would be tallest in thin-and-burn and thin-only treatments where 10- and 100-hour fuel loads were high (fig. 5). Rate of spread was fastest in the control and burn-only treatments (fig. 6). The rate of spread module is influenced by wind speed, and the highest wind speeds were in the control and burn-only plots. Scorch height was lowest in burn-only areas due to reduced fuels (fig. 7).

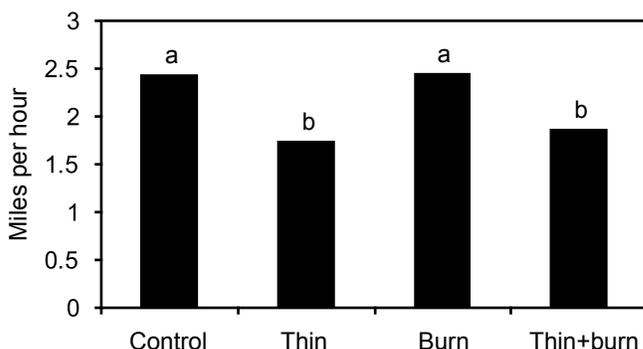


Figure 4—Maximum wind speed in miles per hour posttreatment.

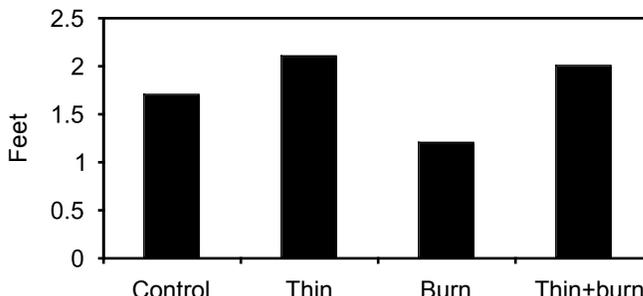


Figure 5—Maximum simulated flame length posttreatment in feet by BehavePlus2.

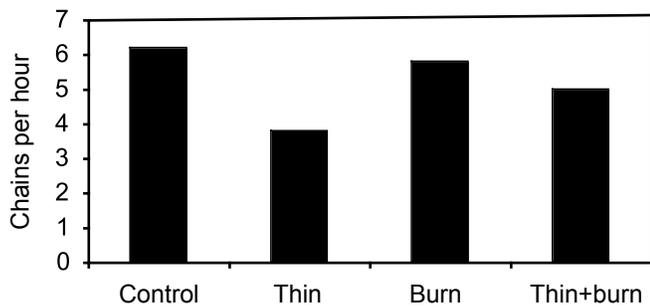


Figure 6—Maximum simulated rate of spread posttreatment in chains per hour by BehavePlus2.

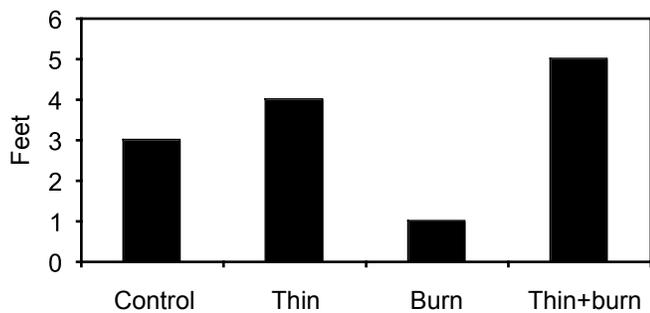


Figure 7—Maximum simulated scorch height in feet posttreatment by BehavePlus2.

## DISCUSSION

The BehavePlus2 models show marginal differences in wildfire behavior among treatments, but this may change as fuels settle and decompose, vegetation continues to grow, and additional prescribed burning occurs. With the information provided here, managers can concentrate on ecological and economic results from the NFFS study when choosing management alternatives. Concerns for preventing severe

wildfire will become secondary to maintaining or restoring ecosystem function. The marginal differences will allow managers to choose among treatments and achieve similar control of wildfire. Such flexibility will allow greater freedom to meet specific management objectives.

## ACKNOWLEDGMENT

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## LITERATURE CITED

- Andrews, P.L.; Bevins, C.; Carlton, D. 2002. BehavePlus2 fire modeling system. Version 2.0.2. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Systems for Environmental Management.
- Brose, P.; Wade, D. 2002. Potential fire behavior in pine flatwood forests following three different fuel reduction techniques. *Forest Ecology and Management*. 163: 71-84.
- Brown, J.K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT-16. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.
- Fernandes, P.; Botelho, H.; Loureiro, C. 1999. Fire hazard implications of alternative fuel management techniques: case studies from northern Portugal. The Joint Fire Science Conference and Workshop. [http://www.nifc.gov/joint\\_fire\\_sci/conferenceproc/TableofContents7.html](http://www.nifc.gov/joint_fire_sci/conferenceproc/TableofContents7.html). Last updated 2/25/03. [Date accessed: January 20, 2003].
- Littell, R.C.; Milliken, G.A.; Stroup, W.W.; Wolfinger, R.D., 1996. SAS system for mixed models. Cary, NC: SAS Institute. 633 p.
- Stephens, S.L. 1998. Evaluation of the effects of silvicultural and fuels treatments on potential fire behaviour in Sierra Nevada mixed-conifer forests. *Forest Ecology and Management*. 105: 21-35.
- van Wageningen, J.W. 1996. Sierra Nevada ecosystem project: final report to Congress. Assessments and scientific basis for management options. Davis, CA: University of California, Centers for Water and Wildland Resources: 1155-1165. Vol. 2.

# PRELIMINARY FUEL CHARACTERIZATION OF THE CHAUGA RIDGES REGION OF THE SOUTHERN APPALACHIAN MOUNTAINS

Aaron D. Stottlemeyer, Victor B. Shelburne, Thomas A. Waldrop,  
Sandra Rideout-Hanzak, and William C. Bridges<sup>1</sup>

**Abstract**—Many areas of the southern Appalachian Mountains contain large amounts of dead and/or ericaceous fuel. Fuel information critical in modeling fire behavior and its effects is not available to forest managers in the southern Appalachian Mountains, and direct measurement is often impractical due to steep, remote topography. An existing landscape ecosystem classification (LEC) model was used as the basis for a characterization of fuel complexes in the Chauga Ridges region in South Carolina. We hypothesized that LEC site units have distinct fuel assemblages. Fuels were characterized using discriminant analysis, which yielded an overall 54 percent success rate of 275 randomly located plots. *Rhododendron maximum* L. biomass, *R. minus* Michx. ground cover, *Vaccinium* L. spp. ground cover, duff depth, and 1,000-hour fuel loading were discriminating fuel characteristics of xeric, intermediate, submesic, and mesic site units. Disturbance was not addressed in this analysis, but future work will address its effect on fuel complexes of LEC site units.

## INTRODUCTION

The use of prescribed fire is becoming increasingly widespread in the southern Appalachians for various silvicultural objectives. Fuel loading information is not readily available, however. Fuel models and other resources traditionally used by fire managers are broad generalizations or specific to some southeastern fuel types but not others (e.g. Deeming and others 1972, Johansen and others 1976, Anderson 1982). These resources assume a homogeneous fuel complex and do not account for large and live ericaceous fuels. Such information is necessary for accurate prediction of fire behavior and developing prescriptions but is not currently available. Direct measurement is impractical since many areas are remote and very steep. Resource managers seek alternative means to obtain fuel loading information.

Landscape ecosystem classification (LEC) was proposed to characterize fuel complexes in the southern Appalachians. Resulting LEC site units are productively similar, the expressive result of soils, vegetation, and topography, and recur predictably on the landscape (Barnes and others 1982, Jones and Lloyd 1993). Site units support distinctive vegetation assemblages and structural attributes. Therefore, fuel complexes should change predictably across an environmental gradient. This paper summarizes preliminary results from work in the Chauga Ridges to determine whether Hutto and others (1999) LEC site units support distinctive fuel types and amounts.

## METHODS

### Study Area

This study was conducted in a 10-square mile area on the southern portion of the Andrew Pickens Ranger District, Sumter National Forest, Oconee County, SC (fig. 1). The region is named after the Chauga River which bisects and drains the majority of the area. Short, steep slopes trend southwest to northeast with the Brevard Fault Zone, a narrow band of low-grade metamorphic rock. Climate, soils, and topography

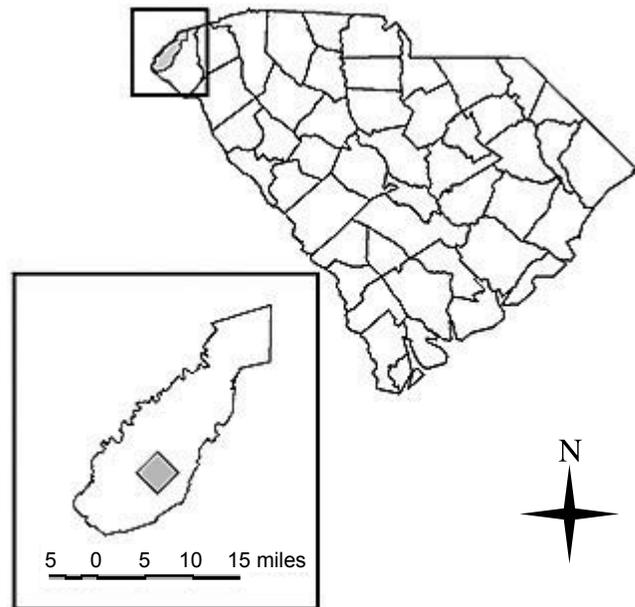


Figure 1—County map of South Carolina with shaded Andrew Pickens Ranger District, Sumter National Forest, Oconee County. Inset = location of 10 square-mile research area in the Chauga Ridges region of the southern Appalachian Mountains.

of the Chauga River watershed are ultimately influenced by this zone (Tobe and others 1992). Elevations in the study area range from 1,000 to 1,900 feet.

The 10-square mile sampling area contained 275 plots located randomly within 5 strata. The plots represented various seral stages of forest development and disturbance regimes. The stratification was by aspect and relative slope position and was intended to provide near-equal representation of four LEC site units.

<sup>1</sup> Graduate Research Assistant and Professor, respectively, Clemson University, Department of Forestry and Natural Resources, Clemson, SC 29634; Research Forester and Research Forester, respectively, USDA Forest Service, Southern Research Station, Clemson, SC 29634; and Professor, Clemson University, Applied Economics and Statistics, Clemson, SC 29634.

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## Landscape Ecosystem Classification

Each plot was classified by LEC site unit using methods developed by Hutto and others (1999). Certain variables known to influence or used to gauge relative moisture availability were involved in the classification. Environmental variables duff depth, slope gradient, landform index (McNab 1993), distance to bottom, and terrain shape index (McNab 1989) were measured. Values were entered into a discriminant function developed by Hutto and others (1999). Equation results indicated which of four LEC site units were most indicative of relative moisture availability. Possible site units included xeric, intermediate, submesic, and mesic.

## Fuel Sampling

Dead woody fuels were sampled using Brown's (1974) planar intersect method and recorded in 1-, 10-, 100-, and 1,000-hour time-lag size classes: 0.00 to 0.25 inch, 0.25 to 1.00 inch, 1.00 to 3.00 inches, and 3.00+ inches, respectively.

Three 50-foot transects originated at each plot center. The center transect was stretched from plot center at a randomly generated azimuth. Two transects were stretched from plot center +22° and -23° from the center transect forming a 45° angle. Fuels in the 1- and 10-hour class were tallied along the first 6 feet of each transect. Fuels in the 100-hour class were tallied along the first 12 feet of each transect. Fuels in the 1,000-hour class were recorded by species, diameter, and decay state (sound or rotten) along the entire length of each 50-foot transect. Litter (Oi), duff (Oe and Oa), and fuel-bed depth were measured at three equally spaced points along each transect. Fuel counts were converted to tons per acre using equations given by Brown (1974). Fuel weights, litter, duff, and fuel-bed depth were averaged across the three transects.

Live ericaceous fuels were sampled within a 22-foot by 50-foot (0.01 ha) plot. Height, basal diameter, and crown dimensions were measured for *Kalmia latifolia* L., *Rhododendron maximum* L., and *R. minus* Michx. Biomass was calculated for *K. latifolia* and *R. maximum* using allometric equations given by Monk and others (1985). Crown dimensions were used to

calculate ground cover for *R. minus* as no biomass equations were available. Ground cover was estimated for *Vaccinium* L. spp.

## Statistical Analysis

Fuel variable means of LEC site units were compared using analysis of variance. Multivariate analysis of variance (MANOVA) was used to test for overall differences among site types based on the entire vector of fuel variables. Pairwise comparisons among LEC site units were evaluated based on Hotelling's T<sup>2</sup> statistic. Differences were considered significant at  $\alpha = 0.05$  in both univariate and multivariate analysis of variance. Stepwise discriminant analysis was used to identify fuel variables that best define the fuel complexes of LEC site units.

## RESULTS AND DISCUSSION

Analysis of variance for overall differences among LEC site units resulted in significant differences in 1,000-hour fuel loading, duff depth, *R. maximum* biomass, and *Vaccinium* spp. ground cover (table 1). Fine fuels, litter depth, fuel-bed depth, *K. latifolia* biomass, and *R. minus* ground cover did not vary among LEC site units. Multivariate analysis of variance provided additional evidence of overall differences in fuel complexes among LEC site units ( $T^2=0.70$ ,  $p<0.0001$ ). Rejection of the multivariate hypothesis justified subsequent procedures to identify discriminating fuel variables. Of the 275 total plots, 148 were correctly resubstituted in stepwise discriminant analysis yielding a success rate of 54 percent. In cross-validation, a more stringent test of the discriminating ability of the discriminant function, 143 plots were correctly classified yielding a success rate of 52 percent.

In discriminant analysis, maximum separation among LEC site units was given by the following fuel variables: 1,000-hour fuel loading, duff depth, *R. maximum* biomass, *R. minus* ground cover, and *Vaccinium* spp. ground cover (table 1). Mesic site units had greater 1,000-hour fuel loading than intermediate and xeric site units. Submesic site units had greater 1,000-hour fuel loading than xeric site units. We attributed higher concentration of large fuels at moist sites to both up-rooting of trees with more shallow root systems and breakage and

**Table 1—Fuel variable means and standard deviations of landscape ecosystem classification site units in the Chauga Ridges region of the southern Appalachian Mountains. Means within a row followed by the same letter are not significantly different among site units at  $\alpha = 0.05$**

Fuel variable	Xeric (n=68)		Intermediate (n=168)		Submesic (n=15)		Mesic (n=24)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1-hour ( $T/ac^{-1}$ )	0.24a	0.01	0.23a	0.01	0.22a	0.03	0.29a	0.02
10-hour ( $T/ac^{-1}$ )	1.21a	0.08	1.04a	0.05	0.98a	0.18	1.18a	0.14
100-hour ( $T/ac^{-1}$ )	2.36a	0.17	1.92a	0.13	1.79a	0.42	1.88a	0.33
1,000-hour ( $T/ac^{-1}$ ) <sup>a</sup>	11.06c	2.66	12.85bc	1.69	23.47ab	5.66	29.21a	4.47
<i>K. latifolia</i> ( $T/ac^{-1}$ )	1.12a	0.34	1.01a	0.22	1.91a	0.73	1.23a	0.58
<i>R. maximum</i> ( $T/ac^{-1}$ ) <sup>a</sup>	0.06b	0.18	0.13b	0.12	0.75b	0.39	2.51a	0.31
<i>R. minus</i> groundcover (%) <sup>a</sup>	4.05ab	1.62	2.06b	1.03	1.22b	3.44	9.46a	2.72
<i>Vaccinium</i> spp. groundcover (%) <sup>a</sup>	11.33a	1.77	3.93b	1.13	0.13b	3.77	0.00b	2.98
Fuel-bed depth (inches)	3.25a	0.37	2.88a	0.23	3.11a	0.78	3.93a	0.62
Duff depth (inches) <sup>a</sup>	1.21a	0.06	0.89b	0.04	1.00ab	0.13	0.87b	0.10
Litter depth (inches)	1.60a	0.08	1.57a	0.05	1.72a	0.16	1.88a	0.13

<sup>a</sup>Fuel variable was discriminating of LEC site units.

abscission of large wood material from trees on these productive sites. These results are consistent with those documented by Rubino and McCarthy (2003), Spies and others (1988), and Waldrop (1993).

Models of southeastern fuel complexes rarely address large fuel particles. The right combination of fuel moisture and fire intensity and residence time is necessary in order for large fuels to be consumed. In periods of drought, large fuels are more likely to be consumed and could greatly influence fire behavior and effects (Hungerford and others 1991). Additionally, a silvicultural objective may be to eliminate these large fuels. For example, where insect activity has killed much of the residual overstory, forest managers may rely on fire to remove fuel loads resulting from tree fall. In such cases, models addressing large fuels are necessary.

Duff thickness of xeric site units was significantly greater than that of other site units. Mesic site units had significantly thinner duff but were not different from submesic and intermediate sites. These results are similar to Hutto and others' (1999) observations in xeric and mesic sites but do not follow the same pattern of decreasing thickness along the moisture gradient. We attribute this to thick duff encountered beneath eastern hemlock (*Tsuga canadensis* L. Carr) and *R. maximum* in alluvial submesic site units. These results are consistent with Abella and others' (2003) findings in mesic hemlock-*Rhododendron* LEC site units in the Jocassee Gorges.

Duff is not generally targeted in prescribed burning operations nor does fire typically reach intensities necessary for consumption of all duff material. However, duff thickness is commonly used to index fire severity. Thick duff on xeric sites helps protect surface soil during fire events. Thin duff on mesic and submesic sites renders these sites more susceptible to soil detriment and/or loss in the event of high-severity fire (Hungerford and others 1991).

Typically a wet habitat-preferring species, *R. maximum* biomass on mesic sites was significantly greater than that of other site units. There were no additional significant differences in *R. maximum* biomass among site units. These results are similar to those obtained by Monk and others (1985), Baker and Van Lear (1998), and Vandermast and others (2002).

*R. minus* ground cover in mesic site units was significantly greater than in submesic and intermediate site units. There were no additional significant differences in *R. minus* ground cover among site units. Like *R. maximum*, moist and shaded conditions are ideal for *R. minus*, but the species also tolerates drier conditions. Abella (2002) noted that *R. minus* was commonly found on north-facing upper slopes in the Jocassee Gorges.

*Vaccinium* spp. ground cover in xeric site units was significantly greater than in intermediate, submesic, and mesic site units. There were no additional significant differences in *Vaccinium* spp. ground cover among site units. Xeric ridgetops contain *Vaccinium* spp. in highest abundance. Oak and pine species contribute foliage that, when dropped amid stems of *Vaccinium* spp., creates a deep, aerated and highly flammable litter layer. Like *K. latifolia*, the foliage of *Vaccinium* spp. contains volatile resins that lead to erratic fire behavior. Ericaceous shrub strata are potential ladders for fire into elevated fuels.

## SUMMARY AND CONCLUSIONS

The need for prescribed burning in the southern Appalachians is well-substantiated, and its use is becoming increasingly widespread. Traditional resources do not adequately represent the mosaic of fuel complexes, the ericaceous fuel component, or large fuel particles. Resource managers require such information in prescribing management and predicting fire's behavior and effects. Direct measurement of fuel is impractical given remote areas and steep topography.

Fuel variables that best define fuel complexes included: 1,000-hour fuel loading, duff depth, *R. maximum* biomass, *R. minus* ground cover, and *Vaccinium* spp. ground cover. Fine woody and litter fuels and *K. latifolia* levels were similar across site units. *K. latifolia* exhibited a ubiquitous growth habit and covered an average of 16 percent of the sampled land area.

The fuel complex of xeric sites is characterized by thick duff and abundant *Vaccinium* spp. Xeric sites also lack *R. maximum* and generally have lesser 1,000-hour fuel loading. Xeric sites may contain moderate densities of *R. minus*. Intermediate sites have moderately thin duff and contain less *Vaccinium* spp. than xeric sites. Intermediate sites may be least likely to contain the dense ericaceous thicket characteristic of the southern Appalachians of any LEC site unit.

Submesic sites are characterized by moderately thick duff and contain greater 1,000-hour fuel loading than both intermediate and xeric sites. Submesic sites contain greater *R. maximum* than intermediate and xeric sites but do not contain densities as high as mesic sites. The fuel complex of mesic sites is characterized by thin duff and high densities of both *R. minus* and *R. maximum*. Both submesic and mesic sites are characterized by the absence of *Vaccinium* spp. Like submesic sites, mesic sites contain high 1,000-hour fuel loading.

Disturbance was not addressed in this analysis. Future work will address the effect of episodic disturbance on the fuel complexes of LEC site units. Landscape ecosystem classification site units are expected to exhibit different burning characteristics and susceptibilities to fire effects.

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## LITERATURE CITED

- Abella, S.R. 2002. Landscape classification of forest ecosystems of Jocassee Gorges, Southern Appalachian Mountains, South Carolina. Clemson, SC: Clemson University. 132 p. M.S. thesis.
- Abella, S.R.; Shelburne, V.B.; MacDonald, N.W. 2003. Multifactor classification of forest landscape ecosystems of Jocassee Gorges, southern Appalachian Mountains, South Carolina. Canadian Journal of Forest Research. 33: 1933-1946.
- Anderson, H.E. 1982. Aids in determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

- Baker, T.T.; Van Lear, D.H. 1998. Relations between density of *Rhododendron* thickets and diversity of riparian forests. *Forest Ecology and Management*. 109: 21-32.
- Barnes, B.V.; Pregitzer, K.S.; Spies, T.A.; Spooner, V.H. 1982. Ecological forest site classification. *Journal of Forestry*. 80: 493-498.
- Brown, J.K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT-16. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.
- Deeming, J.E.; Lancaster, J.W.; Frosberg, M.A. [and others]. 1972. The national fire-danger rating system. Res. Pap. RM-84. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 165 p.
- Hungerford, R.D.; Harrington, M.G.; Frandsen, W.H. [and others]. 1991. Influence of fire on factors that affect site productivity. In: Proceedings of the symposium on management and productivity of western-montane soils. Gen. Tech. Rep. INT-280. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 32-50.
- Hutto, C.J.; Shelburne, V.B.; Jones, S.M. 1999. Preliminary ecological land classification of the Chauga Ridges Region of South Carolina. *Forest Ecology and Management*. 114: 385-393.
- Johansen, R.W.; McNab, W.H.; Hough, W.A.; Edwards, M.B. 1976. Southern forestry smoke management guidebook. Gen. Tech. Rep. SE-10. Macon, GA: U.S. Department of Agriculture, Forest Service, Southern Forest Fire Laboratory, Southeastern Forest Experiment Station. 140 p.
- Jones, S.M.; Lloyd, F.T. 1993. Landscape ecosystem classification: the first step toward ecosystem management in the United States. In: Aplet, G.H.; Johnson, N.; Olson, J.T.; Sample, V.A., eds. Landscape ecosystem classification: the first step toward ecosystem management in the Southeastern United States. Washington, DC: Island Press: 181-201.
- McNab, W.H. 1989. Terrain shape index: quantifying effect of minor landforms on tree height. *Forest Science*. 35(1): 91-104.
- McNab, W.H. 1993. A topographic index to quantify the effect of meso-scale landform on site productivity. *Canadian Journal of Forest Research*. 23: 1100-1107.
- Monk, C.D.; McGinty, D.T.; Day, F.P. 1985. The ecological importance of *Kalmia latifolia* and *Rhododendron maximum* in the deciduous forest of the southern Appalachians. *Bulletin of the Torrey Botanical Club*. 112(2): 187-193.
- Rubino, D.L.; McCarthy, B.C. 2003. Evaluation of coarse woody debris and forest vegetation across topographic gradients in a southern Ohio forest. *Forest Ecology and Management*. 183: 221-238.
- Spies, T.A.; Franklin, J.F.; Thomas, T.B. 1988. Coarse woody debris in Douglas-fir forests of western Oregon and Washington. *Ecology*. 69(6): 1689-1702.
- Tobe, J.D.; Fairey, J.E., III; Gaddy, L.L. 1992. Vascular flora of the Chauga River Gorge, Oconee County, South Carolina. *Castanea*. 57(2): 77-109.
- Vandermast, D.B.; Van Lear, D.H.; Clinton, B.D. 2002. American chestnut as an allelopath in the southern Appalachians. *Forest Ecology and Management*. 165: 173-181.
- Waldrop, T.A. 1993. Dynamics of coarse woody debris- a simulation study for two southeastern forest ecosystems. In: McMinn, J.W.; Crossley, D.A., Jr., eds. Proceedings of the workshop on coarse woody debris in southern forests: effects on biodiversity. Gen. Tech. Rep. SE-94. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 18-24.

# A COMPARISON OF THREE METHODS FOR CLASSIFYING FUEL LOADS IN THE SOUTHERN APPALACHIAN MOUNTAINS

Lucy Brudnak, Thomas A. Waldrop, and Sandra Rideout-Hanzak<sup>1</sup>

**Abstract**—As the wildland-urban interface in the Southern Appalachian Mountains has grown and become more complex, land managers, property owners, and ecologists have found it increasingly necessary to understand factors that drive fuel loading. Few predictive fuel loading models have been created for this important region. Three approaches to estimating fuel loads are compared here. Community type, landscape position, and disturbance may all affect fuel loading, but no prior studies have compared them as predictors of fuel loading. The Landscape Ecosystem Classification system uses information about landform, vegetation, and soils to identify distinct forest community types. Slope position and aspect also contribute to the effects of topography on forest community types. Finally, disturbance type is discussed in the context of its contribution to fuel accumulation. Using discriminant analysis, we found significant differences in resubstitution success rates among the methods. However, the vectors of discriminating fuel variables for these methods are similar, indicating the importance of ericaceous fuels in the Southern Appalachian Mountains.

## INTRODUCTION

Following 50 years of fire exclusion on public lands, we are rediscovering the importance of natural fire regimes in forests of the Southern Appalachian Mountains. However, a much greater use of fire may be necessary to reduce hazardous fuels and to restore fire-dependent communities such as Table Mountain pine (*Pinus pungens* Lamb.) and pitch pine (*P. rigida* Mill.) (Vose 2000, Waldrop and others 2000). To some extent, the limited use of this management tool has resulted from too little knowledge of the nature and character of fuel loads over the highly variable topography of the Southern Appalachian Mountains (Vose 2000). Changes in forest structure that have resulted from the succession of fire-dependent pine-hardwood communities to hardwood-dominated stands, as well as an abundant ingrowth of flammable understory species such as mountain laurel (*Kalmia latifolia* L.), have made it necessary to update fuel load estimates for the region (Harrod and others 2000, Vose and others 1999).

To establish a baseline characterization and quantification of fuel complexes in the region, in April 2003, we began a study of fuel loads on three sites. We used three methods for classifying fuel loading to help determine which was most useful and accurate. The information we gathered will help fire managers create more effective fire plans.

## STUDY SITES

We took measurements within one 10-square-mile study area at each of 3 sites in the Southern Appalachian Mountains: the Chattahoochee National Forest in northeastern Georgia, the Nantahala National Forest in western North Carolina, and the Great Smoky Mountains National Park in southeastern Tennessee. The Chattahoochee National Forest study area is characterized by short, steep slopes, with elevations ranging from 800 to 2,000 feet. The Nantahala National Forest lies in an area described as the high rainfall belt of the Southern Appalachians, receiving an average of about 80 inches of rainfall annually (Carter and others 2000). Slopes in this study

area are steep, and elevations range from 2,000 to 4,500 feet. The Great Smoky Mountains National Park also lies in the high rainfall belt of the Southern Appalachians; elevations here range from 1,100 to 3,000 feet, with topography characterized by long ridges, steep slopes, and deep ravines.

## METHODS

### Field Measurements

Plot locations were generated randomly within each 10-square-mile study area using ArcView<sup>®</sup> geographic information system (GIS) software and were stratified by slope position and aspect. Fifty plots each were located on middle and lower slopes, northeast and southwest aspects, as well as on ridgetops, for a total of 250 plots per study area. We used a global positioning system receiver to locate the plots in the field. Data collection for this study is ongoing; this analysis presents data from only 647 plots.

Fuels were measured in a 50- by 44-foot area using Brown's (1974) planar intersect method. Orientation of each plot was determined randomly by looking at the sweep hand of a wristwatch and multiplying those seconds by six; the resultant number was the azimuth assigned to the center fuels transect. Adding 23 to the center transect azimuth established the right transect, and subtracting 22 from the center transect azimuth established the left transect.

Along the first 6 feet of each transect, we counted the numbers of 1- and 10-hour fuels (0- to 0.25-inch diameter and 0.25- to 1-inch diameter, respectively); along the first 12 feet of each transect, we counted the number of 100-hour fuels (1- to 3-inch diameter). All fuels > 3 inches in diameter were classified as 1,000-hour fuels and were counted along the entire length of each transect. We grouped the 1,000-hour fuels by diameter, species (hardwood or softwood), and decay class (solid or rotten). At the 12-, 25-, and 40-foot marks along each of the 3 transects, we measured litter depth, duff depth, and down and dead woody fuel height.

<sup>1</sup> Biological Science Technician and Research Forester, respectively, USDA Forest Service, Southern Research Station, 239 Lehotsky Hall, Clemson, SC 29634-0331; and Associate Professor, College of Agricultural Sciences and Natural Resources, Texas Tech, Lubbock, TX 79409.

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All trees taller than 4.5 feet were measured within the entire plot area. Trees were identified by species, assigned to a 2-inch diameter class, and given a crown class of 1 (dominant or codominant; receiving sunlight), 2 (midstory; crown mingling with the dominants), or 3 (understory; crown completely below midstory). We also noted a tree's status as live or dead.

On one half of each plot, we estimated the percent coverages of ericaceous shrubs (primarily *Rhododendron maximum* L. and *K. latifolia* L.). Also on one half of each plot, we recorded the coverage of lowbush blueberry (*Vaccinium pallidum* Ait.) and highbush blueberry (*V. constablaei* Gray, *V. corymbosum* L., *V. fuscatum* Ait., and *V. stamineum* L.).

We visually estimated evidence of disturbance and assigned one of five disturbance categories to each plot: none, fire, logging, beetle kill, or windthrow. To corroborate field observations, we obtained disturbance records for each site from offices of the appropriate jurisdiction, e.g., National Park Headquarters.

Landscape Ecosystem Classification (LEC) systems are area-specific models that use vegetation, soils, and topographic variables to apportion the landscape into distinct site units. Areas having the same site unit classification will have similar community assemblages (Jones 1991). We used an LEC model developed for the Chauga Ridges region of South Carolina by Hutto and others (1999) to test whether areas within the same LEC site unit also had similar fuel loading characteristics. Because Hutto's model requires data for specific environmental variables, we also collected landform index (LFI), terrain shape index (TSI), elevation, and root-mat data at each plot. We calculated LFI as the mean of 8 slope measurements—taken in 45° increments—to the horizon (McNab 1993). Similarly, we calculated TSI as the mean of 8 slope measurements to a point 60 feet away at eye-level (McNab 1989). We recorded elevation and estimated distance from plot center to the bottom of the slope. Finally, we measured root-mat thickness (the distance from the top of the mineral soil to the bottom of the litter layer). We used these variables to assign each study plot one of four LEC site unit classifications: xeric, intermediate, submesic, or mesic.

We distinguished 5 strata for the 250 plots at each study area based on a combination of slope position and aspect. In the field, we visually estimated slope position and categorized it as either an upper or lower slope. If the landscape appeared

to decrease in elevation on at least two sides, we categorized a plot location as ridgetop. Aspects were considered northeast-facing if they fell within the range of azimuths from 325° to 125° and southwest-facing if within 145° and 305°.

### Statistical Analyses

We used a multivariate analysis of variance to test for an effect of LEC class, slope/aspect position, and disturbance type on fuel loads. In order to determine which fuel variables best predict LEC class, slope/aspect position, and disturbance type for each plot, we applied stepwise discriminant function analysis. This analysis provides maximum differentiation among groups within these three fuel loading classification methods. Resubstitution success rates in discriminant function analysis are derived from a comparison of plot classifications using all fuel variables, as well as plot classifications using only the discriminating fuel variables. To test for significant differences in resubstitution success rates among the three methods, we performed pairwise binomial proportion comparisons. Differences were considered to be significant at  $\alpha = 0.05$ .

### RESULTS

Multivariate analysis of variance tested for the effects of LEC class, slope/aspect position, and disturbance type based on all fuel variables. Our results showed that different LEC classes, slope/aspect positions, and disturbance types were affected by different vectors of fuel variables. Stepwise discriminant function analysis revealed the important fuel variables that make up those vectors (table 1). Fuel types considered important in the stepwise discriminant function analysis were similar among the three methods. Nearly all ericaceous fuel variables measured were deemed discriminating under each of the three methods, as were litter and duff depths. The smaller 1- and 10-hour time-lag fuels were discriminating under the LEC method, whereas the larger 100- and 1,000-hour time-lag fuels were singled out under the slope/aspect position method. *Rhododendron* was characteristic of lower north-east-facing slopes in the stepwise discriminant function analysis. Down and dead woody fuel height as well as all time-lag (except 1,000-hour) fuels were discriminating under the disturbance type method. The 1-hour time-lag fuels were characteristic of logging disturbance, while lowbush blueberry, 1-, 10-, and 100-hour time-lag fuels were strong discriminators of beetle-kill disturbance.

**Table 1—Important discriminating fuel variables for Landscape Ecosystem Classification class, slope/aspect position, and disturbance type**

LEC class	Slope/aspect position	Disturbance type
Duff depth	Duff depth	Duff depth
Litter depth	Litter depth	Litter depth
<i>Kalmia latifolia</i> coverage	<i>Kalmia latifolia</i> coverage	<i>Kalmia latifolia</i> coverage
<i>Rhododendron maximum</i> coverage	<i>Rhododendron maximum</i> coverage	<i>Rhododendron maximum</i> coverage
<i>Vaccinium pallidum</i> coverage	<i>Vaccinium pallidum</i> coverage	<i>Vaccinium pallidum</i> coverage
1-hour fuels	<i>Vaccinium</i> spp. coverage	Fuel height
10-hour fuels	100-hour fuels	1-hour fuels
	1,000-hour fuels	10-hour fuels
		1,000-hour fuels

LEC = Landscape Ecosystem Classification.

Resubstitution matrices for LEC class (table 2), slope/aspect position (table 3), and disturbance type (table 4) demonstrate the success with which each discriminant function equation allowed reclassification of each plot into a given category. We determined “success” by considering the efficacy of a discriminant function equation in reclassifying a plot into its initial LEC class, slope/aspect position, or disturbance category

(table 1). This is a measure of how well the discriminant function equation’s classification of plots—based on a subset of discriminating fuel variables—matches our *a priori* classification which is based on the entire vector of fuel variables. The resubstitution success rates for the LEC class method, slope/aspect position method, and disturbance type method were 43 percent, 38 percent, and 44 percent, respectively.

**Table 2—Percent resubstitution success for the Landscape Ecosystem Classification class method**

LEC class	Intermediate <sup>a</sup>	Submesic	Mesic	Xeric	n
----- percent -----					
Intermediate <sup>b</sup>	28.68	16.28	31.78	23.26	129
Submesic	15.67	30.60	26.12	27.61	134
Mesic	13.10	16.67	44.05	26.19	84
Xeric	12.33	9.33	23.67	54.67	300

LEC = Landscape Ecosystem Classification.

<sup>a</sup> The LEC classes in the first row represent the way the plots were classified by the discriminant function equation, based only on that subset of fuel variables deemed to be discriminating of LEC class by the discriminant function analysis.

<sup>b</sup> The LEC classes in the first column represent the way the plots were classified prior to discriminant function analysis, based on the entire vector of fuel variables.

**Table 3—Percent resubstitution success for the slope/aspect position method**

Position	NE upper <sup>a</sup>	NE lower	Ridgetop	SW upper	SW lower	n
----- percent -----						
NE upper <sup>b</sup>	37.61	17.09	12.82	12.82	19.66	117
NE lower	16.52	41.74	4.35	6.96	30.43	115
Ridgetop	20.34	2.82	32.20	11.30	33.33	177
SW upper	17.74	5.65	15.32	30.65	30.65	124
SW lower	15.79	10.53	5.26	16.67	51.75	114

NE = northeast; SW = southwest.

<sup>a</sup> The slope/aspect positions in the first row represent the way the plots were classified by the discriminant function equation, based only on that subset of fuel variables deemed to be discriminating of Landscape Ecosystem Classification class by the discriminant function analysis.

<sup>b</sup> The slope/aspect positions in the first column represent the way the plots were classified prior to discriminant function analysis, based on the entire vector of fuel variables.

**Table 4—Percent resubstitution success for the disturbance type method**

Disturbance	None <sup>a</sup>	Fire	Logging	Beetle kill	Windthrow	n
----- percent -----						
None <sup>b</sup>	45.44	14.48	17.86	5.75	16.47	504
Fire	27.27	30.30	18.18	15.15	9.09	33
Logging	17.65	20.59	50.00	5.88	5.88	34
Beetle kill	11.11	11.11	16.67	61.11	0.00	18
Windthrow	27.59	15.52	13.79	12.07	31.03	58

<sup>a</sup> The disturbance types in the first row represent the way the plots were classified by the discriminant function equation, based only on that subset of fuel variables deemed to be discriminating of Landscape Ecosystem Classification class by the discriminant function analysis.

<sup>b</sup> The disturbance types in the first column represent the way the plots were classified prior to discriminant function analysis, based on the entire vector of fuel variables.

Binomial tests for significant differences in resubstitution success rates of the three methods showed mixed results. LEC class resubstitution (43 percent success) and disturbance type resubstitution (44 percent success) were not significantly different ( $p = 0.36$ ). However, slope/aspect position resubstitution (38 percent success) was significantly different from both LEC class resubstitution ( $p = 0.03$ ) and disturbance type resubstitution ( $p = 0.01$ ).

## DISCUSSION

The role of ericaceous shrubs as live fuel has received little attention in previous studies. However, such fuels, along with litter depth and duff depth, recur as discriminating variables in each of the methods we considered. This seems to indicate a congruence among fuel loading classification methods, despite the significant differences in resubstitution success rates. Because similar patterns seem to emerge no matter which method is used, the decision to use or not to use a particular method can be made on the merits of time and resources. Use of the LEC model method is area specific; therefore one must be sure to use an LEC model developed for the area of interest. Because the LEC model used in this study was developed for the Chauga Ridges region of South Carolina, it may not be suitable for broad application across the entire Southern Appalachian region. Perhaps a fusion of this LEC model with the high rainfall belt LEC model developed by Carter and others (2000) or the development of a unique LEC model for the entire Southern Appalachians will prove necessary. However, because implementation of LEC is not widespread, many locations may not have had models developed yet. Such logistical considerations, and not necessarily differences inherent in the three methods we examined, probably will be the key to choosing one method of fuel load classification over another. Both the slope/aspect position and disturbance type methods are easy to use, and neither requires specialized equipment or expertise. However, arriving at a given slope/aspect position or disturbance type classification is subjective and may generate error. In addition, forest disturbance types are often not discrete. For example, a beetle-kill disturbance may result in forest conditions so compromised that subsequent windthrow events occur more readily. Further method development to deal with such disturbance complexes should improve the disturbance type classification problem.

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## LITERATURE CITED

- Brown, J.K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT-16. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 20 p.
- Carter, R.E.; Myers, N.J.; Shelburne, V.B.; Jones, S.M. 2000. Ecological land classification in the high rainfall belt of the southern Appalachian Mountains. *Castanea*. 65: 258-272.
- Harrod, J.C.; Harmon, M.E.; White, P.S. 2000. Post-fire succession and 20<sup>th</sup> century reduction in fire frequency on xeric southern Appalachian sites. *Journal of Vegetation Science*. 11: 465-472.
- Hutto, C.J.; Shelburne, V.B.; Jones, S.M. 1999. Preliminary ecological land classification of the Chauga Ridges region of South Carolina. *Forest Ecology and Management*. 114: 385-393.
- Jones, S.M. 1991. Landscape ecosystem classification for South Carolina. In: Mengel, D.L.; Tew, D.T., eds. Ecological land classification: applications to identify the productive potential of southern forests. Gen. Tech. Rep. SE-68. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 59-68.
- McNab, W.H. 1989. Terrain shape index: quantifying effect of minor landforms on tree height. *Forest Science*. 35(1): 91-104.
- McNab, W.H. 1993. A topographic index to quantify the effect of mesoscale landform on site productivity. *Canadian Journal of Forest Research*. 23: 1100-1107.
- Vose, J.M. 2000. Perspectives on using prescribed fire to achieve desired ecosystem conditions. In: Moser, W.K.; Moser, C.F., eds. Fire and forest ecology: innovative silviculture and vegetation management. Tall timbers fire ecology conference proceedings, No. 21. Tallahassee, FL: Tall Timbers Research Station: 12-17.
- Vose, J.M.; Swank, W.T.; Clinton, B.D. [and others]. 1999. Using stand replacement fires to restore southern Appalachian pine-hardwood ecosystems: effects on mass, carbon, and nutrient pools. *Forest Ecology and Management*. 114: 215-226.
- Waldrop, T.A.; Welch, N.T.; Brose, P.H. [and others]. 2000. Current research on restoring ridgetop pine communities with stand replacement fire. In: Yaussy, D.A., comp. Proceedings: workshop on fire, people, and the central hardwoods landscape. Gen. Tech. Rep. NE-274. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 103-109.

# DEVELOPMENT OF A PHOTO GUIDE FOR FUELS IN THE SOUTHERN APPALACHIAN MOUNTAINS OF NORTHEAST GEORGIA AND WESTERN SOUTH CAROLINA

Sandra Rideout-Hanzak, Lucy Brudnak, and Thomas A. Waldrop<sup>1</sup>

**Abstract**—Current methods of assessing the characteristics of forest fuels are time-consuming, expensive, and impractical in the mountainous terrain of the southeastern United States. A photo guide to fuels is being developed. It will be a quick, inexpensive, and easy-to-use tool for various management applications in the Southern Appalachian Mountains. Fuels data and photos were taken at 250 sites in the Sumter National Forest in South Carolina and 250 sites in the Chattahoochee National Forest in Georgia. Eight major fuel types were identified for the Southern Appalachian Mountains. Using annual summary weather data from the two nearest airports, typical weather conditions were calculated for the season of greatest wildfire activity. The guide will have several example photos for each fuel type with descriptions of the fuel loads and type, vegetation, and terrain. It will also describe potential fire behavior in that fuel type on a day with specified weather conditions.

## INTRODUCTION

The Southern Appalachian Mountains have a great diversity of plants and plant communities. Many factors, including soils, aspect, elevation, weather patterns, disturbances, and land use history combine to create this diversity and a wide range of fuel types and loads. Prescribed burning to reduce fuel loads had only limited use in the Southern Appalachians until the mid- to late 1980s. Land managers considered prescribed fire too risky because of the difficulties of controlling fire on steep slopes and potential damage to valuable hardwoods. Burning is still limited but is increasing as fire managers gain necessary skills.

At present, there is no practical method for rapidly quantifying fuels for management purposes in the Appalachians. Typically, fuels are evaluated either by physically collecting, drying, and weighing plot samples or by the line transect method (Brown 1974). These methods are useful when a high degree of accuracy is necessary, but they are time-consuming, expensive, and often impractical in mountainous terrain. When fire managers lack the time or resources to employ these estimation methods, they must make best guesses at fuel loading to predict fire behavior.

In other regions, photo series have long been used to obtain quick estimates of fuel loading in connection with prescribed burning, smoke management, and wildfire control (Reeves 1988, Sanders and Van Lear 1988, Wade and others 1993). A fuels photo guide for the Southern Appalachians is needed because the 20 fuel models of the National Fire Danger Rating System (Deeming and others 1977) and the 13 standard fire behavior fuel models (Albini 1976, Rothermel 1972) typically are not representative of Appalachian fuels. Fuel loads and types are very diverse, and the existing models do not make allowance for the live ericaceous fuels that are often abundant in Southern Appalachian forests. A photo guide that is constructed specifically for the Southern Appalachians would provide a quick, inexpensive, easy alternative for management purposes when less than perfect fuel load estimations are acceptable.

## SITES

A total of 500 sites in the mountains of western South Carolina and north Georgia were sampled; 250 sites were in the Sumter National Forest, SC, and 250 were in the Chattahoochee National Forest, GA. Initially, a 10-square-mile area that represented many different slope and aspect combinations was identified in each forest. The 250 sites within each area were stratified to ensure that a variety of slope and aspect positions were represented. Fifty sites were located in each of the following five slope positions: ridgetop, upper slope southwest facing, lower slope southwest facing, upper slope northeast facing, and lower slope northeast facing.

## METHODS

Each plot was permanently marked with a 2-foot piece of conduit in the ground and paint on surrounding trees. Three 50-foot tapes were extended horizontally from the conduit and were used for tallying dead fuels. The azimuth for the middle tape was randomized by multiplying the value indicated by the sweep hand of a watch by six. A second tape was extended from the conduit at the azimuth of the middle tape minus 22°, and the third tape was extended along an azimuth 23° greater than that of the middle tape. This resulted in a crow's-foot pattern for the three fuels tapes (fig. 1). The middle tape began with 0 at the common end, while the outer tapes ran from 0 at the far end to 50 at the common end. This was done to avoid surveying all fine woody fuels in one location. Along each tape, dead and down 1- and 10-hour fuels intercepting the tape were tallied along the first 6 feet. The 100-hour fuels were tallied along the first 12 feet, while 1,000-hour fuels were surveyed along the entire 50-foot transect. Diameter, species, and condition were recorded for 1,000-hour fuels. At the 12-, 25-, and 40-foot points along each transect, litter depth, duff depth, and aboveground height of dead woody fuels were recorded to the nearest half inch. Using the center transect as the midline and a tape stretched perpendicular to it at both ends, workers established a 50- by 44-foot (0.02-ha) plot for sampling standing trees (fig. 1). All trees > 6 feet tall were recorded by species, 2-inch diameter class at breast height,

<sup>1</sup> Assistant Professor, Department of Range, Wildlife and Fisheries Management, Texas Tech, University, Lubbock, TX 79409; and Biological Science Technician and Research Forester, respectively, USDA Forest Service, Southern Research Station, 233 Lehotsky Hall, Clemson, SC 29630.

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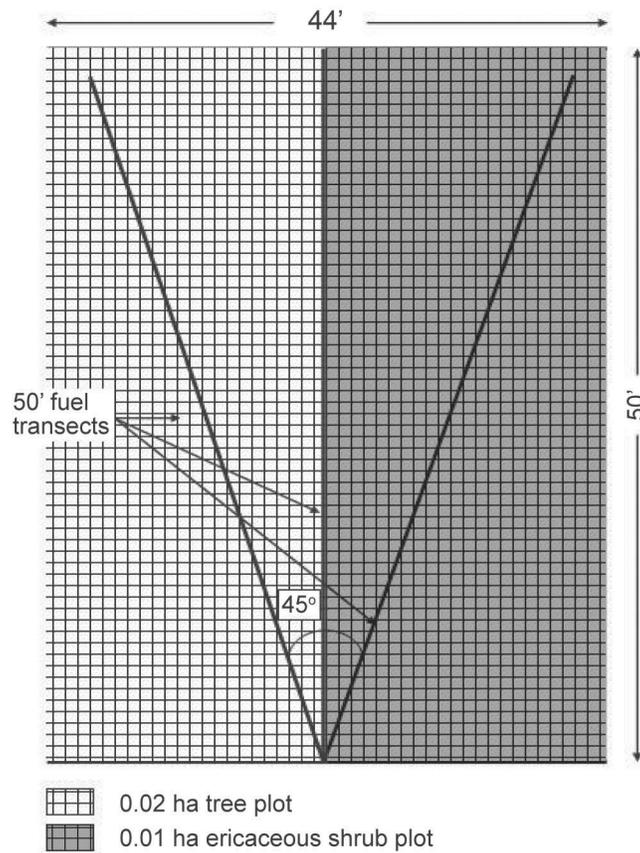


Figure 1—Plot layout for photo and sampling of fuels, trees, and shrubs.

crown class, and status (dead or living). Ericaceous shrubs, which make up the great majority of the live fuel component, were recorded in the half of the plot on one's right when one stands at the zero end and looks down the middle transect (fig. 1). Shrubs were recorded by species and status (dead or living). Height, basal diameter for each stem, and two crown diameters were recorded for each shrub. Last, a photo of each plot was taken from the convergence point of the three transects with a range pole located at the 40-foot point for perspective. All fuels data were converted to tons per acre for each plot.

To begin converting these data to a fuels guide, we first wrote descriptions of all the fuels and vegetation layers visible in the photos: overstory, midstory, understory, surface fuels, ladder fuels, live ericaceous fuels, etc. Because managers will use only visual characteristics of photos and sites to determine which photo best represents fuel conditions for a site, we decided to rely only on visual characteristics of the photos to define fuel categories for the photo guide. This resulted in eight major fuel types for the Southern Appalachians. These are:

1. Hardwood overstory with hardwoods underneath
2. Pine-hardwood mixed overstory with hardwoods underneath
3. Pine or hardwood overstory with nonericaceous ladder fuels

4. Rhododendron fuels
5. Mountain laurel fuels
6. Large dead and down woody fuels
7. Hardwood overstory open underneath
8. Dense hardwood poles

The final product will have example photos for each of these fuel types with descriptions of the fuel loads and types and terrain.

To make the guide useful, descriptions of possible fire behavior in a given fuel type under "bad" fire weather conditions will be included. Annual summary weather data were obtained from the National Climate Data Center in Asheville, NC. Dew point and wind speed were taken from weather data for the closest airports. Certain weather conditions will be identified, such as temperature, wind speed, and relative humidity. Predictions of possible rates of spread, intensity, and ease of containment will be given. The guide will be specific to the lower elevation Appalachian Mountains of north Georgia and western South Carolina. National forest managers and fire management officers will be able to use the photo guide in either wild or prescribed fire situations. However, users will have to make allowances for the presence of multiple fuel types in a large area and adjust for variations in fuel and weather conditions.

## ACKNOWLEDGMENTS

This project was funded by the U.S. Department of Interior and U.S. Department of Agriculture Forest Service Inter-agency Joint Fire Science Program. The authors appreciate constructive comments received from reviewers. This work would not have been possible without data collected by Aaron Stottlemeyer, Adam Coates, Mitch Smith, Gregg Chapman, Chuck Flint, Ross Phillips, and Helen Mohr.

## LITERATURE CITED

- Albini, F.A. 1976. Estimating wildfire behavior and effects. Gen. Tech. Rep. INT-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 92 p.
- Brown, J.K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT-16. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.
- Deeming, J.E.; Burgan, R.E.; Cohen, J.D. 1977. The national fire danger rating system—1978. Gen. Tech. Rep. INT-39. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 63 p.
- Reeves, H.C. 1988. Photo guide for appraising surface fuels in east Texas: grass, clearcut, seed tree, loblolly pine, shortleaf pine, loblolly/shortleaf pine, slash pine, longleaf pine, and hardwood cover types. Nacogdoches, TX: Stephen F. Austin State University, Center for Applied Studies, School of Forestry. 89 p.
- Rothermel, R.C. 1972. A mathematical model for fire spread predictions in wildland fuels. Res. Pap. INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 40 p.
- Sanders, B.M.; Van Lear, D.H. 1988. Photos for estimating residue loadings before and after burning in Southern Appalachian mixed pine-hardwood clearcuts. Gen. Tech. Rep. SE-49. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 21 p.
- Wade, D.D.; Forbus, J.K.; Saveland, J.M. 1993. Photo series for estimating post-hurricane residues and fire behavior in southern pine. Gen. Tech. Rep. SE-82. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 19 p.

# ASSESSMENT OF THE FARSITE MODEL FOR PREDICTING FIRE BEHAVIOR IN THE SOUTHERN APPALACHIAN MOUNTAINS

Ross J. Phillips, Thomas A. Waldrop, Dean M. Simon<sup>1</sup>

**Abstract**—Fuel reduction treatments are necessary in fire-adapted ecosystems where fire has been excluded for decades and the potential for severe wildfire is high. Using the Fire Area Simulator, FARSITE, we examined the spatial and temporal effects of these treatments on fire behavior in the Southern Appalachian Mountains. With measurements from temperature sensors during prescribed burns, we recreated the fires and compared fire behavior simulated by FARSITE with observed behavior. Following calibration, we simulated effects of different fuel reduction treatments on fire behavior. This paper assesses the potential use of FARSITE and the effects of fuel reduction treatments on fire behavior for the Southern Appalachian Mountains.

## INTRODUCTION

Fire has been a factor of the Southern Appalachian Mountain landscape since before Native Americans inhabited the area 10,000 years ago. With the arrival of the Native Americans, the occurrence of fire on the landscape increased as they used fire for maintaining prairies and grasslands, improving wildlife habitat, clearing land for agriculture, and hunting (DeVivo 1991, Van Lear and Waldrop 1989). The presence of fire over this period of time has influenced the species composition and structure of the Southern Appalachian forests (Delcourt and Delcourt 1997).

More recently, fire suppression, logging, and the loss of the American chestnut [*Castanea dentata* (Marsh.) Borkh.] have resulted in a proliferation of mountain laurel (*Kalmia latifolia* L.) and rhododendron (*Rhododendron* spp.) and increased wildfire risk in Southern Appalachian Mountains (Brose and others 2002). As this region becomes more developed, the protection of personal property from wildfire becomes increasingly important.

Studies of the effects of different fuel treatments on fire behavior, vegetation, fuels, and other components of the forest help land managers make informed decisions about how to best apply these treatments. Fire behavior modeling software has allowed researchers, fire management officers, and forest managers to predict fire behavior and allow better planning for allocation of resources for fire suppression. With continued testing and validation, the model outputs will become more reliable, and we can learn more about wildfire behavior while reducing costs of fire fighting and protecting public safety and personal property.

The Fire Area Simulator, FARSITE (Finney 1998), is a fire growth model originally developed for planning and management of prescribed natural fires. Its use has since expanded to suppression efforts for wildfires, evaluating fuel treatments (Finney 2001, Stephens 1998, Stratton 2004, van Wagtenonk 1996), and reconstructing past fires (Duncan and Schmalzer 2004). Developed in the Western United States, the model has been validated on fires in Yosemite, Sequoia, and Glacier

National Parks (Finney 1993, Finney and Ryan 1995). While the use of this software is growing in the Southwestern United States, the Midwestern United States, and Florida, as well as in other countries, it has not received much attention in the Eastern United States.

The objectives of this work were to evaluate FARSITE by comparing fire behavior from simulations to that from a prescribed burn and to test the effects of different fuel treatments on fire behavior in the Southern Appalachian Mountains.

## Study Site

The study is located on the Green River Game Lands in Polk County, NC. The North Carolina Wildlife Resources Commission manages the 5,800-ha game lands for hunting, fishing, habitat conservation, wildlife management, timber production, and recreational activities.

The forest canopy is primarily mixed oak-hickory [*Quercus alba* L., *Q. coccinea* Muenchh., *Q. prinus* L., *Q. rubra* L., *Q. velutina* Lam., *Carya alba* (L.) Nutt. ex Ell., *C. glabra* (Mill.) Sweet, *C. pallida* (Ashe) Engl. & Graebn.] with yellow pines (*Pinus echinata* Mill., *P. rigida* Mill., *P. virginiana* Mill., and *P. pungens* Lamb.) located along the ridge tops and white pines (*P. strobus* L.) interspersed in cove areas. A well-developed shrub layer dominated by mountain laurel, rhododendron (*R. maximum* L., *R. minus* Michx.), and blueberry (*Vaccinium* L. spp.) is scattered throughout the study area.

This site is 1 of the 13 National Fire and Fire Surrogate (NFFS) study sites located across the country. The NFFS study attempts to quantify the effects of fuel reduction treatments on vegetation, fuels, fire behavior, soils, entomology, pathology, wildlife, and economics/utilization in forests that were historically characterized by short-interval, low to medium intensity fire regimes. Each study site has implemented the same randomized complete block design, which calls for three replicates for each treatment: (1) untreated control, (2) burn only, (3) mechanical only, and (4) a combination of mechanical treatment and burning. We present results from replicate 1 only.

<sup>1</sup> Ecologist and Research Forester, respectively, USDA Forest Service, Southern Research Station, 233 Lehotsky Hall, Clemson, SC 29634; and Wildlife Forester, North Carolina Wildlife Resources Commission, Division of Wildlife Management, 8676 Will Hudson Road, Lawndale, NC 28090.

For the Southern Appalachian site, our prescriptions for burning were to have a low to medium intensity fire that would remove the shrub layer and topkill some trees in the suppressed and intermediate canopy classes. Using aerial ignition, we conducted prescribed burns on March 12 and 13, 2003. For our mechanical treatment, we targeted small trees (taller than 2 m and diameter at breast height < 10 cm) and shrubs of mountain laurel and rhododendron, which were cut by contract chain saw crews. The mechanical treatment occurred in the winter of 2001-2002. All fuels created from this treatment were left on site.

## METHODS

FARSITE requires a minimum of five raster layers to generate simulations. These layers are elevation, aspect, slope, fuel model, and canopy cover. The landscape data (elevation, slope, and aspect) are used for making adiabatic adjustments for temperature and humidity as well as computing slope effects on fire spread and solar radiation effects on fuel moisture. We created these files from a 30-m digital elevation model (DEM) for the Cliffield Mountain quadrangle.

Photo interpretation of color infrared aerial photographs with 1-m resolution obtained April 2, 1998, was performed to aid in determining fuel model assignment. We based polygon delineations on tone, texture, and shape. We developed five classes for photo interpretation: (1) deciduous overstory, (2) deciduous overstory with dense evergreen understory, (3) deciduous overstory with sparse evergreen understory, (4) evergreen overstory, and (5) mixed overstory. Based on overstory composition and evergreen understory, we then assigned these polygons to 1 of the 13 standard Northern Forest Fire Laboratory fire behavior fuel models (Albini 1976, Rothermel 1972). Classes 1, 4, and 5 were grouped as fire behavior fuel model (FBFM) 9 for all treatments. Polygons classified as 2 or 3 that occurred within the burn only or the control treatment boundaries were assigned FBFM 6 because of the height and flammability of the shrub component (Anderson 1982). Polygons containing an evergreen understory (classes 2 and 3) within the mechanical treatment boundaries were assigned to FBFM 11 because of the prescriptions and the fuels created from the mechanical treatment.

We took hemispherical images in each treatment area and analyzed them for crown closure. A digital camera modified with a Nikon FC-E8 fish-eye lens converter and mounted in a self-leveling tripod was positioned 1.5 m above the ground, high enough so that shrub cover would not be included in the image. We analyzed the images for percent open sky using WinSCANOPY (Regent Instruments) and then converted them to crown closure. This information was transferred into a geographic information system to create a canopy cover raster layer for the entire area, which was then exported to FARSITE.

In addition to these layers, text files of wind and weather are necessary. We created wind and weather files from data collected on March 13, 2003, the day of the actual burn. Temperatures ranged from 19 to 26 °C, relative humidity was 39 to 49 percent, and wind, when there was any, gusted from 3 to 5 miles per hour out of the southwest.

The geographic information system was used to create fire-line barriers and ignition sources that followed the pattern

observed during the prescribed burn. These ignition files were then imported into FARSITE during the simulation at the appropriate time.

Model parameters for the simulations were set so the time step and the primary visible step were 15-minute intervals, fine enough to visualize fire behavior at the small scale yet not too fine as to slow processing time. Perimeter and distance resolutions were set to the same scale as the DEM (30 m) to make the fire spread sensitive to small-scale variations in topography and fuels. The burn period extended from 1130 to 1415 to coincide with data recorded by thermocouples during the actual burn.

We compared results from the simulations to data recorded during the prescribed burn. Fifty-six HOBO® data loggers (Onset Computer Corporation) with stainless steel type K thermocouples were co-located with fuel transects and vegetation sampling plots within each treatment area to record time of arrival, maximum temperature, and residence time. Visual observations of rate of spread and flame length were also recorded during the burn. With these data we calibrated the fire simulations by adjusting rates of spread for each fuel model to accurately describe the fire's progression.

After calibrating FARSITE, we tested the effects of different fuel treatments on fire behavior. We developed a new fuel model layer to reclassify the areas burned by the prescribed fire; custom fuel model FBFM15 reduced specified fuel loadings for 1-, 10-, and 100-hour fuels and fuel height by 50 percent (Stevens 1998, van Wagendonk 1996). We also created a new canopy layer using hemispherical images taken following treatment implementation. New simulations were performed for each treatment area under identical wind and weather conditions with the same fuel moistures for the same time period. Ignition sources were placed in the center of each treatment area to prevent fire spreading from one treated area and its associated fuel complexes into another area.

## RESULTS AND DISCUSSION

### Simulation vs. Actual Burn

Initial simulations using default settings of FARSITE for fuel moisture values resulted in overpredictions for all FBFM. These results were expected because the standard fuel models estimate fire behavior during the fire season when fuel moisture contents are low (Anderson 1982). Fuel moisture values collected prior to burning (table 1) were input into FARSITE, and subsequent simulations underpredicted fire spread for FBFM 9 and FBFM 11 but still overpredicted spread for FBFM 6. Adjustment factors were then used to tune the FBFM appropriately so the spread rate would resemble that of the actual burn. For FBFM 6, we decreased the adjustment factor to 0.2, increased FBFM 9 to 1.5, and increased FBFM 11 to 2.0. These changes resulted in average rates of spread of 1.4 m per minute for the burn only and 1.6 m per minute for the mechanical/burn treatment areas.

The predicted rate of spread is slightly less than that observed during the burn (table 2). We attribute the differences to the influence of the multiple fires from the pattern of burning, which would cause some fires to draw in others and thus increase rates of spread. This result violates one assumption of Huygens's principle, which is the basis for the vector modeling approach: that fire acceleration is dependent on fuel but

**Table 1—Fuel moisture content for fine fuels in burn only and mechanical/burn treatments prior to prescribed burn**

Treatment	Fuel moisture content	1 hr	10 hr	100 hr
Burn only	Percent moisture content	17.28	26.51	41.98
	Standard deviation	6.63	24.84	41.8
Mechanical/burn	Percent moisture content	15.83	13.56	32.49
	Standard deviation	1.83	3.32	37.86

**Table 2—Average flame length and rate of spread for observed and simulated fire behavior**

Fire characteristic	Observed		Simulated output	
	Burn only	Mechanical/burn	Burn only	Mechanical/burn
Flame length (m)	0.5	1	0.8	0.9
Rate of spread (m/min)	1.8	2.5	1.4	1.7

independent of fire behavior. One weakness of FARSITE is that it does not address the effects of the two-dimensional fire shape on acceleration. Instead, it models point-source fire acceleration because of simplicity.

Slope had a significant effect on fire behavior. Figure 1 depicts the simulated fire perimeters at each 15-minute interval for

the burn only and mechanical/burn treatment areas, where the distance between perimeter lines indicates rate of spread. Frequent runs in the more rugged terrain of the mechanical/burn treatment occurred in areas classified as FBFM 9. Here, 1-hour fuels dry out more quickly than the 10- and 100-hour fuels associated with FBFM 11.

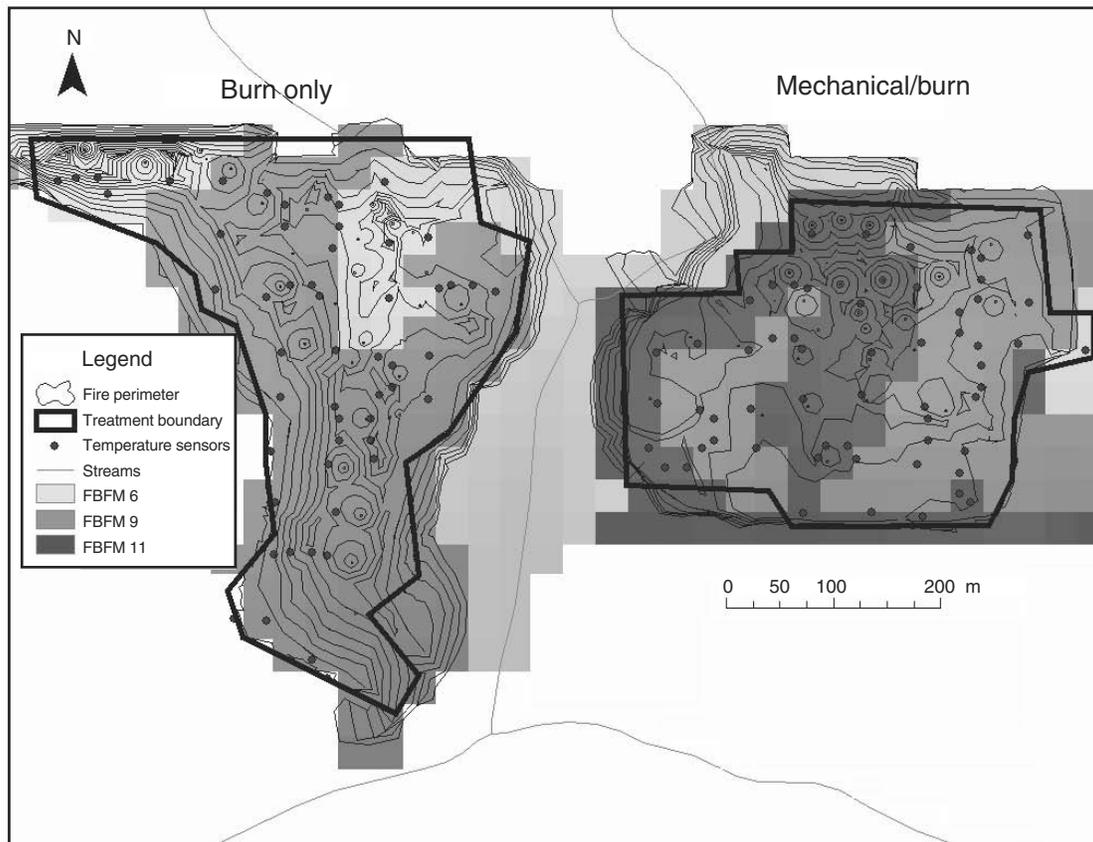


Figure 1— FARSITE output of simulated fire perimeters for every 15-minute interval. Spacing between lines indicates rate of spread.

Fuel moisture content is an important factor in this area. The standard fuel models have not incorporated high fuel moisture contents characteristic of the Southern Appalachian Mountains and thus proved to be problematic for the simulations. Scott and Burgan (2005) developed a new set of dynamic fuel models, which might better represent the high dead fuel moistures typical of the region. FARSITE version 4.1.0 accommodates these new models, but it was not available at the time of this work.

After adjustments, the rate of spread, flame length, and fire intensity for FBFM 9 appeared to adequately represent fire behavior in the leaf litter of oak-hickory forests. Also, FBFM 11 seemed appropriate for modeling the mechanical treatment.

For FBFM 6, adjustments allowed realistic rate of spread. However, the other variables of flame length and fire intensity were excessive, with predicted flame lengths of up to 20 m and fire intensities up to 27,000 kW/m, which were not observed during the prescribed burn. A new fuel model needs to be developed to better represent fire behavior in ericaceous shrubs of the Appalachian Mountains.

Changing the scale and type of the fuel model may also improve the ability to model fires for this region. Using 10-m DEM would allow for higher resolution and a more accurate representation of the heterogeneity of fuels. Grupe (1998) showed that FARSITE's sensitivity to small spatial variations in fuel models (areas that occupied only 10 percent of the landscape) would affect the average rate of spread, flame length, and fire-line intensity. Another option is to develop site-specific fuel models from fuel data collected at this location, which will help decrease the uncertainty in simulation results (Miller and Yool 2002).

### Effects of Different Fuel Treatments on Fire Behavior

Simulations testing the effects of different fuel treatments showed the mechanical/burn treatment produced the least intense fire while areas left untreated would exhibit more extreme behavior (table 3). Fire intensity and flame length for the mechanical only and control treatments were considerably higher than burn only and mechanical/burn treatments. In the control treatment, fire intensity approached the level at which heavy equipment would be required for suppression.

Results for rate of spread and area burned show a similar pattern (table 3). The burn only and mechanical/ burn treatments are comparable, while the mechanical only and control treatments are much higher. The numbers for the thin only treatment do not entirely represent that treatment because, in spite of the efforts to keep fires within each treatment area's boundary, it was not possible to keep the mechanical only simulated fire from expanding into other treatment areas.

### CONCLUSIONS

FARSITE should be viewed as an option for fire modeling in the Southern Appalachian Mountains, but work needs to be done on developing fuel models that better represent existing conditions of fuels before the model receives wide use in this region. In particular, fuel moisture and presence of ericaceous shrubs presented difficulties for simulations. A new fuel model is necessary for areas with high ericaceous shrub cover. Once the FARSITE model is calibrated for the region and/or more representative fuel models are developed, fire managers will be able to run "what-if" scenarios under various conditions to help direct fuel management for areas of the Southern Appalachian Mountains.

### ACKNOWLEDGMENTS

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### LITERATURE CITED

- Albini, F.A. 1976. Estimating wildfire behavior and effects. Gen. Tech. Rep. INT-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 92 p.
- Anderson, H.L. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 22 p.
- Brose, P.H.; Tainter, F.H.; Waldrop, T.A. 2002. Regeneration history of three table mountain pine/pitch pine stands in northern Georgia. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silviculture research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 296-301.
- Delcourt, H.R.; Delcourt, P.A. 1997. Pre-Columbian Native American use of fire on Southern Appalachian landscapes. *Conservation Biology* 11(4): 1010-1014.

**Table 3—Range of fire behavior variables for simulated fires in different fuel treatments (burn period from 1130 to 1415)**

Variable	Burn only	Mechanical/burn	Mechanical only	Control
Fire intensity (kW/m)	9.9 – 53.6	9.5 – 43.3	32.0 – 230.5	50.9 – 328.2
Flame length (m)	0.3 – 0.5	0.2 – 0.4	0.3 – 1.0	0.4 – 1.1
Rate of spread (m/min)	0.3 – 1.4	0.3 – 1.1	0.5 – 3.4	0.6 – 3.8
Area burned (ha)	0.9	0.7	5.4	2.3

- DeVivo, M.S. 1991. Indian use of fire and land clearance in the Southern Appalachians. In: Novin, S.C.; Waldrop, T.A., eds. Fire and the environment: ecological and cultural perspectives. Gen. Tech. Rep. SE-069. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 306-310.
- Duncan, B.W.; Schmalzer, P.A. 2004. Anthropogenic influences on potential fire spread in a pyrogenic ecosystem of Florida, USA. *Landscape Ecology*. 19: 153-165.
- Finney, M.A. 1993. Modeling spread and fire behavior of prescribed natural fires. In: Cohen, J.D.; Saveland, J.M.; Wade, D.D., eds. Proceedings of the 12<sup>th</sup> conference on fire and forest meteorology. Bethesda, MD: Georgia Society of American Foresters: 138-143.
- Finney, M.A. 1998. FARSITE: fire area simulator-model development and evaluation. Res. Pap. RMRS-RP-4. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 47 p.
- Finney, M.A. 2001. Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. *Forest Science*. 47(2): 219-228.
- Finney, M.A.; Ryan, K.C. 1995. Use of the FARSITE fire growth model for fire prediction in U.S. national parks. In: Sullivan, J.D.; Wybo, J.L.; Buisson, L., eds. International emergency management and engineering conference. Sofia Antipolis, France: International Emergency Management and Engineering Society: 183-189.
- Grupe, M.A. 1998. Assessing the applicability of the terrestrial ecosystem survey for FARSITE. Albuquerque, NM: University of New Mexico. 95 p. M.S. thesis.
- Miller, J.D.; Yool, S.R. 2002. Modeling fire in semi-desert grassland/oak woodland: the spatial implications. *Ecological Modeling*. 153: 229-245.
- Rothermel, R.C. 1972. A mathematical model for fire spread predictions in wildland fuels. Res. Pap. INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 40 p.
- Scott, J.H.; Burgan, R.E. 2005. Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. Gen. Tech. Rep. RMRS-GTR-153. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 72 p.
- Stephens, S.L. 1998. Evaluation of the effects of silviculture and fuel treatments on potential fire behaviour in the Sierra Nevada mixed-conifer forests. *Forest Ecology and Management* 105: 21-35.
- Stratton, R.D. 2004. Assessing the effectiveness of landscape fuel treatments on fire growth and behavior. *Journal of Forestry*. 102(7): 32-40.
- Van Lear, D.H.; Waldrop, T.A. 1989. History, uses, and effects of fire in the Appalachians. Gen. Tech. Rep. SE-054. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 24 p.
- van Wagtenonk, J.W. 1996. Use of a deterministic fire growth model to test fuel treatments. Sierra Nevada ecosystem project: final report to Congress. Assessments and scientific basis for management options. Davis, CA: University of California, Centers for Water and Wildland Resources: 1155-1166. Vol. 2.

# THE NATIONAL FIRE AND FIRE SURROGATE STUDY: EARLY RESULTS AND FUTURE CHALLENGES

Thomas A. Waldrop and James McIver<sup>1</sup>

**Abstract**—Fire-adapted ecosystems today have dense plant cover and heavy fuel loads as a result of fire exclusion and other changes in land use practices. Mechanical fuel treatments and prescribed fire are powerful tools for reducing wildfire potential, but the ecological consequences of their use is unknown. The National Fire and Fire Surrogate Study examines the effects of alternative fuel reduction techniques involving fire and mechanical “surrogate” treatments on numerous environmental and economic variables. Impacts of mechanical fuel treatments and prescribed fire on the Piedmont site are shown for several variables. However, a complete understanding of ecosystem function cannot be gained by considering each of these variables alone. Each component of the ecosystem has a distinct reaction to fuel treatment that may be caused by the treatment directly or by interactions with one or more of the other variables. The goal of the National Fire and Fire Surrogate Study is to understand the complex interactions and pathways among all components of the ecosystem.

## INTRODUCTION

Several studies document fuel loads after fuel-reduction treatments. However, none has attempted to establish the interactions between fuel reduction and ecological processes. The National Fire and Fire Surrogate (NFFS) Study was established to compare ecological and economic impacts of prescribed fire and mechanical fuel-reduction treatments. Thirteen independent study sites across the United States (eight in the West and five in the East) use identical treatment and measurement protocols. All western sites are dominated by ponderosa pine (*Pinus ponderosa* Douglas ex Lawson & C. Lawson). They represent a geographical range extending from the Eastside Cascades of Washington to the Jemez Mountains of New Mexico. Eastern sites include hardwood-dominated sites in the Ohio Hill Country and Southern Appalachian Mountains of North Carolina, a pine-hardwood site in the Piedmont of South Carolina, a site dominated by longleaf pine (*P. palustris* Mill.) in Alabama, and a site dominated by slash pine (*P. elliotii* Engelm.) in Florida. This paper will focus on results from the Piedmont site and future analyses at the national level.

## METHODS

The Piedmont study site is on the Clemson Experimental Forest, which is managed by Clemson University. Topography ranges from rolling hills to moderately steep slopes and is strongly influenced by past agricultural erosion. Elevation ranges from 600 to 900 feet above mean sea level. Most soils are of the Cecil-Lloyd-Madison association. These are Ultisols with moderate to extremely severe erosion. Entisols and Inceptisols are present but not abundant. Entisols occur along streams, and Inceptisols occur on steep slopes. Erosional rills and gullies are common; as much as 100 percent of the surface layer has been removed.

Twelve study sites, to accommodate three replications of each of four treatments, were selected on the basis of size, stand age, and management history. Each site had to be at least 35 acres in size to allow for a 25-acre measurement area and a buffer of at least 1 tree length (approximately 60 feet) around the measurement area. Stand ages varied from 15 to 60 years,

but age was used as a blocking factor to reduce variability. Each of three blocks contained four sites dominated either by pulpwood-sized trees [diameter at breast height (d.b.h.) 6 to 10 inches, block 1], by sawtimber-sized trees (d.b.h. > 10 inches, block 3), or by a mixture of pulpwood- and sawtimber-sized trees (block 2). All sites were dominated by either loblolly (*P. taeda* L.) or shortleaf (*P. echinata* Mill.) pines with mixtures of oaks and other hardwoods in the understory and midstory.

Treatments included thinning, prescribed burning, thinning followed by prescribed burning, and an untreated control. Levels of thinning and prescribed burning are defined by NFFS protocols to reduce fuels sufficiently so that most overstory trees will survive a subsequent wildfire. At the Piedmont site, thinning was from below and left a residual basal area of 80 square feet per acre. The burn-only treatment was conducted in spring 2001 with a prescription designed to open the canopy. A combination of strip head fires and flanking fires was used. Flame heights varied from 1 foot to > 10 feet. Burning on the thin and burn treatment was delayed until the spring of 2002 to allow heavy fuel loads to partially decompose. The prescription for these fires was for intensity to be high enough to remove fuels but not high enough to damage overstory trees. Strip head fires were used with flame heights that ranged from 1 to 4 feet.

Over 400 variables were measured for individual studies on the Piedmont site. Detailed methods for all measurements cannot be described here but can be found in the study proposal located at <http://www.fs.fed.us/ffs/execsumm-4-17-00.htm>. Measurements were made 1 year prior to treatment and 1, 3, and 5 years after treatments. Study results for selected variables for the first year following treatment are presented here.

## RESULTS

### Vegetation and Fuels

Fuel-reduction treatments changed vegetative structure and composition (fig. 1) (Phillips and others 2004). Burn-only plots had composition similar to that of controls but fewer trees. Thinning and thinning plus burning created distinctly different

<sup>1</sup> Research Forester, USDA Forest Service, 239 Lehotsky Hall, Clemson, SC 29634-0331; and Research Ecologist, USDA Forest Service, Forestry and Range Sciences Laboratory, 1401 Gekeler Lane, La Grande, OR 97850, respectively.

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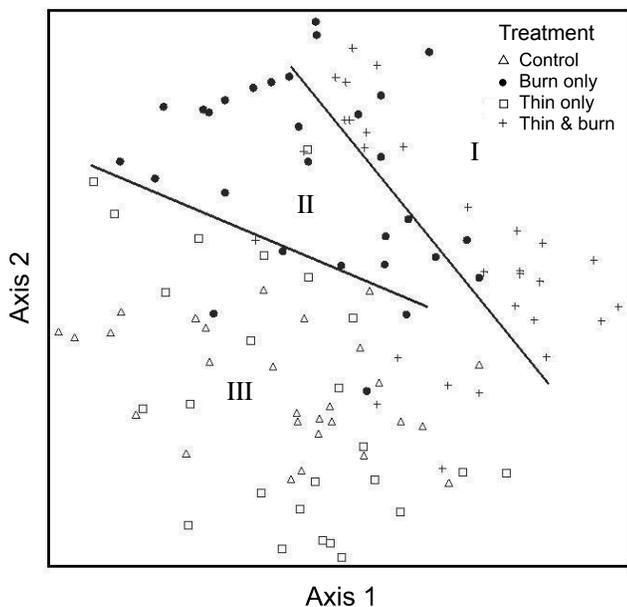


Figure 1—Nonmetric multidimensional scaling ordination for understory vegetation and shrub cover (Phillips and others 2004).

communities. The thin plus burn treatment was the only one that increased grasses and forbs. All treatments reduced litter, but the burn-only treatment reduced it most (fig. 2) (Waldrop and others 2004). Thinning increased fine woody fuels, and they remained high after burning. Treatment had no effect on loading of large woody fuels. BEHAVE predicted that wildfires would be more difficult to control after thinning until logging slash had begun to decompose (Mohr and others 2004).

### Soil Properties

Thinning and thinning plus burning increased bulk density of the surface soil layer (Shelburne and others 2004). Both thinning and burning reduced total carbon (C) and nitrogen (N) in the O horizon. Thinning and burning together reduced C and N more than single treatments. In the A/Bt horizon, burning

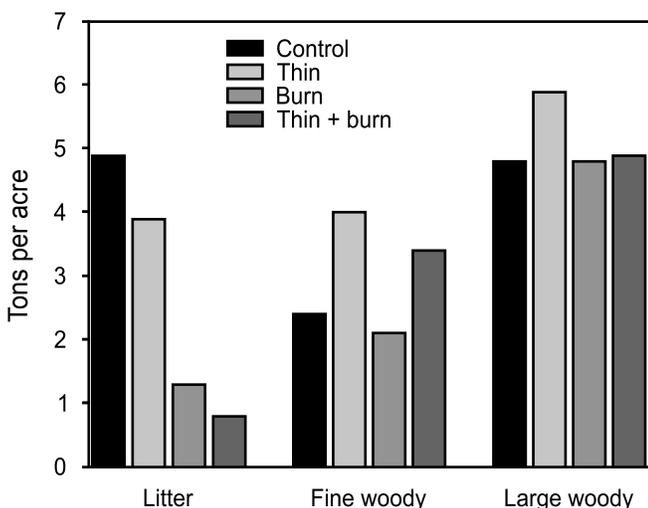


Figure 2—Loading of litter and woody fuels by treatment at the Piedmont NFFS site (Waldrop and others 2004).

reduced total C and N. Thinning and burning together reduced C and N more than burning alone. Burning significantly reduced total exchangeable capacity relative to other treatments. Decomposition of leaf litter was slower in thinned stands than in burned or control stands (Callaham and others 2004). Nitrogen dynamics varied more over time in thinned and burned stands than in controls. Soil respiration was lower in burned stands than in control or thinned stands, possibly as a result of fire-induced reductions in potentially mineralizable C pools in the forest floor (Callaham and others 2004). These results suggest that C and N dynamics are altered by thinning and burning, but that these alterations are manifested in fundamentally different ways.

### Wildlife

Thinning had a positive effect on herpetofaunal abundance, possibly because increased insolation allowed an increase in the area for thermoregulation (fig. 3) (Kilpatrick and others 2004). Small mammal trapping did not yield enough individuals for statistical analysis. Prolonged drought may have reduced the already low population of small mammals on the Piedmont. Spring counts did not indicate that there were treatment-to-treatment differences in songbird abundance and richness (Zebehazy and others 2004). Nest starts increased one season after all fuel-reduction treatments.

### Insects and Diseases

The number and size of beetle-killed spots were larger the year after treatment (Boyle and others 2004). However, there were no significant treatment-to-treatment differences. Beetle activity was reduced where tree latewood was high and resin production was greater. Posttreatment *Leptographium* incidence was reduced in all areas including controls. However, incidence was apparently reduced by fuel reduction. Diseases caused by *Phytophthora* were increased by thinning alone and by burning alone but decreased by the combination of thinning and burning.

### FUTURE ANALYSES

Numerous reports from individual studies will be published as each of the 13 NFFS sites completes treatment installation

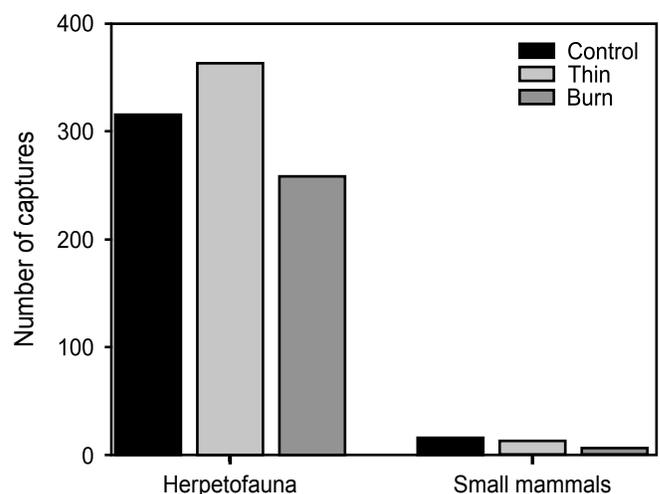


Figure 3—Number of captures of herpetofauna and small mammals during the first year after treatment at the Piedmont NFFS site (Kilpatrick and others 2004).

and posttreatment measurements. These publications will add significantly to our knowledge of multiple ecosystem components. However, the greater challenge will be to determine if fuel treatments create entirely different ecosystems and if these systems continue to function differently over time. Analyses of ecosystem-level questions are complex because they are interdisciplinary: variables may impact other variables in previously unknown ways.

An example of this complexity is the change to the forest floor (fig. 4). Each treatment produced a different forest floor structure. Burning removes the litter layer in a relatively uniform fashion throughout the treatment area. However, thinning completely removes the litter and duff in some areas but leaves other areas undisturbed. Thinning plus burning created the greatest disturbance. The problem goes far beyond identifying simple differences in forest floor structure. The forest floor affects numerous variables such as nutrient cycling, decomposition, and herpetofaunal abundance. Each of these variables in turn impacts many others. The pathways in this simple example are complex and represent only one potential analysis at one NFFS study site. Similar pathways must be investigated for all disciplines at each NFFS site and for all NFFS sites combined. Such analyses will be conducted by NFFS cooperators using a number of univariate and multivariate tools for individual study sites and multiple study sites.

### Single-Site Univariate Analyses

At the site level, since experimental units are replicated and treatments assigned randomly, analyses have been and will be conducted primarily with analysis of variance and regression techniques. These techniques are flexible in the sense

that independent factors can be added to models depending on the response variable in question. Although these types of analyses can be used to evaluate multivariate questions, they are most suitable for analyzing effects on individual variables. Analyses of these kinds can answer questions such as (1) how do alternative fuel-reduction treatments influence plant species diversity, and (2) how do fire-only and mechanical-plus-fire treatments compare with respect to fuel reduction?

### Multi-Site Univariate Analyses

Analysis of variance and regression techniques are also useful for evaluating the responses of individual variables at the network level. For example, we can ask to what extent alternative fuel reduction treatments influence plant diversity in relation to forest type across the NFFS network, or we can ask how differences among logging methods influence the relative effectiveness of fire-only and mechanical-plus-fire treatments in reducing fuels. We plan to use mixed-model analyses of variance to investigate these kinds of questions across the network. However, we will need to use meta-analyses for some questions, especially those that involve variables that respond to different degrees in different systems.

Meta-analysis has been used in medical research for decades (Cooper and Hedges 1994). One of this method's best applications is in the analysis of datasets from separate studies that evaluate the treatment response of a single variable. Typically a researcher surveys the literature for studies on the variable in question, assembles a dataset that describes response of that variable to some set of treatments, and then evaluates the commonality of response, or effect size, to treatment. With this method, the researcher can also explore the extent to

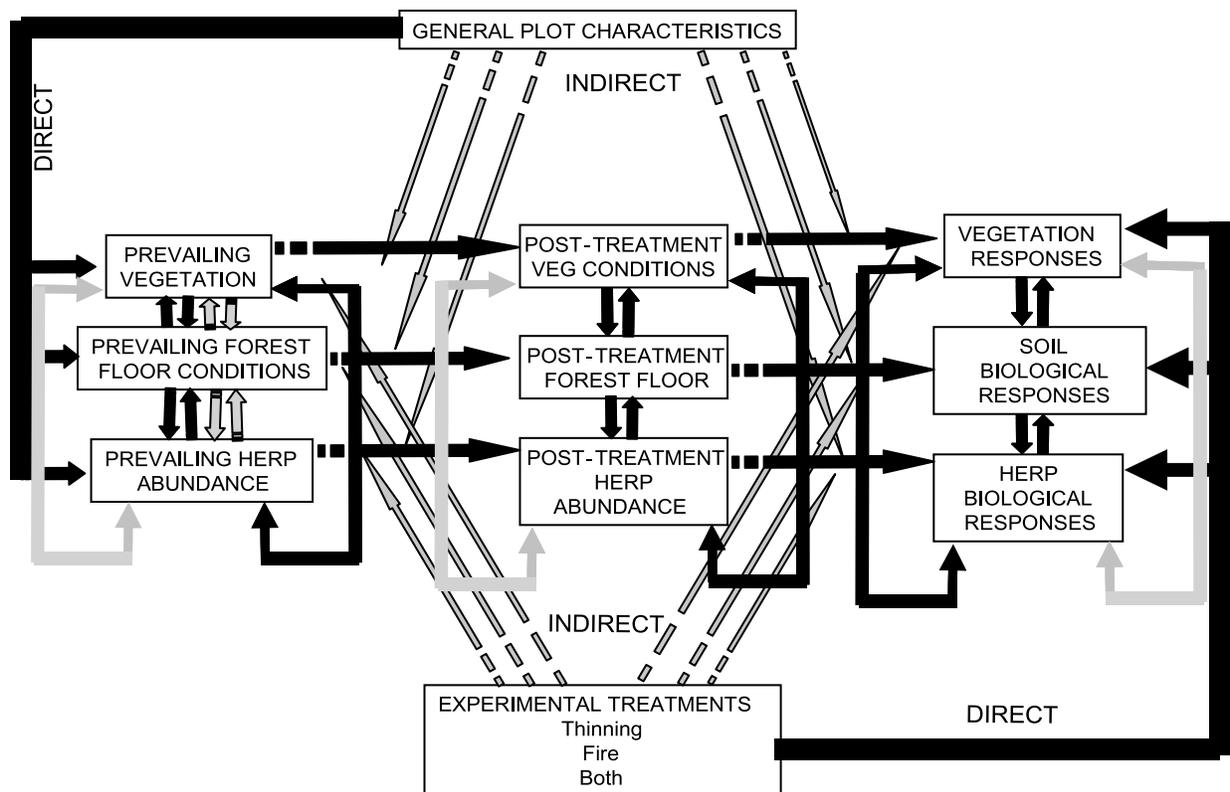


Figure 4—Hypothetical within-site path model of NFFS treatment effects on forest floor, vegetation, and herpetofauna.

which other variables influence the effect size of the dependent variable in question. Meta-analysis has been used sparingly in forest ecology, primarily in the past 10 years. Its use has been limited by the relative scarcity of studies that are both robust and similar enough to provide data that can be aggregated effectively. For example, Kopper (2002) found only eight major studies that had a robust enough experimental design to be included in a meta-analysis on the influence of prescribed fire on fuel reduction in ponderosa pine systems. In contrast, the NFFS project has three design features that make it uniquely suitable for meta-analytic techniques: (1) each of the 13 sites can be regarded as a separate study; (2) each site has a robust stand-alone experimental design; and (3) the experimental designs are identical among sites. With meta-analysis, we can ask not only to what extent forest types influence how plant species diversity is affected by alternative fuel reduction treatments but also how a number of other variables affect diversity, including soil type, fuel loadings, season of burn, and logging technique. Information on conditional response to treatment will allow managers to better predict how a treatment will perform given their unique sets of circumstances.

### Single-Site, Multivariate Analyses

At the site level, the FFS study is a multivariate experiment and is an attempt to capture whole-system responses to fire and fire surrogate treatments. This design has great value from a management perspective, because the information we generate will allow managers to assess tradeoffs in response to treatment for different key variables. For example, we can determine how much fuel must be removed to prevent wildfire and also determine whether that level of fuel reduction will eliminate key habitat for wildlife (fig. 4). Also, we can determine the cost per ton of fuel reduction for different fire and fire surrogate treatments. From a scientific perspective, the multivariate design will allow us to better understand not only how multiple components of the system respond but also how relationships among components change when treatments are applied. Use of multivariate techniques is necessary to extract this kind of information. For example, standard multivariate techniques such as ordination and classification can help us understand how treatments influence plant species composition (fig. 1) rather than just diversity as expressed by a single measure (McCune and Grace 2002). Compositional changes are likely to be more important than diversity changes because species differ with respect to their function, e.g. nitrogen fixers, or with respect to their relative value for humans, e.g. native plants vs. invasive plants.

In order to evaluate how relationships among components within a system respond to treatment, we need multivariate techniques that go beyond simple ordination and classification. A potentially useful tool is structural equation modeling (SEM) (Pugesek and Tomer 2003). SEM has been used for many years in economics and social science, but there are relatively few examples of SEM in ecology (Grace and Pugesek 1998). One way to describe SEM is to compare it to multiple regression. Multiple regression allows one to determine simultaneously how a number of key independent variables influence one dependent variable. A typical multiple regression model identifies both the relative influence of each independent variable on the dependent variable and the correlations among independent variables. Although this technique can be useful for exploring complex relationships, it has limited

applicability in modeling of real systems because possible interactions among variables are constrained: in real systems, independent variables can only be correlated to one another and can only be related to the dependent variable with a one-way cause-to-effect relationship. A typical SEM model, on the other hand, can have a much more flexible structure of relationships. The technique requires that the investigator build a hypothetical model, such as the one shown in figure 4, that includes the key variables and their causal relationships not only to the dependent variable but to one another. In essence, one builds a model of how the system is predicted to work and then tests the model with real data from the experiment. With SEM, we can answer questions about the response of key variables within the context of the whole system. For example, we can answer questions about the influence of soil type on the degree to which fire and fire surrogates affect the susceptibility of trees to bark beetles. Factors such as slope, elevation, aspect, and initial fuel loads can also be evaluated in the context of a structural equation model.

### Multi-Site, Multivariate Analyses

Each of the multivariate techniques described in the previous section can also be used for among-site analyses. Ordination can be used to investigate site-to-site differences in how plant species composition changes due to treatment. For example, do invasive plants respond similarly to treatment across the network? Do fire and fire surrogate treatments tend to cause common responses in nitrogen-fixing species? Similarly, SEM can be used for multi-site analyses as well. A single structural model may be confirmed for one site but not for another, leading the investigator to identify the factors responsible for the difference. These techniques can be very useful in helping to understand the conditional response to treatment of key variables, which will allow managers to better predict how fire and fire surrogate treatments will function in systems under their care.

### Current Status

Installation of treatments for the NFFS is nearing completion at all 13 sites across the country. Publications describing single-site univariate studies are becoming numerous and are listed on the NFFS web site (<http://www.fs.fed.us/ffs/>). Single-site multivariate analyses are underway at some locations. Multiple site analyses have begun for vegetation, fuels, and wildlife. Results of interdisciplinary studies should become available in 2006.

### ACKNOWLEDGMENT

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### LITERATURE CITED

Boyle, M.F., II; Hedden, R.L.; Waldrop, T.A. 2004. Impact of prescribed fire and thinning on host resistance to the southern pine beetle: preliminary results of the national fire and fire surrogate study. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 60-64.

- Callaham, M.A., Jr.; Anderson, P.H.; Waldrop, T.A. [and others]. 2004. Litter decomposition and soil respiration responses to fuel-reduction treatments in Piedmont loblolly pine forests. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 25-30.
- Cooper, H.; Hedges L. 1994. The handbook of research synthesis. New York, NY: Russell Sage Foundation. 573 p.
- Grace, J.; Pugeseck, B. 1998. On the use of path analysis and related procedures for the investigation of ecological problems. *American Naturalist*. 152: 151-159.
- Kilpatrick, E.S.; Kubacz, D.B.; Guynn, D.C., Jr. [and others]. 2004. The effects of prescribed burning and thinning on herpetofauna and small mammals in Piedmont pine-hardwood forests: preliminary results of the national fire and fire surrogate study. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 18-24.
- Kopper, K.E. 2002. Meta-analysis design and interpretation: a case study of prescribed fire effects on fuel loadings in ponderosa pine ecosystems. Seattle, WA: University of Washington. 36 p. M.S. thesis.
- McCune, B.; Grace, J. 2002. Analysis of ecological communities. Glenden Beach, OR: MJM Software Design. 300 p.
- Mohr, H.H.; Waldrop, T.A.; Rideout, S. [and others]. 2004. Effectiveness of fire and fire surrogate treatments for controlling wildfire behavior and mortality in Piedmont forests: a simulation study. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 71-73.
- Phillips, R.J.; Waldrop, T.A.; Chapman, G.L. [and others]. 2004. Effects of fuel reduction techniques on vegetative composition of Piedmont loblolly-shortleaf pine communities: preliminary results of the National Fire and Fire Surrogate Study. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 44-47.
- Pugeseck, B.; Tomer, A. von E. 2003. Structural equation modeling. Applications in ecological and evolutionary biology. Cambridge: Cambridge University Press. 424 p.
- Shelburne, V.B.; Boyle, M.F., II; Lione, D.J.; Waldrop, T.A. 2004. Preliminary effects of prescribed burning and thinning as fuel reduction treatments on the Piedmont soils of the Clemson Experimental Forest. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 35-38.
- Waldrop, T.A.; Glass, D.W.; Rideout, S. [and others]. 2004. An evaluation of fuel reduction treatments across a landscape gradient in Piedmont forests: preliminary results of the national fire and fire surrogate study. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 54-59.
- Zebehazy, L.A.; Lanham, J.D.; Waldrop, T.A. 2004. Seasonal avifaunal responses to fuel reduction treatments in the upper Piedmont of South Carolina: results from phase 1 of the national fire and fire surrogate study. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 82-86.

# MANAGING COMPOSITION OF PIEDMONT FORESTS WITH PRESCRIBED FIRE

Kenneth W. Outcalt<sup>1</sup>

## Poster Summary

Native Americans used frequent burning of forests in the South's Piedmont to maintain pine-dominated stands, to favor oak regeneration over other hardwoods, and to keep understories open. From 1950 to 1990, fire occurred rarely in the region, resulting in a gradual replacement of pines with hardwoods. More recently, however, prescribed burning has been used much more extensively to restore open pine stands for key species such as the red-cockaded woodpecker (*Picoides borealis*). Burning maintains open pine forests and also reduces fuel-loading and the likelihood of damaging wildfires.

The silvicultural effects of burning at different frequencies and in different seasons, especially in stands that have a significant hardwood component and very little herbaceous understory, are less well understood. To determine the effect of prescribed burning regime on overstory and understory composition, in 1987 we established a series of plots on the Hitchiti Experimental Forest in central Georgia.

The study was within a representative stand of naturally regenerated loblolly pine (*Pinus taeda* L.) aged 80 years or older. Our randomized block design was based on initial overstory basal area, and we looked at six different treatments: dormant season burns every 2 years with headfires, dormant season burns every 3 years with headfires, dormant season burns every 3 years with backfires, growing season burns every 3 years with headfires, growing season burns every 6 years with headfires, and an unburned control. Each plot was about 2 acres, and there were four replications of each treatment.

Prior to treatment, plots were dominated by loblolly pine with a significant midstory of hardwoods. Since treatment, control

plots have changed very little, although there has been some natural thinning of saplings. None of the treatments has reduced midstory hardwoods, although it appears the 2-year dormant burns are keeping them in check. The growing season burns have reduced the density of hardwood saplings and increased the density of seedlings. Saplings have been nearly eliminated by dormant season prescribed burns on a 2-year cycle. The density of small shrub stems, however, was greatly increased by dormant season burns. Herbaceous cover decreases in the season immediately following burning but then quickly recovers. The dormant season headfires have been most successful in increasing herbaceous cover.

It is apparent that even infrequent burns greatly reduce the understory hardwood component, thereby curtailing succession and maintaining an open, pine-dominated stand. However, none of the treatments we studied was successful in reducing midstory hardwoods, and this suggests that mechanical or chemical treatments may be necessary to restore or maintain stands used by red-cockaded woodpecker. An herbaceous-dominated ground cover did result from the frequent dormant season headfires even where there were significant midstory hardwoods. Therefore, managers who want some midstory and overstory hardwoods for wildlife and aesthetic reasons can maintain these while still providing significant woody browse and herbaceous species in the understory. Without fire, the hardwood stems will increase in all layers, just as they did in the unburned controls. Thus, the choice of allowing conversion to mostly hardwoods, maintaining pines and hardwoods, or fostering mostly pines becomes a management decision, because all these forest types can be maintained in a dynamic stable state using appropriate silvicultural practices.

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<sup>1</sup> Research Ecologist, USDA Forest Service, Southern Research Station, Athens, GA, 30602.



## **Hardwoods: Natural Regeneration**

*Moderator:*

**JOHN HODGES**  
Mississippi State University



# EFFECT OF GROUND SKIDDING ON OAK ADVANCE REGENERATION

Jeffrey W. Stringer<sup>1</sup>

**Abstract**—Vigorous advance regeneration is required to naturally regenerate oaks. However, a reduction in the number of advance regeneration stems from harvesting activities could be an important factor in determining successful oak regeneration. This study assessed the harvest survivability of advance regeneration of oak (*Quercus* spp.) and co-occurring species in four mixed upland hardwood stands subjected to commercial clearcutting in Kentucky. Regression indicated a positive curvilinear relationship between height and survival and between ground line diameter and survival for oak. No significant differences were found in survival among oak species. Analysis of survival across all oak species by height class indicated a statistical difference in mean survival percent between oaks  $\leq 3$  feet (54.1 percent) and  $> 3$  feet (87.4 percent) in height. Maple (*Acer* spp.) and other co-occurring species  $\leq 3$ -feet-tall exhibited a slightly higher and significant ( $p < 0.05$ ) increase in survival compared to oaks  $\leq 3$ -feet-tall. However, oak advance regeneration  $> 3$ -feet-tall maintained similar or greater harvest survivability compared to co-occurring species.

## INTRODUCTION

It has long been known that oak (*Quercus* spp.) forests have been mismanaged and that successful oak regeneration is the key to their rejuvenation (Liming and Johnson 1944). It is also well understood that maintaining oak after a regeneration harvest requires the occurrence of advance regeneration and/or stems capable of stump sprouting (Cook and others 1998, Lorimer 1983, Ross and others 1986, Sander 1971, Sander 1972). These stems must be present prior to a regeneration event, and adequate numbers must survive harvest for oaks to successfully regenerate (Cook and others 1998).

Regeneration predictions and decisions regarding regeneration timing are often based on pre-harvest advance regeneration inventories. However, the use of these inventories does not account for losses that can occur to the advance regeneration pool during harvest operations. This research was designed to determine the survivability of advance regeneration of oak and co-occurring species subjected to ground skidding associated with a commercial clearcut.

## STUDY SITE

The study was located at Berea College Forest on the western edge of the Cumberland Plateau Physiographic region in central Kentucky. Four 8-acre tracts were selected for study. Tracts were dominated by mixed upland oak species including white oak (*Q. alba* L.), black oak (*Q. velutina* Lam.), chestnut oak (*Q. prinus* L.), and associated species including yellow-poplar (*Liriodendron tulipifera* L.), hickory (*Carya* spp.), American beech (*Fagus grandifolia* Ehrh.), red maple (*Acer rubrum* L.), and, sugar maple (*A. saccharum* Marsh.). Tracts ranged in site index from 65 to 80 feet (upland oak site) and contained 90 to 120 square feet of basal area per acre with over 4,500 board feet (International 1/4 Rule) of harvestable sawtimber and associated pulpwood. All tracts were located on lower and toe slope positions with an average slope percent of  $< 20$ .

## STUDY DESIGN AND ANALYSIS

Each 8-acre tract was subjected to a commercial clearcut accomplished with chainsaw felling and ground skidding with

wheeled skidders by one operator. Due to the relatively gently-sloping topography (slope percent  $< 20$ ), wheeled skidders were not restricted to constructed skid trails but could move freely throughout the harvest area; loads were skidded directly from the stump to the landing.

Each tract was divided into 7 sections, and a set of regeneration plots were centrally-located in each of the sections. The regeneration plots included one 0.01-acre fixed area plot (28 total) and three 0.001-acre plots (84 total). All trees  $> 4.5$ -feet-tall to 10 inches d.b.h. in the 0.01-acre plots and all oaks between 0.5- and 4.5-feet-tall and all other species 1.0- to 4.5-feet-tall in the 0.001-acre plots were permanently tagged with a combination of a heavy aluminum tag and a nylon whisker tag pinned to the ground with #9 galvanized wire. Species, height, and ground line diameter (gld) were measured prior to harvest. Operators were unaware of the regeneration plots, and harvest operations, including skidding, occurred without bias to the plots.

Each tag was located directly after harvest, and the stem was coded as either present or absent. Stems were also coded as to type and degree of damage (data not presented). At the end of the first growing season after harvest, trees were measured, and a damage code was assigned to each stem including no damage, missing, and present but dead. Each tree was placed into a height and a basal diameter class for analysis. Regression was used to determine relationships between survival (dependent variable) and gld and height (independent variables). Analysis of variance was used to determine differences among species and sizes using arc sine transformed survival data.

## RESULTS AND DISCUSSION

Harvest survival of oak advance regeneration varied with height and gld. Figure 1 indicates the effect of height on harvest survival across all oak species. Data points represent the average oak survival by height class, and the curve represents the best fit equation  $y = 0.759376 + (-1.219738) \cdot \exp(-x/0.77275)$  ( $r^2 = 0.7676$ ). Analysis by height class (data pooled across species and tracts) indicated a statistical difference ( $p < 0.05$ )

<sup>1</sup> Associate Professor and State Extension Specialist in Hardwood Silviculture, University of Kentucky, Department of Forestry, Lexington, KY 40546-0073.

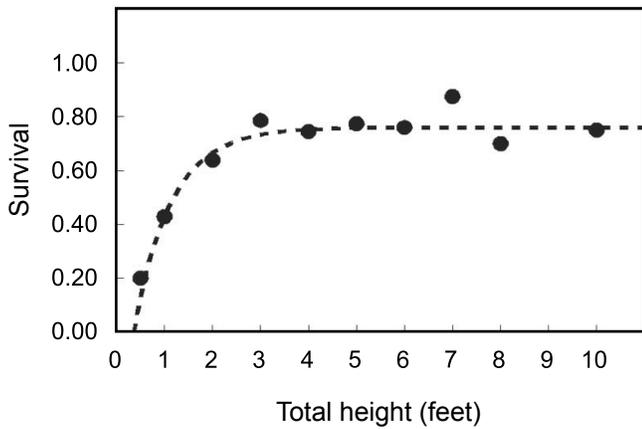


Figure 1—Effect of height on harvest survivability of *Quercus* spp. advance regeneration. Symbols represent mean survival for each height class. The line represents the best fit equation:  $y=0.759376+(-1.219738)*\exp(-x/0.77275)$  ( $r^2=0.7676$ ).

in survival between oaks  $\leq 3$ -feet- and  $> 3$ -feet-tall (54.1 versus 87.4 percent, respectively). While no statistical difference in survival percent was found among tracts, analysis indicated mean tract survival ranging 43 to 65 percent for oaks  $\leq 3$  feet in height (fig. 2). All tracts maintained 80 to 90 percent survival for oaks  $> 3$ -feet-tall. All oak species had lower mean survival for trees  $\leq 3$ -feet-tall compared to trees  $> 3$ -feet-tall. However, significant differences ( $p < 0.05$ ) were only found in scarlet and chestnut oak, while white, northern red (*Q. rubra* L.), and black oak exhibited no statistical difference among height groups (fig. 3).

Figure 4 shows the relationship between height and survival percent for red maple and sugar maple, pooled, and other species pooled [predominately sourwood (*Oxydendrum arboretum* [L.] DC), blackgum (*Nyssa sylvatica* Marsh.), eastern dogwood (*Cornus florida* L.), American beech, hickory, and

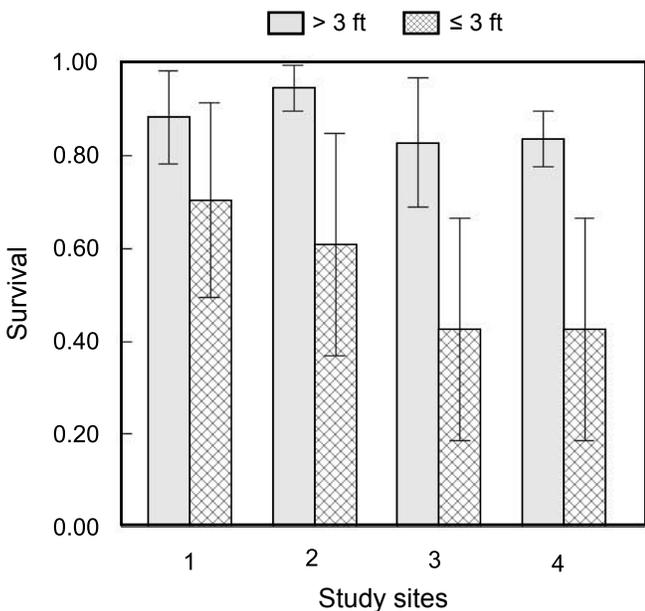


Figure 2—Mean survival of advance regeneration of *Quercus* spp. by study site (tract) pooled by height class  $\leq 3$  feet and  $> 3$  feet in height.

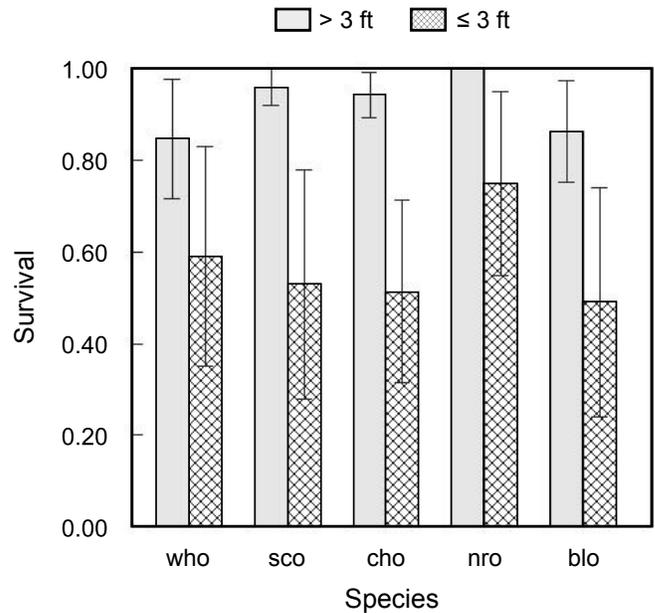


Figure 3—Mean survival of advance regeneration of *Quercus* spp. by species pooled by height class  $\leq 3$  feet and  $> 3$  feet in height.

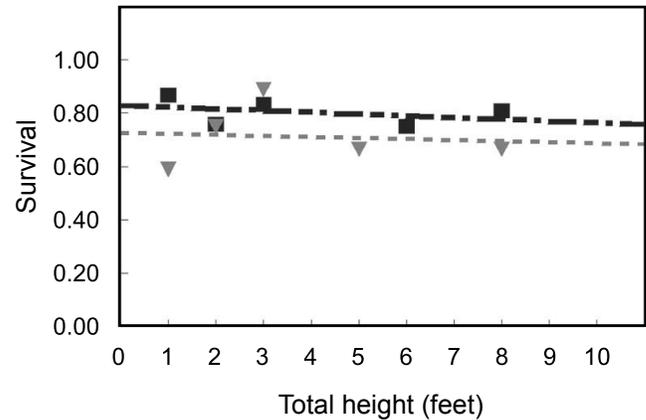


Figure 4—Effect of height on harvest survivability of *Acer* spp. (square) and miscellaneous species, predominately *Oxydendrum arboretum*, *Nyssa sylvatica*, *Cornus florida*, *Fagus grandifolia*, and *Carya* spp. (triangle). Bold line represents best fit linear equation for *Acer* spp. ( $y=-0.006382x+0.829129$ ) and for miscellaneous species ( $y=-0.003903x+0.72663$ ).

others]. Data points represent means by height class. The dashed line represents the best fit linear equation for maple ( $y = -0.006382x + 0.829129$ ), and the solid line represents the best fit linear equation for other species ( $y = -0.003903x + 0.72663$ ). No statistical difference in survival percent by height class was found either between or within these two species groups.

As would be expected, the same pattern of trends and differences were found between gld and survival as was found between height and survival. Regression yielded  $y=0.783527+(-0.436994)*\exp(-x/0.28592)$  for oak survival percent by gld ( $r^2 = 0.7270$ ) (fig. 5). Oaks  $\leq 0.5$  inch gld averaged 57 percent survival and were significantly different ( $p < 0.05$ ) from trees 1 to 10 inches in gld (78 percent). Maples

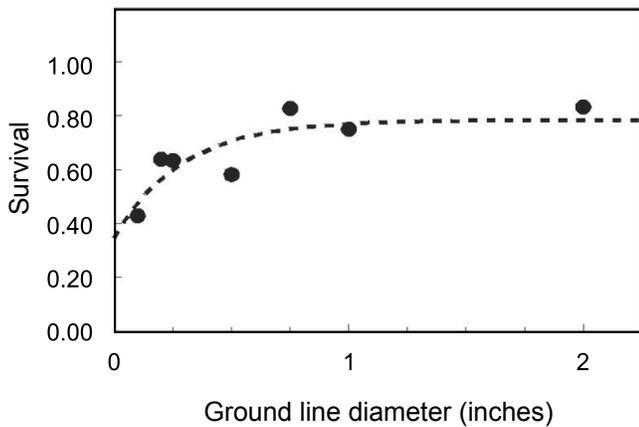


Figure 5—Effect of height on harvest survivability of *Quercus* spp. advance regeneration. Symbols represent mean survival for ground line diameter class. The line represents the best fit equation:  $y=0.783527 + (-0.436994)*\exp(-x/0.28592)$ .

and other species showed no relationship between gld and survival percent (fig. 6) averaging 76.6 and 73.4 percent survival, respectively.

## CONCLUSIONS

Over all tracts and size classes, oak averaged 66.7 percent harvest survival. The maples averaged 80.1 percent, and

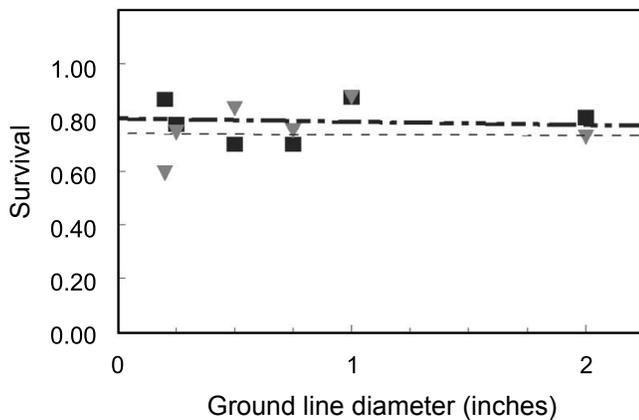


Figure 6—Effect of height on harvest survivability of *Acer* spp. (square) and miscellaneous species, predominately *Oxydendrum arboretum*, *Nyssa sylvatica*, *Cornus florida*, *Fagus grandifolia*, *Carya* spp. (triangle). Bold line represents best fit linear equation for *Acer* spp. ( $y=-0.0063x+0.8292$ ) and for miscellaneous species ( $y=0.0038x+0.7445$ ).

miscellaneous species had an average survival of 71.1 percent. However, significant differences in survival percent among species groups were found only in stems  $\leq$  3-feet-tall. This study indicates that significant harvest losses can be expected in oak advance regeneration pools, particularly those trees  $\leq$  3-feet-tall. These losses can vary by harvest unit. Not only can commercial clearcutting with wheeled skidders significantly reduce the population of this sized oak advance regeneration, but oaks incur proportionally higher losses in smaller size classes compared to co-occurring and competing species. However, this study indicates that oak advance regeneration  $>$  3 feet in height can maintain similar or greater harvest survivability compared to co-occurring species.

The results of this study suggest that models predicting regeneration outcomes from data collected in pre-harvest inventories should be adjusted to account for proportionally higher losses of oak advance regeneration  $<$  3-feet-tall compared to maples and other co-occurring species. This study also indicates that oak advance regeneration  $>$  3-feet-tall is required if stable advance regeneration species proportions are to be maintained after a harvest. From a silvicultural perspective, this research provides operational support to previous guidelines indicating the need for oak advance regeneration with a minimum height of 4.5 feet prior to the implementation of a regeneration harvest in upland oak stands.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Cook, J.E.; Sharik, T.L.; Smith, D.W. 1998. Oak regeneration in the southern Appalachians: potential, problems, and possible solutions. *Southern Journal of Applied Forestry*. 22: 11-18.
- Liming, F.G.; Johnson, J.P. 1944. Reproduction in oak-hickory forest stands of the Missouri Ozarks. *Journal of Forestry*. 42: 175-180.
- Lorimer, C.G. 1983. 80-year development of northern red oak after partial cutting in a mixed-species Wisconsin forest. *Forest Science*. 29: 371-383.
- Ross, M.S.; Sharik, T.L.; Smith, D.W. 1986. Oak regeneration after clear felling in southwest Virginia. *Forest Science*. 32: 157-169.
- Sander, I.L. 1971. Height growth of new oak sprouts depends on size of advance reproduction. *Journal of Forestry*. 69: 809-811.
- Sander, I.L. 1972. Size of oak advance reproduction: key to growth following harvest cutting. Res. Pap. NC-79. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 6 p.

# LONG-TERM EFFECTS OF CLEARCUTTING ON TREE SPECIES COMPOSITION IN AN OAK-HICKORY FOREST

Jessica A. Yeagle and John W. Groninger<sup>1</sup>

**Abstract**—In 1973, a silvicultural clearcut, with and without a post-harvest herbicide treatment, was performed on an upland oak-hickory forest in southern Illinois. Prior to harvest, permanent plots were established, and a survey was conducted to determine stand structure and composition. In 2003, a post-harvest survey was performed using the permanent plots. Relative density and relative basal area were calculated for all oaks and dominant mesic species. Differences in stand structure were compared between the pre-harvest and post-harvest stand. Overall, disturbance-dependent species such as oak appeared to be decreasing while mesic species were increasing.

## INTRODUCTION

Currently in the central United States, upland hardwood stands are a mixture of species that reflect site conditions and past treatments (Steinbeck and Kuers 1996). Following harvest treatments, it has been observed that the oak component on certain sites has not been regenerating successfully. These regeneration failures have led to the decrease of oak dominance, the loss of one species of oak, or virtually a total loss of the oak component in a stand (McGee and Loftis 1993). Foresters need a thorough understanding of how different types of harvesting methods affect species regeneration and stand composition.

Changes in disturbance regimes over the past several decades is believed to play an integral part in species composition shifts in hardwood forests of this region. Suppression of disturbances such as fire negatively impact the growth of disturbance-dependent species (Fralish 1997). Light fires favor oak regeneration by killing fire-intolerant species, promoting growth of sprouts, and reducing overstory density (Larsen and Johnson 1998). Without these disturbances shade tolerant species such as sugar maple (*Acer saccharum* Marsh.) and American beech (*Fagus grandifolia* Ehrh.) have encroached upon historically oak-dominated sites. Within the Shawnee National Forest, managers are faced with the dilemma of maintaining an oak-hickory cover type in an environment where creating necessary disturbance regimes on public lands has become difficult. The general objective of the study was to assess the shift in stand composition 30 years following a clearcut and herbicide treatment.

## METHODS

The research site was located on the Shawnee National Forest at Atwood Ridge, Union County, IL. This region of southwestern Illinois is on the easternmost extension of the Ozark Province and is characterized by steep, hilly topography (Thornbury 1965).

In 1973, a silvicultural clearcut was performed on 24 ha with maintenance of the present cover type of mixed oak-hickory as the management objective. After harvest, to increase the amount of light reaching the forest floor, undesirable residual trees >10 cm d.b.h. were treated with 2,4,5-T and 2,4-D

herbicides using a tree injector. Economically-desirable trees, such as oak, were felled and not treated with herbicide so they would resprout (Weaver and Robertson 1981). Prior to harvest, 52 permanent plots, 0.04-ha in size, were established and inventoried for species composition and tree diameter. In the summer of 2003, the plots were again surveyed.

## RESULTS AND DISCUSSION

Changes in overstory relative density occurred between the pre-harvest and 30-year post-harvest stand. In 1973, white oak (*Quercus alba* L.) was the most numerous species in the overstory with a relative density of 18 percent (fig. 1). Thirty-years later, the most numerous species present was yellow-poplar (*Liriodendron tulipifera* L.), which comprised 288 stems/ha (table 1). When there are seed sources present, yellow-poplar can be expected to comprise most of the reproduction after a clearcut (Merz and Boyce 1958). Rapid growth enables it to quickly capture growing space and out-compete a cohort of species (Beck and Hooper 1986, Loftis and others 2004).

The status of the oak component had changed dramatically from pre-harvest to post-harvest conditions. In 1973, oak species dominated the basal area in the stand (fig. 2). Thirty-years later, chestnut oak (*Quercus prinus* L.) is the only oak to have maintained its relative basal area. Shifts in oak density have also occurred. These changes include a decrease in the amount of white oak and black oak (*Quercus velutina* Lam.). However, both chestnut oak and northern red oak (*Quercus rubra* L.) have increased in stem density.

In addition to decreases in the oak-hickory component, increases in the mesic species component present in the 30-year post-harvest stand have been observed. All mesic species maintained or surpassed their pre-harvest absolute and relative densities and relative basal areas. The number of stems/ha of the mesic species also greatly increased compared to pre-harvest amounts. Several studies in uncut or partially cut forests have reported mesic species encroaching upon historically oak-dominated sites in Illinois due to low intensity or complete lack of disturbance (Fralish 1997, Fralish and others 1991, Groninger and others 2002, Ruffner and Groninger 2004, Zaczek and others 2002). This encroachment

<sup>1</sup> Graduate Student and Associate Professor, Department of Forestry, Southern Illinois University Carbondale, Carbondale, IL, 62901, respectively.

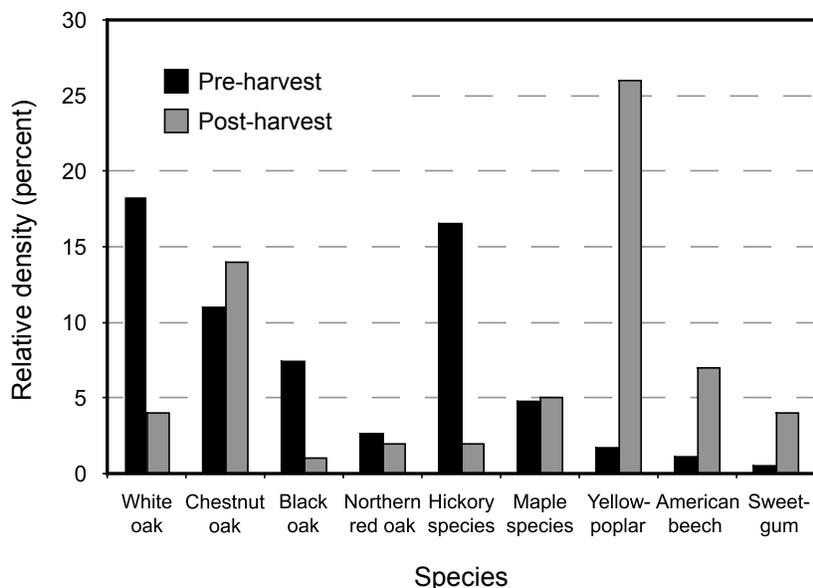


Figure 1—Relative density: pre-harvest stand versus 30-year post-harvest stand.

**Table 1—Number of stems per hectare in the pre-harvest and 30-year post-harvest stand**

Species	Pre-harvest	Post-harvest
White oak	82	43
Hickory spp.	74	20
Chestnut oak	49	161
Black oak	33	12
Maple spp.	22	59
Northern red oak	12	17
Yellow-poplar	8	288
American beech	5	78
Sweetgum	2	50

of mesic species has been attributed to the lack of fire as a disturbance in the ecosystem.

### CONCLUSIONS

Chestnut oak was the only oak to maintain its pre-harvest density and basal area. The oak-hickory component that was present prior to harvest has diminished greatly. Mesic species present in the overstory have increased from pre-harvest conditions. This influx of mesic species will most likely continue with the absence of disturbance or management of the site. Cutting or herbicide injection of unwanted mesic species in the overstory followed by a prescribed burn would remove a large amount of seed sources as well as control established mesic stems in the understory.

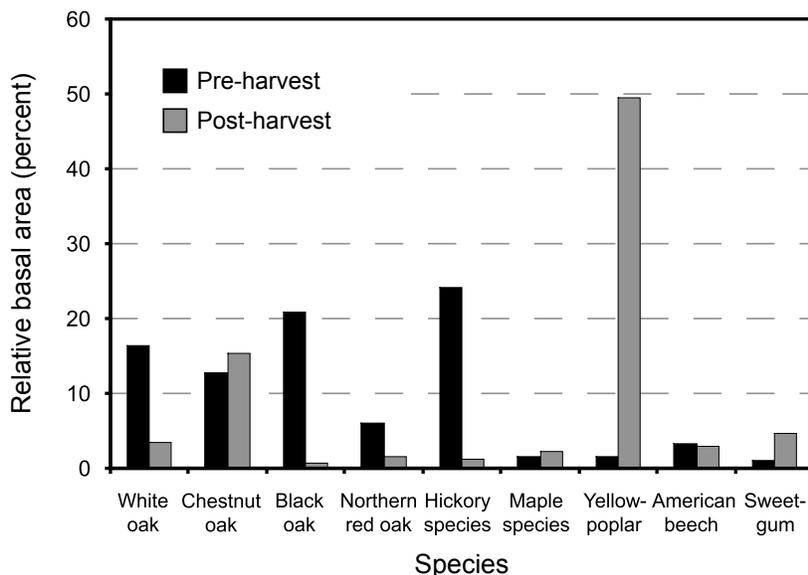


Figure 2—Relative basal area: pre-harvest stand versus 30-year post-harvest stand.

## ACKNOWLEDGMENTS

The authors would like to thank Dr. Phil Robertson, who originally established this project and Saskia Edden for her field assistance.

## LITERATURE CITED

- Beck D.E.; Hooper, R.M. 1986. Development of a southern Appalachian hardwood stand after clearcutting. *Southern Journal of Applied Forestry*. 10: 168-172.
- Fralish, J.S. 1997. Community succession, diversity, and disturbance in the central hardwood forest. *Conservation in highly fragmented landscapes*. New York, NY: Chapman and Hall: 234-266.
- Fralish, J.S.; Crooks, F.B.; Chambers, J.L.; Harty, F.M. 1991. Comparison of presettlement, second-growth and old-growth forest on six site types in the Illinois Shawnee Hills. *American Midland Naturalist*. 125: 294-309.
- Groninger, J.W.; Ozier, T.B.; Ruffner, C.M. 2002. Stand compositional dynamics in a mature Illinois Ozarks forest: implications for management. In: Van Sambeek, J.W.; Dawson, J.O.; Ponder, F., Jr. [and others], eds. *Proceedings, 13<sup>th</sup> central hardwood forest conference*. Gen. Tech. Rep. NC-234. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 296-302.
- Larsen, D.R.; Johnson, P.S. 1998. Linking the ecology of natural oak regeneration to silviculture. *Forest Ecology and Management*. 106: 1-7.
- Loftis, D.L.; McNab, W.H.; Berg, E.C.; Oprean, T.M. 2004. Lessons learned in 84-year-old plots at Looking-Glass Rock, North Carolina. *RMRS-P-34*. Fort Collins, CO: U.S. Department of Agriculture, Forest Service Proceedings: 235-241.
- McGee, C.E.; Loftis, D.L. 1993. Oak regeneration: a summary. In: Loftis, D.; McGee, C.E., eds. *Oak regeneration: serious problems, practical recommendations*. Symposium proceedings. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 316-319.
- Merz, R.W.; Boyce, S.G. 1958. Reproduction of upland hardwoods in southeastern Ohio. *Tech. Paper 155*. Columbus, OH: U.S. Department of Agriculture, Forest Service, Central States Forest Experiment Station. 24 p.
- Ruffner, C.M.; Groninger, J.W. 2004. Oak ecosystem restoration and maintenance in southern Illinois. In: Spetich, M.A., ed. *Upland oak ecology symposium: history, current conditions, and sustainability*. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 177-181.
- Steinbeck, K.; Kuers, K. 1996. Development of pine-hardwood mixtures following clearcutting on two upland sites in the Georgia Piedmont: 10 year results. *Southern Journal of Applied Forestry*. 20(4): 203-208.
- Thornbury, W.D. 1965. *Regional geomorphology of the United States*. New York: John Wiley and Sons, Inc. 609 p.
- Weaver, G.T.; Robertson, P.A. 1981. Regrowth of *Quercus prinus* and associated tree species following regeneration harvesting in the Ozark Hills of Illinois. *Bulletin of the Torrey Botanical Club*. 108: 166-179.
- Zaczek, J.J.; Groninger, J.W.; Van Sambeek, J.W. 2002. Stand dynamics in an old-growth hardwood forest in southern Illinois. *U.S.A. Natural Areas Journal*. 22: 211-219.

# REGENERATION MICROSITES AND RESOURCE LEVELS RESULTING FROM A RANGE OF SILVICULTURAL TREATMENTS IN TENNESSEE OAK-HICKORY FORESTS

Brian A. Barwatt, David S. Buckley, and Wayne K. Clatterbuck<sup>1</sup>

**Abstract**—Regeneration microsites were investigated by measuring photosynthetically active radiation (PAR), soil moisture, nutrients, and understory vegetation in (1) uncut controls and plots with partial cutting to either 50, 25, or 12.5 percent of original basal area, (2) commercial clearcuts, and (3) silvicultural clearcuts. Treatments and controls were replicated in north-facing, south-facing, and ridgetop blocks within mature oak-hickory forest. Abundance and height of herb species increased with decreases in residual basal area and shaded the regeneration layer in clearcuts. Mean percent full PAR was 3.8, 41.0, 70.0, 77.4, 81.8, and 86.7 percent in the uncut, 50 percent, 25 percent, 12.5 percent, commercial clearcut, and silvicultural clearcut plots, respectively. A regression equation ( $p < .0001$ ,  $r^2 = .91$ ) was developed that relates percent full PAR to basal area. No significant differences in moisture or nutrients occurred between treatments. This was likely due to high spatial variability in these resources and above-average precipitation during the study.

## INTRODUCTION

Apart from direct effects, such as the removal of competing stems and the addition of stems through planting, desired results of hardwood regeneration practices are often obtained through indirect effects on basic factors and resources such as growing space, temperature, light, soil moisture, and nutrients. Although a number of proven and promising prescriptions have resulted from the substantial body of silvicultural research conducted up to the present (e.g., Brose and others 1999, Johnson and others 1986, Loftis 1990, Weigel and Johnson 2000), our understanding of the mechanisms underlying the degree of success or failure achieved with a given silvicultural alternative in a given stand is often incomplete. Further, specific levels of light, soil moisture, or nutrients that optimize establishment, growth, and survival during regeneration have yet to be identified for many hardwood species. It can be argued that variation in these basic factors can influence the results of the same regeneration treatment from region to region, and that identification of precise target levels of basic factors would expedite the adaptation of regeneration practices for different regions.

As hardwood regeneration research progresses, it is becoming increasingly recognized that the key to guiding the process of hardwood regeneration toward desired outcomes lies in understanding the physiology of oak and other hardwood species and the differential response of these species to subtle changes in basic factors (e.g., Dickson and others 2000, Gardiner and Hodges 1998, Kolb and Steiner 1990, Lockhart and others 2003). Studies of hardwood tree physiology involve variables, such as photosynthetically active radiation (PAR), that are related to but not easily converted into measures that are commonly used by field foresters to implement silvicultural treatments, such as basal area. The gap in variables that exists between the tree physiology and silviculture disciplines provides additional impetus for measurement of specific levels of light, soil moisture, nutrients, and other basic factors created by a given regeneration treatment in different stands and regions.

A replicated study was initiated in 2002 to investigate and demonstrate the effect of a range of silvicultural alternatives on the regeneration of hardwood species in the oak-hickory forest type in the Ridge and Valley Province of Tennessee. Objectives included long-term monitoring of natural regeneration in response to treatments and artificial regeneration with high-quality northern red oak seedlings planted before and after implementation of treatments. Additional objectives were to document light, soil moisture, nutrients, and the abundance and composition of competitors in the immediate vicinity of each planted northern red oak seedling. We could then identify optimum levels of these factors for artificial regeneration of this species, as well as the treatments in which these optimum conditions occurred. Results for planted oaks were not yet definitive in 2003 and thus will not be presented.

The specific objective of the portion of the overall study presented here was to establish levels of PAR, soil moisture, macronutrients, and vegetation in the immediate vicinity of planted oak nursery seedlings in six different silvicultural treatments: uncut (Control), 50 percent basal area retention (BAR), 25 percent BAR, 12.5 percent BAR, commercial clearcutting (CCC), and silvicultural clearcutting (SCC).

## METHODS

This study was conducted at the University of Tennessee Forestry Experiment Station in Oak Ridge, TN (36.01° N, 84.26° W). Treatment blocks were established within a 30 ha oak-hickory forest that had experienced minimal disturbance in the 50 years prior to implementation of the study. Soils on the study site are moderately productive and belong to the Fullerton soil series.

A randomized complete block design was used for this experiment. Three blocks containing all treatments and an uncut control were delineated based on stand structure, forest composition, and landscape position. Variation between the blocks was primarily due to topographic position and aspect. All treatments and controls were randomly assigned to 1.6 ha plots, and treatments were implemented within all blocks in

<sup>1</sup> Graduate Research Assistant and Associate Professors, respectively, University of Tennessee, Department of Forestry, Wildlife and Fisheries, 274 Ellington Plant Sciences Building, Knoxville, TN 37996-4563.

July, 2002. In order of decreasing canopy cover, treatments were: 50 percent BAR, 25 percent BAR, 12.5 percent BAR, CCC, and SCC.

Stands with 50, 25, and 12.5 percent BAR were marked with the general guideline of creating uniformly distributed stands comprised of desirable trees. Species in the plots with reasonably high and high market value were: white oak (*Quercus alba* L.), chestnut oak (*Quercus montana* Willd.), yellow-poplar (*Liriodendron tulipifera* L.), northern red oak (*Quercus rubra* L.), black oak (*Quercus velutina* Lam.), and southern red oak (*Quercus falcata* Michx.). Trees in the 36 to 46 cm d.b.h. category were favored for retention, but trees in other size classes were retained as necessary to maintain an even distribution across all of the treatment units (Olson 2003). Blocks one, two, and three were located on a north-facing slope, flat ridge top (generally), and south-facing slope, respectively. Plots within blocks were generally arranged in a linear fashion, parallel to the contour of the slope.

In the spring of 2003, 60 northern red oak nursery seedlings were planted on a 6.1 x 6.1 m spacing within all 6 plots in each of the 3 replicate blocks, which resulted in a total of 1,080 seedlings planted in the study. Seedling planting locations were concentrated near the center of each plot with a 20.1 m buffer left between the outermost seedlings and the plot edge in order to minimize edge effects. Since microsite conditions experienced by each seedling were of interest, seedling planting locations were used as the focal points for all measurements of PAR, soil moisture, nutrients, and vegetation.

PAR was measured immediately above the terminal leader of each seedling within all six treatments and all three blocks. Overall mean heights of seedlings at the time of planting and at the end of the 2003 growing season were 131 and 154 cm, respectively. PAR measurements were taken mid-May, mid-June, mid-July, and mid-August of 2003 within three 2-hour periods during the day: morning, noon, and afternoon. All measurement periods were centered around solar noon on each measurement date. For example, if solar noon occurred at 1:33 p.m. local time, noon measurements were taken from 12:33 to 2:33 p.m., morning measurements were obtained from 9:33 to 11:33 a.m., and afternoon measurements were obtained from 3:33 to 5:33 p.m.

Two Decagon Accupar Ceptometers (Decagon Devices, Pullman, WA) were used to collect all measurements of PAR. One Ceptometer was used to measure PAR within treatment plots and uncut controls. The second Ceptometer was programmed to log data in an unattended mode and placed on a tripod in either of 2 large openings that were located within 400 m of all measurement locations within the treatment plots. Synchronous measurements of PAR were obtained with the Ceptometer placed in the open and the Ceptometer carried between treatment plots for the purpose of calculating percent full PAR. This methodology eliminated the confounding effects of changes in incoming PAR resulting from time of day and minimized effects of intermittent cloud cover.

Soil moisture to a depth of 15 cm was measured in units of percent volumetric soil moisture with a portable Trase Time Domain Reflectometry (TDR) probe (Soilmoisture Corp., Goleta, CA). Measurements were taken 15 cm from the base of each planted seedling in the latter half of May, June, July, and August, 2003.

Macronutrient availability was quantified at the treatment level with Plant Root Simulator (PRS™) probes (Western Ag Innovations Inc., Saskatoon, SK). Sixteen PRS™ probes were systematically inserted into the soil 15 cm from the base of 16 northern red oak seedlings within each control and treatment plot. Eight of the PRS™ probes within each plot were negatively charged to adsorb cations, and the remaining eight were positively charged to adsorb anions. All PRS™ probes were placed in the field in mid-August and retrieved in mid-October, followed by analysis of each PRS™ probe for nitrate, ammonium, calcium, magnesium, potassium, phosphorus, iron, manganese, copper, zinc, borate, sulfur, lead, and aluminum by the manufacturer.

Potential competitors above and adjacent to 10 randomly selected northern red oak seedlings per treatment plot and control were sampled within each block during September, 2003. As a result, vegetation was measured in the immediate vicinity of a subset of 180 planted seedlings. Overstory basal area was measured with a 10-factor prism using the planted oak seedling as plot center. Percent cover of herbaceous vegetation alone and herbaceous and woody vegetation combined were estimated using a model c concave spherical densiometer (Lemmon Forest Densimeters, Bartlesville, OK) held just above the terminal leader of each planted oak seedling. All woody species were tallied using 3 height classes: 0 to 50 cm, 51 to 149 cm, and >150 cm. All woody stems 0 to 50 cm and 51 to 149 cm tall were sampled within a 1 m radius of a given planted oak seedling, and all stems >150 cm tall were sampled within a 2 m radius of a given planted oak.

Analysis of variance appropriate for a randomized complete block design was performed to explore treatment effects on PAR, soil moisture, macronutrients, and vegetation. Tukey's HSD was used for pair-wise comparisons. Simple linear regression was also used to investigate the relationship between percent full PAR and basal area. All tests were conducted with  $\alpha = 0.05$ .

## RESULTS

Treatment implementation created a full spectrum of basal areas ranging from a mean of 29.1 m<sup>2</sup>/ha in the uncut controls to 0.9 m<sup>2</sup>/ha in the silvicultural clearcuts (fig. 1). Percent full PAR received by the six different treatments increased as basal area and canopy cover decreased (fig. 2). On average, the uncut controls received the least percentage of full PAR (3.8 percent), and the SCC treatments received the greatest percentage (86.7 percent). Tukey's mean separation technique revealed significant increases in percent full PAR with each increasing level of basal area and canopy cover removal, except in the case of the CCC, which did not differ significantly from the 25 percent BAR or SCC treatments (fig. 2). Mean percent full PAR for the north-facing block was lower than mean percent full PAR measured in the ridgetop and south-facing blocks.

Although values for the means in the treatments were 2 to 4 percent greater than mean percent volumetric soil moisture in the uncut controls, these differences were not significant (fig. 3). Mean percent volumetric soil moisture ranged from 13.0 percent in the uncut controls to 17.7 percent in plots with 50 percent BAR. Total precipitation in June, 2003, was lower than the seasonal average for the study region, but amounts of precipitation in May, July, and August were substantially greater than the seasonal average in 2003.

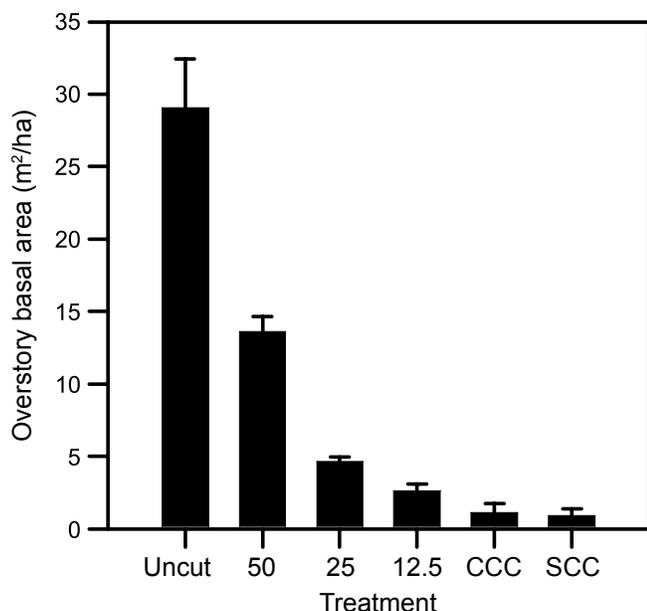


Figure 1—Mean post-treatment overstory basal area in uncut controls and treatments in 2003 in the silvicultural alternative study at the University of Tennessee Forestry Experiment Station, Oak Ridge, TN. Error bars represent 1 standard error. Uncut = uncut control, 50 = 50 percent basal area retention, 25 = 25 percent basal area retention, 12.5 = 12.5 percent basal area retention, CCC = commercial clearcut, and SCC = silvicultural clearcut.

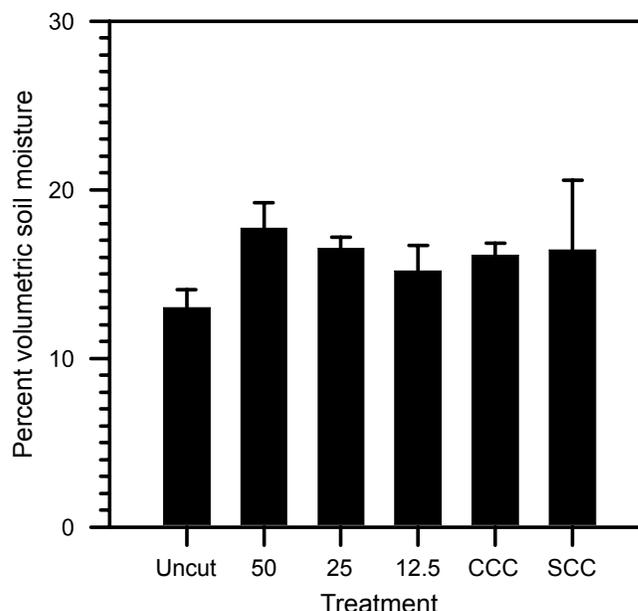


Figure 3—Mean percent volumetric soil moisture in uncut controls and treatments in 2003 in the silvicultural alternative study at the University of Tennessee Forestry Experiment Station, Oak Ridge, TN. Error bars represent 1 standard error. Uncut = uncut control, 50 = 50 percent basal area retention, 25 = 25 percent basal area retention, 12.5 = 12.5 percent basal area retention, CCC = commercial clearcut, and SCC = silvicultural clearcut.

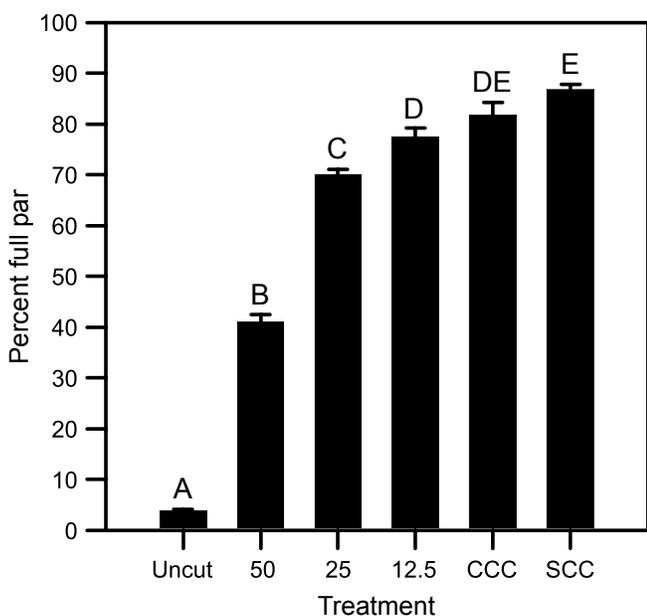


Figure 2—Mean percent full PAR in uncut controls and treatments in 2003 in the silvicultural alternative study at the University of Tennessee Forestry Experiment Station, Oak Ridge, TN. Means with the same letter are not significantly different at  $\alpha = 0.05$ . Error bars represent 1 standard error. Uncut = uncut control, 50 = 50 percent basal area retention, 25 = 25 percent basal area retention, 12.5 = 12.5 percent basal area retention, CCC = commercial clearcut, and SCC = silvicultural clearcut.

No significant differences in macronutrients were detected between treatments. There was a slight trend toward greater amounts of nitrate in the treatment plots than in the uncut controls, but variability between blocks in nitrate levels was very high (fig. 4).

Results for mean percent herbaceous and woody cover measured above each planted oak seedling with a densiometer in September, 2003, revealed that the proportion of percent cover overtopping oak seedlings comprised of herbaceous species generally increased with decreasing levels of basal area (table 1). A mean value of 0 percent herbaceous cover overtopped planted oak seedlings in the uncut controls, and the greatest mean percent cover of herb species occurred in the CCC treatment. Of the herbaceous vegetation overtopping the northern red oak seedlings in this study, 54 percent was fireweed (*Erechtites hieracifolia* L.), 38 percent was horseweed (*Erigeron canadensis* L.), and the other 8 percent was either pokeweed (*Phytolacca americana* L.) or wild lettuce (*Lactuca* spp. L.). The density of woody competitors 0 to 50 cm tall in the vicinity of planted oak seedlings was significantly greater in the 50 percent BAR treatment than in the uncut controls (table 2). However, no significant differences were detected between the treatments and controls in the density of woody competitors in the 51 to 149 cm and >150 cm size classes.

The amount of basal area retained within treatments was highly correlated with percent full PAR measured in the understory of treatments. Results of regression analysis indicated that nearly 91 percent of the variation in the percent full PAR received within a given treatment can be explained by the basal area of that treatment (fig. 5). Actual PAR values change from minute to minute and across the growing season, but mean PAR values calculated across all 4 measurement months

**Table 1—Mean percent cover of woody vegetation, herbaceous vegetation, and open sky above planted oak seedlings by treatment in 2003 in the silvicultural alternative study at the University of Tennessee Forestry Experiment Station, Oak Ridge, TN**

Treatment <sup>a</sup>	Woody vegetation	Herbaceous vegetation	Open sky
----- percent cover -----			
Control	88	0	12
50 % BAR	35	1	64
25 % BAR	17	7	76
12.5 % BAR	27	5	68
CCC	10	12	78
SCC	6	5	89

<sup>a</sup> BAR = basal area retention; CCC = commercial clearcut; SCC = silvicultural clearcut.

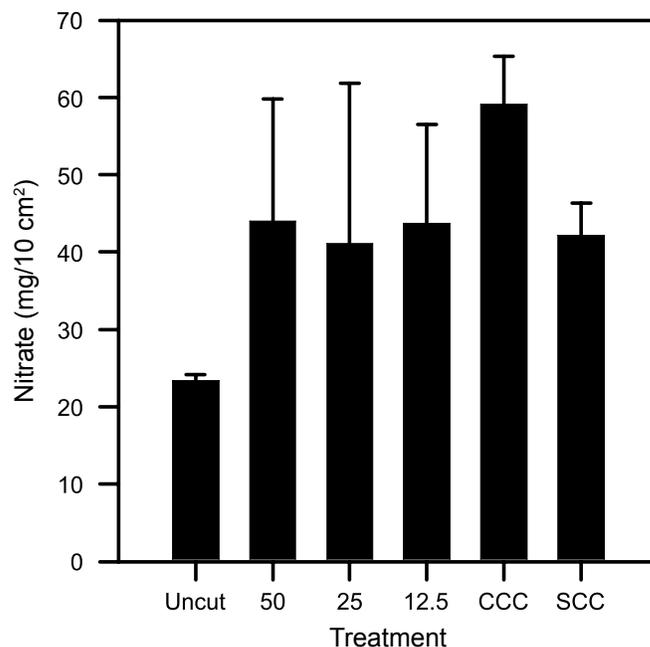


Figure 4—Mean amounts of nitrate in uncut controls and treatments in 2003 in the silvicultural alternative study at the University of Tennessee Forestry Experiment Station, Oak Ridge, TN. Error bars represent 1 standard error. Uncut = uncut control, 50 = 50 percent basal area retention, 25 = 25 percent basal area retention, 12.5 = 12.5 percent basal area retention, CCC = commercial clearcut, and SCC = silvicultural clearcut.

**Table 2—Mean density of woody stems in the immediate vicinity of planted oak seedlings by treatment and height class in 2003 in the silvicultural alternative study at the University of Tennessee Forestry Experiment Station, Oak Ridge, TN**

Treatment <sup>a</sup>	Height class		
	0-50 cm	51-149 cm	> 150 cm
----- stems/ha -----			
Control	56,582 (6,856) <sup>b</sup> B <sup>c</sup>	4,459 (1,505)A	18,843 (4,465)A
50% BAR	130,149 (2,4571)A	5,308 (2,131)A	9,289 (3,388)A
25% BAR	114,225 (16,657)AB	7,113 (2,791)A	10,616 (2,955)A
12.5% BAR	114,756 (8,495)AB	5,839 (1,860)A	6,369 (1,657)A
CCC	120,173 (12,827)AB	4,618 (1,805)A	6,900 (3,909)A
SCC	115,180 (3,996)AB	5,626 (1,914)A	6,369 (1,657)A

<sup>a</sup> BAR = basal area retention; CCC = commercial clearcut; SCC = silvicultural clearcut.

<sup>b</sup> One standard error is presented in parentheses.

<sup>c</sup> Within height classes, means with the same letter are not significantly different at  $\alpha = 0.05$ .

were 46, 429, 798, 907, 941, and 1,085  $\mu\text{moles m}^{-2} \text{s}^{-1}$  in the uncut controls, 50 percent BAR, 25 percent BAR, 12.5 percent BAR, CCC, and SCC treatments, respectively.

## DISCUSSION AND CONCLUSIONS

The result of significant increases in percent full PAR with increased levels of basal area removal was intuitive as a reduction in canopy cover and leaf area that would intercept incoming PAR should accompany removal of basal area.

However, the most substantial differences in percent full PAR existed primarily between the controls and overstory treatments with greater canopy cover (that is, 50 percent BAR, and 25 percent BAR). Increases in mean percent full PAR were relatively minor, and some variances were greater in treatments with < 25 percent BAR. Further, mean percent full PAR in CCCs was not significantly different from that in 12.5 percent BAR, or that in SCCs. The fact that mean percent full PAR did not reach 100 percent in either the CCCs or SCCs is likely a

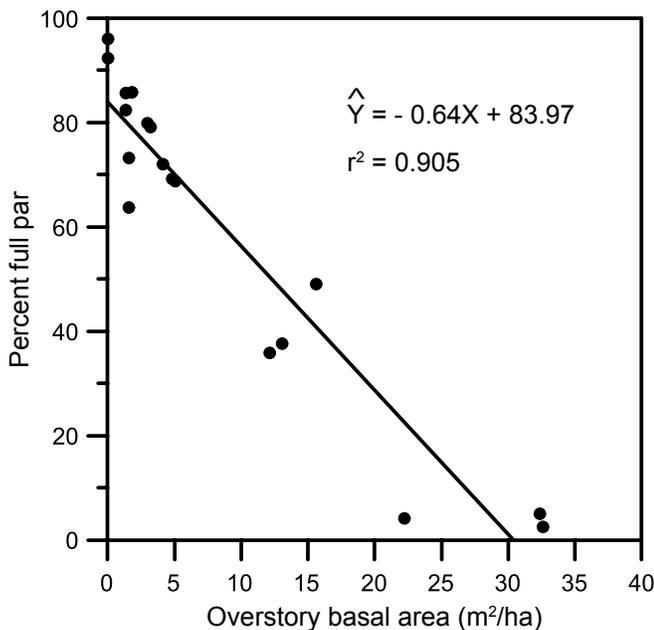


Figure 5—Scatter plot of percent full PAR versus overstory basal area with regression line and equation based on measurements obtained in uncut controls and treatments in 2003 in the silvicultural alternative study at the University of Tennessee Forestry Experiment Station, Oak Ridge, TN.

function of the height above the ground at which PAR measurements were taken and the influence of stump sprouts, small residual stems, and tall herbaceous vegetation that occurred in the clearcuts. PAR was not measured at various heights to obtain vertical profiles in PAR in this study, but it is very likely that seedlings smaller than the planted oaks receive < 86.7 percent full PAR. Horizontal patchiness in the regeneration layer of clearcuts is fairly common 1 to 2 years after cutting, and the greater variance in percent full PAR observed in the 12.5 percent BAR and CCCs was likely due to variability in the distribution of sprout clumps, residual stems, and effects of down wood and seedbed conditions on the germination and growth of herbaceous and woody vegetation.

The lack of significant differences in percent volumetric soil moisture could have resulted from above-average precipitation during the 2003 growing season and perhaps from variability in soil moisture between blocks. Although differences were not statistically significant, the lower mean value for soil moisture in the uncut controls than in the treatments is consistent with previous research in which cutting led to short-term increases in soil moisture. Using the same instrument and measurement protocol on drier, coarse-textured soils in northern Lower Michigan, Buckley and others (1998) demonstrated significantly greater volumetric soil moisture in partially cut and clearcut northern red oak and red pine stands over the first two growing seasons following treatment implementation.

It is likely that high variability in macronutrients within and between blocks was responsible for the lack of significant differences in measured amounts of macronutrients between treatments. The inherent patchiness in down wood, litter, forest floor disturbance, and other factors influencing nutrient dynamics probably contributed to the high variability in nitrate and other macronutrients within the treatments as opposed

to the controls. Although no differences were significant and variances were high, the trend toward greater amounts of nitrate in the treatments than in the controls is consistent with the greater decomposition and nitrogen mineralization that might be expected in recently harvested stands (Vitousek and Matson 1984). A more intensive sampling effort may have revealed statistically significant differences between treatments and controls for some macronutrients, and it is clear that in conjunction with variability in light, patchiness in nutrients may contribute to within-treatment variation in the performance of tree seedlings and saplings.

Results for herbaceous and woody competitors in the immediate vicinity of planted oak seedlings suggest that release of regenerating seedlings from competition with overstory trees for resources is at least partially attenuated by increased competition with herbs and woody stems in the regeneration layer. In this study, fireweed and horseweed were very abundant in treatments with little or no canopy cover, and the development of these species over the growing season was reflected in decreases in percent full PAR measured immediately above planted oaks within these treatments from May to August. In fact, many planted oaks received 100 percent full PAR in May and June in treatments with little or no residual basal area but were overtopped by fireweed and horseweed by the end of the growing season. Whether these species or completely different suites of herbaceous species develop in treatments with low residual basal area depends on species composition of the seed bank and local seed sources. It can be argued that differences in the composition of herb species could result in different outcomes of a regeneration treatment from region to region. The development of the herbaceous layer in response to overstory treatments and competitive effects of different herbaceous species on tree regeneration warrant further investigation.

The significantly greater abundance of woody stems in the 0-50 cm height class in the 50 percent BAR treatment than in the controls and lack of significant differences between the remaining treatments and controls for this size class suggest that increased levels of logging disturbance and perhaps fewer seed sources in treatments with low residual basal area may have offset the positive effects of increased levels of percent full PAR. The lack of significant differences in the density of stems 51 to 149 cm tall and  $\geq 150$  cm tall may have also been due to logging disturbance and an insufficient amount of time for regenerating stems to enter these larger size classes following treatment implementation. Based on follow-up visits to the study sites in 2004 and 2005, this situation is changing rapidly as stump sprouts continue to develop.

The strong relationship between percent full PAR and overstory basal area indicated by the regression results suggests that managers could use this relationship as a guide in selecting an appropriate amount of basal area retention in order to achieve a specified level of percent full PAR in the understory of oak-hickory forests similar to those studied. Percent full PAR and basal area relationships for additional forest types would be useful, although the relationship may be weaker in stands with more complex canopy structure, such as old-growth northern hardwoods. Strong relationships between mean percent full PAR and basal area were demonstrated by Buckley and others (1999) in northern red oak and red pine stands. Slopes of the regression equations varied

with forest type. Due to differences between species in leaf placement and crown architecture (Horn 1971), it is likely that levels of percent full PAR achieved in the understory of stands reduced to a given level of basal area can vary with changes in canopy species composition. Thus, it is possible for the same prescription to result in different levels of PAR across stands differing in composition. The magnitude of these differences warrants further investigation, and additional work in this area is planned.

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## LITERATURE CITED

- Brose, P.H.; Van Lear, D.H.; Keyser, P.D. 1999. A shelterwood-burn technique for regenerating productive upland oak sites in the piedmont region. *Southern Journal of Applied Forestry*. 23: 158-163.
- Buckley, D.S.; Sharik, T.L.; Isebrands, J.G. 1998. Regeneration of northern red oak: positive and negative effects of competitor removal. *Ecology*. 79: 65-78.
- Buckley, D.S.; Isebrands, J.G.; Sharik, T.L. 1999. Practical field methods of estimating canopy cover, PAR, and LAI in Michigan oak and pine stands. *Northern Journal of Applied Forestry*. 16: 25-32.
- Dickson, R.E.; Tomlinson, P.T.; Isebrands, J.G. 2000. Partitioning of current photosynthate to different chemical fractions in leaves, stems, and roots of northern red oak seedlings during episodic growth. *Canadian Journal of Forest Research*. 30: 1308-1317.
- Gardiner, E.S.; Hodges, J.D. 1998. Growth and biomass distribution of cherrybark oak (*Quercus pagoda* Raf.) seedlings as influenced by light availability. *Forest Ecology and Management*. 108: 127-134.
- Horn, H.S. 1971. *The adaptive geometry of trees*. Princeton, NJ: Princeton University Press. 144 p.
- Johnson, P.S.; Dale, C.D.; Davidson, K.R.; Law, J.R. 1986. Planting northern red oak in the Missouri Ozarks: a prescription. *Northern Journal of Applied Forestry*. 3: 66-68.
- Kolb, T.E.; Steiner, K.C. 1990. Growth and biomass partitioning of northern red oak and yellow-poplar seedlings: effects of shading and grass root competition. *Forest Science*. 36: 34-44.
- Lockhart, B.R.; Hodges, J.D.; Gardiner, E.S.; Ezell, A.W. 2003. Photosynthate distribution patterns in cherrybark oak seedling sprouts. *Tree Physiology*. 23: 1137-1146.
- Loftis, D.L. 1990. A shelterwood method for regenerating red oak in the southern Appalachians. *Forest Science*. 36: 917-929.
- Olson, M.G. 2003. Mechanical damage incurred by underplanted northern red oak (*Quercus rubra*) following six overstory treatments and the development of planted northern red oak seedlings under closed canopy: first-year results. M.S. Thesis. Knoxville, TN: University of Tennessee. 77 p.
- Vitousek, P.M.; Matson, P.A. 1984. Mechanisms of nitrogen retention in forest ecosystems: a field experiment. *Science*. 225: 51-52.
- Weigel, D.R.; Johnson, P.S. 2000. Planting red oak under oak/yellow-poplar shelterwoods: a provisional prescription. Gen. Tech. Rep. NC-210. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 16 p.

# USING GROUP SELECTION TO REGENERATE OAKS IN NORTHERN ARKANSAS

Eric Heitzman and John Stephens<sup>1</sup>

**Abstract**—We examined the regeneration dynamics within group selection openings in 12 mature oak-hickory forests in the Ozark Mountains of northern Arkansas. Plots were established in openings harvested in 1991, 1994, 1995, and 1998. Seventy seven percent of the openings were < 0.4 acre, which is the frequently reported minimum opening size for successfully regenerating oaks. Openings were dominated by black cherry (*Prunus serotina* Ehrh.), blackgum (*Nyssa sylvatica* Marsh.), red maple (*Acer rubrum* L.), and flowering dogwood (*Cornus florida* L.). White oak (*Quercus alba* L.) and red oak (*Q. rubra* L. and *Q. velutina* Lam.) density varied widely among study sites but averaged 9 percent. Most oaks were in a free-to-grow position. No oaks were recorded in about one-third of the openings. The future species composition of the openings will probably be more diverse than that of the unharvested portions of the forests studied.

## INTRODUCTION

Successfully regenerating oak species in upland hardwood forests of the Southern and Eastern United States has been a vexing problem for generations of foresters. On many sites, mature oak forests have been replaced by shade tolerant and fire sensitive non-oak species (Abrams 1998, Lorimer 1993). Where adequate oak regeneration has been obtained, cutting methods generally create environmental conditions favorable for shade intolerant and intermediate species. These methods include clearcutting (Sander and Graney 1993), shelterwood (Brose and others 1999, Loftis 1990), and group selection (Murphy and others 1993).

Group selection is a regeneration harvest combined with improvement cutting throughout the stand that promotes an uneven-aged structure (Minckler 1986). Compared to clearcutting and shelterwood, group selection has been less frequently applied to hardwood forests in general and oak forests in particular. One reason for its limited adoption by forest managers may be an uncertainty of how to regulate the harvest and the residual stand structure. Roach (1974) and Nyland (2002) suggest that group selection after the third or fourth harvest becomes difficult to apply because of the increasing number of groups. Miller and others (1995) and Smith (1980) distinguish between group selection, which is regulated by volume and basal area, and patch cutting, for which area control is used.

Despite the limited number of group selection studies established in oak forests, two recommendations have been consistently reported. First, the average diameter of openings should be at least one to two times the height of the surrounding overstory trees (Clark and Watt 1971, Fischer 1981, Law and Lorimer 1989, Miller and others 1995, Minckler 1989, Minckler and Woerheide 1965, Trimble 1973). At least twice the tree height is favored by most authorities. Thus, a circular opening placed among 75-foot-tall trees should be at least 150 feet in diameter and 0.4 acre in size. However, these values would vary by slope and aspect (Fischer 1981, Law and Lorimer 1989). Second, an abundance of well-developed and vigorous oak advance regeneration and/or small stems

with sprouting potential are required prior to harvest (Hill and Dickmann 1988, Johnson and others 2002, McQuilkin 1975, Murphy and others 1993, Weigel and Parker 1995).

In the Ozark Mountains of northern Arkansas, group selection has been practiced, albeit infrequently, by the U.S. Forest Service over the past 15 years. For example, in the Sylamore Ranger District of the Ozark National Forest, 89 oak stands totaling about 3,600 acres are being managed using group selection (Personal communication. Bob Rhodey, Ozark National Forest, Mountain View, AR). However, the structure and species composition of regenerated openings are unknown. Thus, we selected 12 group selection stands on the Sylamore Ranger District for study. The objectives were: (1) to evaluate the level of success in regenerating oaks, and (2) to examine if the density of oak regeneration was influenced by opening size, opening age, and site.

## METHODS

### Study Areas

The 12 study sites are mature white oak (*Quercus alba* L.)-red oak-hickory (*Carya* spp.) forests located in Stone and Baxter Counties in north-central Arkansas. Red oaks include northern red oak (*Q. rubra* L.) and black oak (*Q. velutina* Lam.). Site index is 60 to 70 feet at age 50. Elevations range from 760 to 1,210 feet. Most soils are Noark, Clarksville, and Nixa very cherty silt loams on side slopes and ridgetops (Ward 1983, Ward and McCright 1983).

The study sites were selected from a USDA Forest Service database and shared the following characteristics: oak-hickory forests that had naturally regenerating group selection openings; 20 to 100 acres in size located on the southern part of the Sylamore Ranger District; and site preparation followed harvest by 1 year or less and consisted of: (1) felling unmerchantable oaks to encourage sprouting and (2) hand tool and chemical control of unmerchantable non-oaks. To describe the regeneration dynamics over time, we selected three sites that were harvested in each of the following years: 1991, 1994, 1995, and 1998. No one directly or indirectly involved with this study was present during site preparation

<sup>1</sup> Assistant Professor and Research Specialist, respectively, University of Arkansas, School of Forest Resources, Monticello, AR 71656.

or harvesting. Also, there is no record of the amount of oak advance regeneration in the openings prior to or after the harvests.

### Data Collection and Analysis

In August and December, 2004, and January, 2005, 5 group openings at 11 sites and 4 group openings at 1 site were selected for measurement. All openings were located along or near a main skid trail. A transect was established along the long axis of each opening from one side of the opening to the other. Transects were oriented in a variety of bearings. Three 0.01 acre plots were installed on each transect so that plots fell at 25 percent, 50 percent, and 75 percent of the transect length. In each plot, living trees > 1.0 inch d.b.h. were tallied by species and d.b.h. Oaks were also classified as either free-to-grow or suppressed. The perimeter of every opening was mapped with a global positioning system (GPS) receiver.

Acreage was calculated for every opening from the GPS data. Opening locations were overlaid on digital topographic maps so that the landscape position and aspect of every opening could be examined. Based on this visual examination, openings were classified as either xeric or mesic. Xeric openings were on ridgetops, south-facing slopes, and other dry sites, while mesic openings were in hollows and on north- and east-facing slopes.

Plot data were summarized to describe species composition and stand structure. Simple linear regression was used to explore the relationship between oak density and opening size. Analysis of variance was used to test for differences in oak density by age of the openings. A t-test was used to compare the mean oak density on xeric and mesic sites (SAS Institute 1993). Significance for all analyses was accepted at  $P \leq 0.05$ .

### RESULTS AND DISCUSSION

Seventy seven percent of the group openings were 0.4 acre or less in size. Twenty percent of the openings were 0.4 to 0.6 acre and 3 percent were larger than 0.6 acre. The smallest opening was 0.09 acre and the largest was 0.94 acre.

All 12 study sites had abundant stems per acre (table 1). Tree density ranged from 1,133 to 2,080 stems per acre and

averaged 1,461 stems per acre ( $s=297$ ). Twenty nine tree species were recorded. Of these, black cherry (*Prunus serotina* Ehrh.), blackgum (*Nyssa sylvatica* Marsh.), red maple (*Acer rubrum* L.), and flowering dogwood (*Cornus florida* L.) were dominant. At each site, one of these taxa was the most abundant or second-most abundant species. Combined, their densities ranged from 200 to 986 stems per acre with a mean of 672 stems per acre ( $s=264$ ). In contrast, density of white oak and red oak ranged from 0 to 207 stems per acre and 0 to 133 stems per acre, respectively. Mean white oak density was 83 stems per acre ( $s=70$ ), and red oak was 56 stems per acre ( $s=49$ ). Across all sites, 9 percent ( $s=6$ ) of the trees were oaks. Other important species in some stands included sassafras [*Sassafras albidum* (Nutt.) Nees] and hickory.

Most regeneration was 1 or 2 inches d.b.h. (fig. 1). Not surprisingly, stems 3 to 6 inches d.b.h. were more abundant in the older harvests. Most large trees were black cherry, blackgum, and red maple. Few oaks were larger than 3 inches d.b.h. In spite of this, most oaks were not suppressed. In fact, 71 percent of red oak and 67 percent of white oak were free-to-grow. There was no significant difference ( $P=0.11$ ) in the mean number of oaks among sites cut in 1991 (121 stems per acre), 1994 (133 stems per acre), 1995 (213 stems per acre), and 1998 (76 stems per acre). The low number of trees in the 1998 harvests (fig. 1) probably indicates that not enough time has elapsed for many trees to grow into the 1 inch d.b.h. size class.

There was not a significant linear relationship ( $P=0.52$ ,  $r^2=0.01$ ) between the mean number of oaks in a group opening and the size of the opening. Large openings did not have more oaks than small openings. Nineteen of the 59 total openings, or about one third, had no oaks at all. Similarly, there was no significant difference ( $P=0.33$ ) in the mean number of oaks in openings on xeric (164 stems per acre) and mesic (120 stems per acre) sites.

Our results indicated that group selection openings were dominated by non-oak species 6 to 13 years after harvest. Perhaps the relatively low number of oaks was due to the small opening size, lack of oak advance regeneration, and/or inadequate site preparation after harvesting. For example, over three-fourths of the openings were less than the 0.4 acre

**Table 1—Stems per acre greater than 1 inch d.b.h. in group openings at the 12 study sites located in mature oak-hickory stands in northern Arkansas**

Species	Sites <sup>a</sup>												Mean
	1	2	3	4	5	6	7	8	9	10	11	12	
Red oak	7	7	100	133	40	7	120	53	40	0	113	47	56
White oak	60	27	200	87	120	13	140	207	80	47	0	20	83
Blackgum	87	213	292	193	60	247	493	380	53	107	120	33	190
Black cherry	247	220	50	320	147	233	67	47	407	287	153	93	189
Dogwood	147	380	233	33	40	13	207	67	40	160	7	7	111
Red maple	53	67	200	440	100	33	113	333	413	280	87	67	182
Sassafras	80	73	33	80	53	187	13	33	73	80	0	533	103
Hickory	47	20	117	413	87	33	73	20	53	0	193	53	92
Others	553	413	233	233	533	600	327	940	480	240	620	280	454
Total	1,280	1,420	1,458	1,933	1,180	1,367	1,553	2,080	1,640	1,200	1,293	1,133	1,461

<sup>a</sup> Sites 1-3 harvested in 1991; sites 4-6 harvested in 1994; sites 7-9 harvested in 1995; and sites 10-12 harvested in 1998.

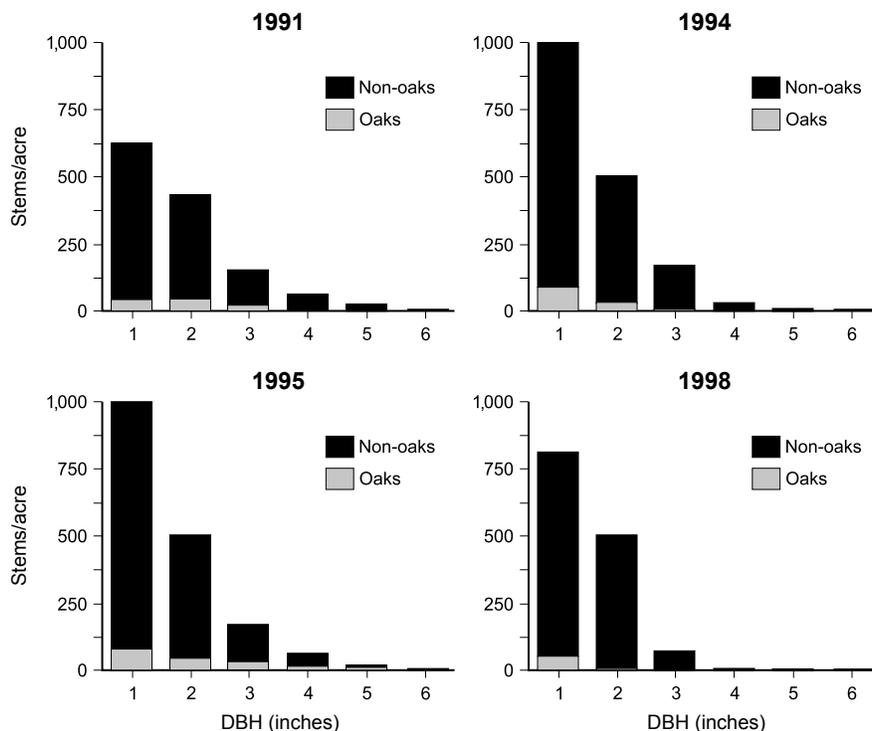


Figure 1—Diameter distribution of trees in group openings harvested in 1991, 1994, 1995, and 1998 in mature oak-hickory stands in northern Arkansas.

minimum recommended for regenerating oaks (Clark and Watt 1971, Fischer 1981, Law and Lorimer 1989, Miller and others 1995, Minckler 1989, Minckler and Woerheide 1965, Trimble 1973). Any or all of these factors could have influenced oak survival and development and confounded the relationships between oak regeneration, opening age, and site (mesic or xeric). Weigel and Parker (1995) noted that some group selection studies, ours included, are limited because they are not established prior to harvesting. This does not permit controlling opening size, and it provides an incomplete picture of regeneration dynamics and the factors influencing regeneration.

Despite the high density of non-oak species, oaks were measured at all sites. In fact, 9 of the 12 sites had at least 67 oaks per acre, 7 sites had over 100 oaks per acre, and 4 sites contained at least 220 oaks per acre. Most of these trees were in a free-to-grow position. It is unclear how these oaks will fare in the future. One possibility is that the combination of small opening size and competition from faster-growing species will eventually limit the ability of oaks to attain upper canopy positions. On the other hand, a number of studies indicate that oaks may not be the predominant species early in stand development but over time can increase in importance relative to competing species (Clatterbuck and Hodges 1988, Johnson and Krinard 1988, Oliver and Larson 1996).

Mature forests in the vicinity of the study sites are dominated by oak and hickory, with other overstory species generally making up < 10 percent of total density and < 5 percent of total basal area (Soucy and others 2004). It seems likely that some oak will survive and perhaps thrive in most of the openings for an extended period. However, given that one-third of the openings we sampled had no oaks, we speculate that the

long-term species composition within the openings will be more diverse in general than that of the surrounding, older forests.

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#### LITERATURE CITED

- Abrams, M.D. 1998. The red maple paradox. *Bioscience*. 48(5): 355-364.
- Brose, P.H.; Van Lear, D.H.; Keyser, P.D. 1999. A shelterwood-burn technique for regenerating productive upland oak sites in the Piedmont region. *Southern Journal of Applied Forestry*. 16(3): 158-163.
- Clark, F.B.; Watt, R.F. 1971. Silvicultural methods for regenerating oaks. In: *Oak symposium proceedings*. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 37-43.
- Clatterbuck, W.K.; Hodges, J.D. 1988. Development of cherrybark oak and sweetgum in mixed, even-aged bottomland stands in central Mississippi, USA. *Canadian Journal of Forest Research*. 18(1): 12-18.
- Fischer, B.C. 1981. Designing forest openings for the group selection method. In: Barnett, J.P., ed. *Proceedings of the first biennial southern silvicultural research conference*. Gen. Tech. Rep. SO-34. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 274-277.
- Hill, J.P.; Dickmann, D.I. 1988. A comparison of three methods for naturally reproducing oak in southern Michigan. *Northern Journal of Applied Forestry*. 5(2): 113-117.

- Johnson, R.L.; Krinard, R.M. 1988. Regeneration in small and large sawtimber sweetgum-red oak stands following selection and seed tree harvest: 23-year results. *Southern Journal of Applied Forestry*. 7(4): 176-184.
- Johnson, P.S.; Shifley, S.R.; Rogers, R. 2002. The ecology and silviculture of oaks. New York, NY: CABI Publishing. 503 p.
- Law, J.R.; Lorimer, C.G. 1989. Managing uneven-aged stands. In: Clark, F.B.; Hutchinson, J.G., eds. *Central hardwood notes*. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 6.081-6.086.
- Loftis, D.L. 1990. A shelterwood method for regenerating red oak in the southern Appalachians. *Forest Science*. 36(4): 917-929.
- Lorimer, C.G. 1993. Causes of the oak regeneration problem. In: Loftis, D.L.; McGee, C.E., eds. *Oak regeneration: serious problems, practical solutions: Symposium proceedings*. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 14-39.
- McQuilkin, R.A. 1975. Growth of four types of white oak reproduction after clearcutting in the Missouri Ozarks. Res. Pap. NC-116. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 5 p.
- Miller, G.W.; Schuler, T.M.; Smith, H.C. 1995. Method for applying group selection in central Appalachian hardwoods. Res. Pap. NE-696. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 11 p.
- Minckler, L.S. 1986. Who really understands group selection? *Journal of Forestry*. 84 (4): inside back cover.
- Minckler, L.S. 1989. Intensive group selection silviculture in central hardwoods after 40 years. In: Rink, G.; Budelsky, C.A., eds. *Proceedings of the seventh central hardwood forest conference*. Gen. Tech. Rep. NC-132. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 35-39.
- Minckler, L.S.; Woerheide, J.D. 1965. Reproduction of hardwoods 10 years after cutting as affected by site and opening size. *Journal of Forestry*. 63(2): 103-107.
- Murphy, P.A.; Shelton, M.G.; Graney, D.L. 1993. Group selection-problems and possibilities for the more shade-intolerant species. In: Gillespie, A.R.; Parker, G.R.; Pope, P.E.; Rink, G., eds. *Proceedings of the ninth central hardwood forest conference*. Gen. Tech. Rep. NC-161. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 229-247.
- Nyland, R.D. 2002. *Silviculture: concepts and applications*. New York, NY: McGraw-Hill. 682 p.
- Oliver, C.D.; Larson, B.C. 1996. *Forest stand dynamics*. New York, NY: John Wiley and Sons, Inc. 520 p.
- Roach, B.A. 1974. What is selection cutting and how do you make it work: what is group selection and where can it be used. AFRI Miscellaneous Report No. 5. State University of New York, College of Environmental Science and Forestry. 9 p.
- Sander, I.L.; Graney, D.L. 1993. Regenerating oaks in the central states. In: Loftis, D.L.; McGee, C.E., eds. *Oak regeneration: serious problems, practical solutions: Symposium proceedings*. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 174-183.
- SAS Institute. 1993. *SAS/ETS user's guide*. Version 6, 2<sup>d</sup> ed. Cary, NC: SAS Institute, Inc. 1022 p.
- Smith, H.C. 1980. An evaluation of four uneven-age cutting practices in central Appalachian hardwoods. *Southern Journal of Applied Forestry*. 4(4): 193-200.
- Soucy, R.; Heitzman, E.; Spetich, M.A. 2004. Age distribution of oak forests in north-central Arkansas. In: Spetich, M.A., ed. *Upland oak ecology symposium: history, current conditions, and sustainability*. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 53-56.
- Trimble, G.R. 1973. The regeneration of central Appalachian hardwoods with emphasis on the effects of site quality and harvesting practice. Res. Pap. NE-282. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 14 p.
- Ward, L.B. 1983. *Soil survey of Stone County, Arkansas*. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 152 p.
- Ward, L.B.; McCright, R.T. 1983. *Soil survey of Baxter and Marion Counties, Arkansas*. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 136 p.
- Weigel, D.R.; Parker, G.R. 1995. Tree regeneration following group selection harvesting in southern Indiana. In: Gottschalk, K.W.; Fosbroke, S., eds. *Proceedings of the tenth central hardwood forest conference*. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 316-325.

# STUMP SPROUT DOMINANCE PROBABILITIES OF FIVE OAK SPECIES IN SOUTHERN INDIANA 15 YEARS AFTER CLEARCUT HARVESTING

Dale R. Weigel, Daniel C. Dey, and Chao-Ying Joanne Peng<sup>1</sup>

**Abstract**—Oak stump sprouts are vital to sustaining oak's presence and long-term dominance when regenerating oak-, mixed-hardwood forests. A study was initiated on the Hoosier National Forest in southern Indiana in 1987 to predict the sprouting potential and dominance probability of oaks. Before clearcutting, we sampled 2,188 trees of 5 oak species: white oak (*Quercus alba* L.), chestnut oak (*Q. prinus* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), and northern red oak (*Q. rubra* L.). Measurements were taken during 15 years to develop sprouting and dominance probability models. A dominant oak was one that had 1 or more sprouts per stump in the dominant or codominant crown class 15 years after clearcutting. We used logistic regression to develop models for estimating dominance probabilities of the five species. Two models were developed that predict future sprout dominance based on a preharvest stand inventory, and six models were developed based on postharvest measurements of stump sprouts and competing vegetation.

## INTRODUCTION

Oaks are important for timber, wildlife food, and stand biodiversity. Oak regeneration continues to be a problem (Lorimer 1983, 1989). Oak advanced reproduction has been considered the main source of stems for the future forest (Sander and others 1984, Sander and others 1976). One component of the future stand is oak stump sprouts, often-overlooked because of the limited information about the percent of oak stumps that sprout and produce competitively successful oak stump sprouts. Thus, predicting the success or dominance of stump sprouts following overstory removal is important for understanding the role of stump sprouts for regenerating oaks.

Early research showed that parent tree age, diameter, and site quality were significant predictors of stump sprouting (Roth and Hepting 1943). In Missouri, parent tree age, stump diameter, and site index were important predictors of oak stump sprouting (Dey and others 1996, Johnson 1977). In northern lower Michigan, parent tree age and stump diameter were important predictors of stump sprouting for white oak (*Quercus alba* L.) and black oak (*Q. velutina* Lam.) (Bruggink 1988). Diameter breast height (d.b.h.) was a significant predictor for white, black, northern red (*Q. rubra* L.), and chestnut oak (*Q. prinus* L.) in Tennessee (Mann 1984).

Our objectives were to determine significant predictors of oak stump sprouting in southern Indiana and to develop dominance probability models for oaks that permit the forest manager to predict the amount of dominant or codominant oak stump sprouts in future stands. Two different types of models were developed to provide the forest manager the ability to predict dominance probability when either preharvest or postharvest data are available.

## METHODS

### Study Sites

The study was conducted on the Hoosier National Forest in south central Indiana. Nine stands scheduled to be clearcut were selected for measurement. There were 3 stands in each of 3 age classes: 71-90, 91-110, and 110+. Harvesting was

done between October 1987 and May 1989. In any given year, it was not possible to determine what season (growing or dormant) individual stems were harvested, because harvesting occurred over two seasons. For a complete discussion of the study sites, measurements, model building, and data analysis see Weigel and Peng (2002).

### Measurements

Prior to harvest, 0.04-ha plots were established along transects in the nine stands. We inventoried and tagged 1,371 white oak, 180 chestnut oak, 399 black oak, 130 scarlet oak (*Q. coccinea* Muenchh.), and 108 northern red oak > 4.0 cms d.b.h. on the plots. Measurements included d.b.h. on all trees and heights and ages of selected trees used for site index determination. Postharvest measurements were completed 1, 5, 10, and 15 years after clearcutting. First-year measurements included aging the parent tree by counting rings on the stump surface and noting if any sprouts were present. Fifth- and 10<sup>th</sup>-year measurements included recording the number of sprouts and the height of tallest sprout. Tenth-year measurements also included recording the crown class. At year 15, we remeasured surviving oak stump sprouts and recorded the number of sprouts and the height, crown class, and d.b.h. of the tallest sprout.

Each stand was subdivided into smaller units that were uniform in aspect (north, 315°-135°; south, 136°-314°) and slope (ridge, upper slope, lower slope, and bottom). The mean height of the competition was computed for each of these units by averaging the heights of measured dominant or codominant competition within 1 m of selected stumps. The mean height of competition was used to determine if a stump sprout at years 5 and 10 was competitively successful, which it was if its height equaled or exceeded 80 percent of the mean height of the competition for the individual unit. This was done because stand crown closure does not happen in the first 10 years, so the traditional concept of crown class (Smith and others 1997) is not useful in determining the social position, or competitiveness, of tree reproduction. At age 15, oak sprout success was determined by its crown class position. This measure of sprout potential, success, or competitiveness

<sup>1</sup> Forester, USDA Forest Service, North Central Research Station, Bedford, IN 47421; Research Forester, USDA Forest Service, North Central Research Station, Columbia, MO 65211; and Professor, Indiana University, Bloomington, IN 47405, respectively.

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is embodied in the concept of dominance probability (Spetich and others 2002). By year 15, crown closure had occurred, and the use of crown class would provide meaningful success rates.

### Data Analysis

We used logistic regression for modeling the dominance probability of oak stump sprouts based on the above definition of a successful, competitive, or dominant sprout, i.e., that the main sprout was at least 80 percent of the mean competition height at stand ages 5 and 10; or that the oak sprout was in the dominant or codominant crown class at age 15.

The five-step model building approach suggested by Hosmer and Lemeshow (2000) was used. We used the maximum likelihood method implemented in PROC LOGISTIC of SAS version 9.1 (SAS Institute Inc. 2004) to perform the logistic modeling.

Two different types of models were developed. The first type of model used preharvest measurements and therefore was not dependent on sprouting success at years 1, 5, or 10. The second type of model did not use preharvest data and consequently was dependent on sprouting success at years 1, 5, or 10.

Because the first type of model is not conditioned on stump sprouting status at years 1, 5, or 10, the model is useful when preharvest measurements can be made. Thus probability estimates for year 15 can be obtained for the stand before harvest. The same dependent variable and independent variables for year 15 were used as in the 1, 5, or 10 year models (Weigel and Peng 2002). The dependent variable was presence of a dominant or codominant stump sprout 15 years after the parent stem was harvested. The independent variables were species, parent tree age, d.b.h., natural log of d.b.h., site index, natural log of site index, and interactions between two or more of these independent variables.

Previous research emphasized developing preharvest models, which are not useful for evaluating regeneration after harvesting. To accommodate the need for predicting oak stump sprout performance after harvest, the postharvest models were developed. Postharvest models estimate dominance probabilities of stems at age 15 from stumps that had at least 1 live sprout at age 1, 5, or 10. These models used the same dependent variable as in the preharvest models, but the number of independent variables was reduced so that only stump diameter, species, and site index were required. These models were

developed with the understanding that foresters would be examining the harvested stands at 1, 5, or 10 years after harvest, and thus they would not have preharvest tree age or d.b.h. information.

The species were grouped into the white oak group and the red oak group for both types of models. The white oak group consisted of white and chestnut oaks while the red oak group consisted of northern red, black, and scarlet oaks.

## RESULTS

### Preharvest to Age 15-Year Models

**White oak group**—The best model (model 1 in table 1) included four predictors: species, the interaction of parent tree age with d.b.h., site index, and the natural log of site index.

The overall significance of model 1 reached a Likelihood Ratio chi-square value of 453.0505 which was significant at  $p < 0.0001$  with 4 degrees of freedom. The four predictors were each significant at  $p < 0.05$ . The goodness-of-fit of model 1 was confirmed by the insignificant Hosmer-Lemeshow (H-L) test (chi-square =8.1702,  $p =0.4170$ ) (table 1) (Hosmer and Lemeshow 2000).

The overall correct classification rate based on model 1 was 84.0 percent which was an improvement over the chance level. Model 1 was more successful in classifying stumps that did not produce a dominant or codominant stump sprout than those that did. This observation was supported by the magnitude of specificity (94.9 percent), compared with that of sensitivity (34.9 percent). False positive and false negative rates were 39.9 percent and 13.2 percent, respectively.

Chestnut oak had higher dominance probabilities than white oak for a given tree age, d.b.h., and site quality (fig. 1). For example, when age, d.b.h., and site index were held constant at 50 years, 10 cms, and 18 m, respectively, 93 percent of chestnut oak stumps are expected to produce a dominant sprout compared to only 59 percent of white oak stumps at stand age 15 years. Also, lower quality sites (site index 18 m) had higher dominance probabilities than higher quality sites. For instance, the dominance probability for white oak was 59 percent at site index 18 m compared to 52 percent at site index 22 m. This influence of site quality on sprout dominance has been reported for 10-year-old stands (Weigel and Peng 2002). As in previous years, dominance probabilities decreased as oak trees became older and larger in diameter.

**Table 1—Preharvest models: logistic regression models for estimating the probability that an oak stump sprout will be dominant or codominant at year 15**

Model number	Species	Parameter estimates <sup>a, b</sup>				Model evaluation statistics	
		$b_0$	$b_1$	$b_2$	$b_3$	$\chi^2$	H-L <sup>c</sup>
1	White oak	-77.8896	-0.00148	-2.0931	40.3664	453.0505 ( $p < 0.0001$ )	8.1702 ( $p=0.4170$ )
	Chestnut oak	-75.6726	-0.00148	-2.0931	40.3664		
2	Red and black oaks	0.3237	-0.00060			122.4697 ( $p < 0.0001$ )	10.3071 ( $p=0.2441$ )
	Scarlet oak	1.7248	-0.00060				

<sup>a</sup> Regression models are of the form  $P = [1 + e^{-(b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3)}]^{-1}$ , where  $P$  is the estimated probability that a cut tree will produce a successful (dominant or codominant) stump sprout at age 15;  $X_1$  = (d.b.h. in cms x tree age);  $X_2$  is black oak site index in m (where site index is derived from Carmean and others (1989));  $X_3$  is the natural log of site index.

<sup>b</sup> All parameter estimates differ significantly from zero at  $p < 0.05$ .

<sup>c</sup> Hosmer-Lemeshow goodness-of-fit test (Hosmer and Lemeshow 2000).

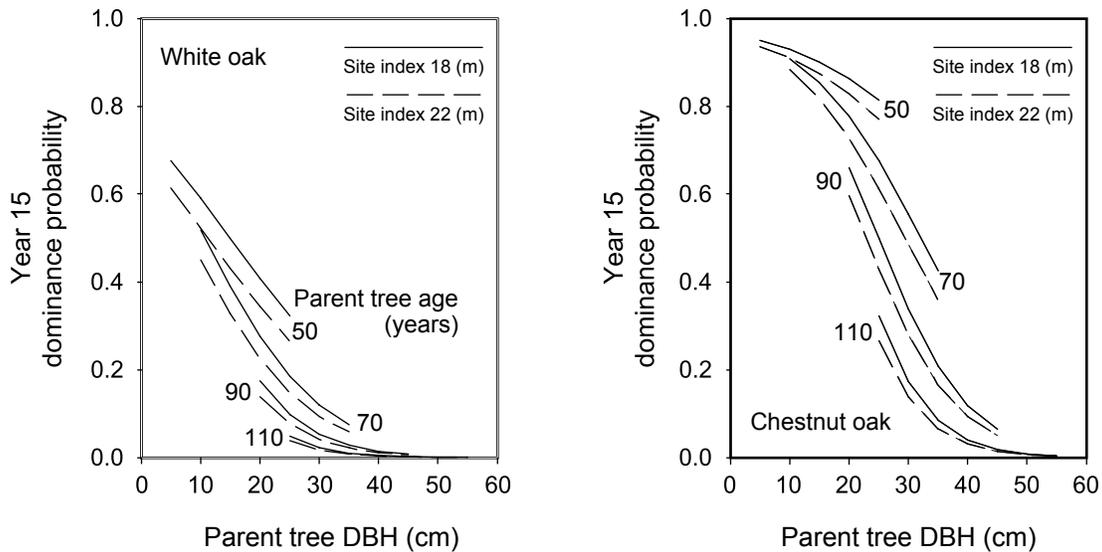


Figure 1—Estimated dominance probability that a white oak or chestnut oak stump will produce a sprout that is either dominant or codominant 15 years after the parent tree is cut in a clearcut regeneration harvest based on parent age, d.b.h., and black oak site index (model 1, table 1).

**Red oak group**—The dominance probabilities for northern red oak and black oak did not differ significantly ( $p > 0.05$ ) at year 15. They did, however, differ significantly from scarlet oak ( $p < 0.05$ ). Therefore, the two species were combined in subsequent analysis. Similar to the white oak model, the best red oak year-15 model (model 2 in table 1) included similar variables that were in the year-10 dominance probability model presented by Weigel and Peng (2002). Species and the interaction of parent tree age with d.b.h. were significantly related to future dominance probability in red oak stump sprouts.

The overall significance of model 2 reached a Likelihood Ratio chi-square value of 122.4697 which is significant at  $p < 0.0001$  with 2 degrees of freedom. The two predictors were each significant at  $p < 0.05$ . The goodness-of-fit of model 2 was confirmed by the insignificant H-L test (chi-square = 10.3071,  $p = 0.2441$ ) (table 1).

The overall correct classification rate based on model 2 was 71.6 percent which was an improvement over the chance level. Model 2 correctly classified stumps that did not produce a dominant or codominant stump sprout more frequently than those that did. This observation was supported by the magnitude of specificity (88.9 percent), compared with that of sensitivity (33.0 percent). False positive and false negative rates were 43.0 percent and 25.2 percent, respectively.

In general, scarlet oak trees had higher stump sprout dominance probabilities than northern red oak and black oak combined (fig. 2). Overall dominance probabilities continued to decline from year 1 (Weigel and Peng 2002) to year 15 since harvest. The continued decline in dominance probability indicated that the three species were not able to compete with the surrounding vegetation. Scarlet oak had higher sprouting probabilities at smaller d.b.h.s and younger ages

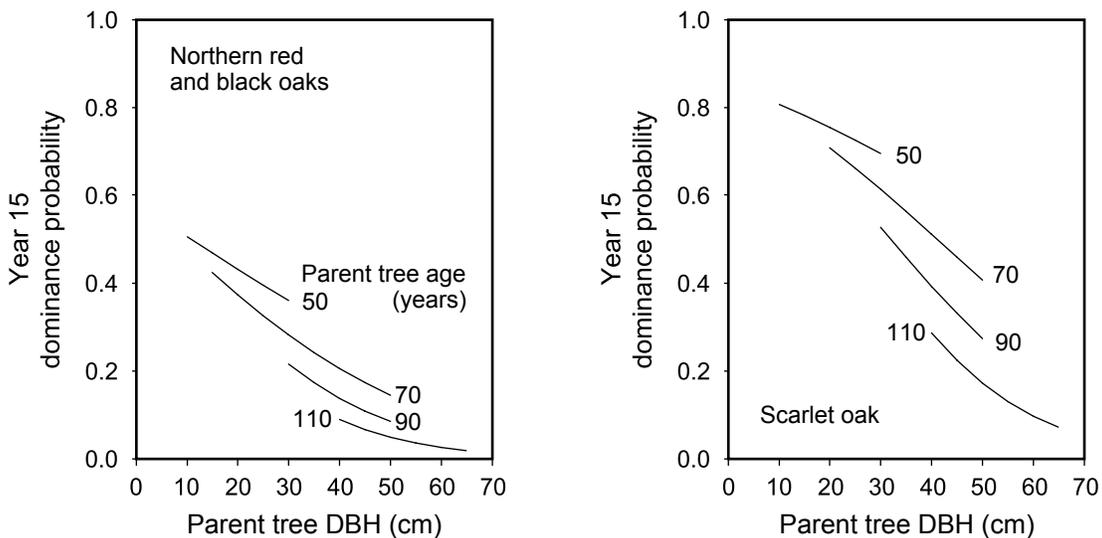


Figure 2—Estimated dominance probability that either a black oak or northern red oak (combined species model 2, table 1), or scarlet oak (model 2, table 1) stump will produce a sprout that is either dominant or codominant 15 years after the parent tree is cut in a clearcut regeneration harvest based on parent tree age and d.b.h.

than northern red and black oak (81 percent at age 50 and 10 cms d.b.h. versus 51 percent at age 50 and 10 cms d.b.h., respectively).

### Postharvest to Age 15 Models

The after harvest models allow foresters to enter a harvested stand 1, 5, or 10 years after harvest to determine the dominance probability at year 15 for those stumps that have sprouts at 1, 5, or 10 years.

#### White Oak Group

**Year 1**—At year 1, the success probabilities for white and chestnut oak were not statistically different so they were combined ( $p > 0.05$ ). The significant predictors were diameter at stump height and the interaction of site index with the natural log of site index (model 3 in table 2).

The overall significance of model 3 reached a Likelihood Ratio chi-square value of 103.1926, which is significant at  $p < 0.0001$  with 2 degrees of freedom. The two predictors each were significant at  $p < 0.05$ . The insignificant H-L test (chi-square = 5.2709,  $p = 0.7283$ ) confirmed the goodness-of-fit of model 3 (table 2).

The overall correct classification rate based on model 3 was 69.4 percent, which was an improvement over the chance level. Model 3 more correctly classified stump sprouts whose sprouts were dominant or codominant at year 15 than those that were no longer dominant or codominant at year 15. This observation was supported by the magnitude of sensitivity (77.3 percent), compared with that of specificity (60.1 percent). False positive and false negative rates were 30.6 percent and 30.7 percent, respectively.

On lower-quality sites, oaks were more likely to produce dominant or codominant stems at year 15 than on higher quality sites (fig. 3A). Dominance and codominance probabilities also were greater for smaller diameter stumps. The best results

were for 10 cm diameter stumps with site index of 18 m (85 percent), while the lowest dominance probability was for sprouts on 60 cm diameter stumps with site index of 22 m (6 percent). The higher quality sites most likely had more and faster growing competition. Consequently, the oaks were unable to compete as well on higher quality sites, compared to lower quality sites.

**Year 5**—Three predictors for model 4 were significant ( $p < 0.05$ ): species, diameter at stump height, and the interaction of site index with the natural log of site index (model 4 in table 2).

The overall significance of model 4 reached a Likelihood Ratio chi-square value of 70.6896, which is significant at  $p < 0.0001$  with 3 degrees of freedom. The goodness-of-fit of model 4 was confirmed by the insignificant H-L test (chi-square = 8.2287,  $p = 0.4115$ ) (table 2).

The overall correct classification rate based on model 4 was 70.4 percent, which was an improvement over the chance level. Model 4 more correctly classified stump sprouts that were dominant or codominant at year 15 than those that were no longer dominant or codominant at year 15. This observation was supported by the magnitude of sensitivity (83.6 percent) compared with that of specificity (44.4 percent). False positive and false negative rates were 25.2 percent and 42.2 percent, respectively.

White oak stump sprouts present at year 5 had higher dominance probabilities at year 15 than corresponding chestnut oak stump sprouts (fig. 3B, 3C). While chestnut oak stumps were more likely to sprout, white oak stumps that did sprout were more successful in becoming dominant or codominant at year 15. As in the year 1 model, the smallest stumps on lower quality sites had the highest dominance rates. The dominance probabilities decreased with increasing parent tree stump diameter and increasing site index.

**Table 2—Postharvest models: logistic regression models for estimating the dominance probability that an oak stump sprout will be in either the dominant or codominant crown class at year 15 when sprouts were present at year 1, 5, or 10 after clearcutting**

Model number	Species and year	Parameter estimates <sup>a, b</sup>				Model evaluation statistics	
		$b_0$	$b_1$	$b_2$	$b_3$	$\chi^2$	H-L <sup>c</sup>
3	White and chestnut oaks, 1	5.1261	-0.0755	-0.0501		103.1926 ( $p < 0.0001$ )	5.2709 ( $p=0.7283$ )
4	White oak, 5	6.6136	-0.0451	-0.0772		70.6896 ( $p < 0.0001$ )	8.2287 ( $p=0.4115$ )
	Chestnut oak, 5	5.8780	-0.0451	-0.0772			
5	White oak, 10	6.7320	-0.0263	-0.0816		55.3027 ( $p < 0.0001$ )	6.1702 ( $p=0.6282$ )
	Chestnut oak, 10	5.8194	-0.0263	-0.0816			
6	Black and red oaks, 1	12.4027	-0.0310		-3.7613	54.4996 ( $p < 0.0001$ )	6.6816 ( $p=0.5713$ )
	Scarlet oak, 1	14.1682	-0.0310		-3.7613		
7	Black and red oaks, 5	4.9552		-0.0704		50.3936 ( $p < 0.0001$ )	12.0004 ( $p=0.1005$ )
	Scarlet oak, 5	6.2045		-0.0704			
8	Black and red oaks, 10	4.8243		-0.0649		40.3735 ( $p < 0.0001$ )	2.5005 ( $p=0.9271$ )
	Scarlet oak, 10	6.1680		-0.0649			

<sup>a</sup> Regression models are of the form  $P = [1 + e^{-(b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3)}]^{-1}$ , where  $P$  is the estimated dominance probability that a cut tree will produce a stump sprout that is successful (dominant or codominant crown class) at age 15:  $X_1$  = stump diameter (cms) 15 cms above ground level;  $X_2$  is black oak site index in m x natural log of site index (where site index is derived from Carmean and others (1989));  $X_3$  is the natural log of site index.

<sup>b</sup> All parameter estimates differ significantly from zero at  $p < 0.05$ .

<sup>c</sup> Hosmer-Lemeshow goodness-of-fit test (Hosmer and Lemeshow 2000).

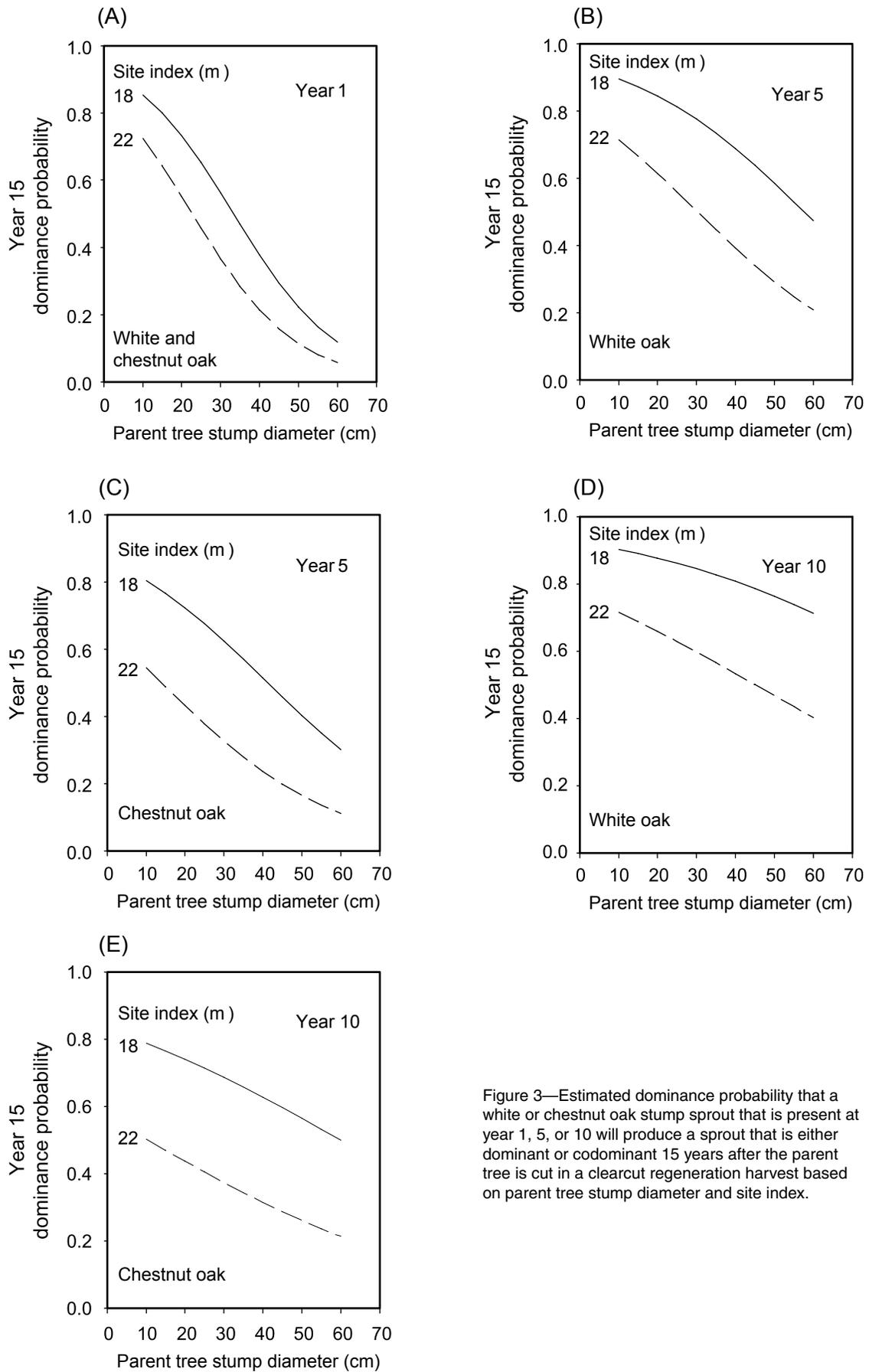


Figure 3—Estimated dominance probability that a white or chestnut oak stump sprout that is present at year 1, 5, or 10 will produce a sprout that is either dominant or codominant 15 years after the parent tree is cut in a clearcut regeneration harvest based on parent tree stump diameter and site index.

**Year 10**—Once again as in the year 5 model, chestnut oak differed significantly ( $p < 0.05$ ) from white oak. The same additional predictors were also significant ( $p < 0.05$ ): diameter at stump height and the interaction of site index with the natural log of site index (model 5 in table 2).

The overall significance of model 5 reached a Likelihood Ratio chi-square value of 55.3027, which is significant at  $p < 0.0001$  with 3 degrees of freedom. The goodness-of-fit of model 5 was confirmed by the insignificant H-L test (chi-square = 6.1702,  $p = 0.6282$ ) (table 2).

The overall correct classification rate based on model 5 was 72.9 percent, which was an improvement over the chance level. Model 5 more correctly classified stump sprouts that were dominant or codominant at year 15 than those that were no longer dominant or codominant at year 15. This observation was supported by the magnitude of sensitivity (92.9 percent), compared with that of specificity (20.6 percent). False positive and false negative rates were 24.6 percent and 47.6 percent, respectively.

For white oak, the dominance or codominance probabilities at year 15 were best predicted by the presence of a stump sprout at year 10 (fig. 3D), followed by that at year 5 (fig. 3B), then year 1 (fig. 3A). The trend was more complex for chestnut oak (fig. 3E). At smaller diameters (< 20 cms), the dominance or codominance probabilities at year 15 were best predicted by the presence of a stump sprout at year 1 (fig. 3A), followed by that at year 5 (fig. 3C), then year 10 (fig. 3E). For larger diameters (> 20 cms), the order reversed. The dominance or codominance probability at year 15 was best predicted by the presence of a stump sprout at year 10 (fig. 3E), followed by that at year 5 (fig. 3C), then year 1 (fig. 3A). Sprouts on smaller stumps were unable to compete as well as sprouts on larger diameter stumps.

### Red Oak Group

**Year 1**—Scarlet oak was significantly different ( $p < 0.05$ ) from black and northern red oak and thus modeled separately.

The significant predictors ( $p < 0.05$ ) beside species were: diameter at stump height and the natural log of site index (model 6 in table 2).

The overall significance of model 6 reached a Likelihood Ratio chi-square value of 59.4996, which is significant at  $p < 0.0001$  with 3 degrees of freedom. The goodness-of-fit of model 6 was confirmed by the insignificant H-L test (chi-square = 6.6816,  $p = 0.5713$ ) (table 2).

The overall correct classification rate based on model 6 was 68.7 percent, which was an improvement over the chance level. Model 6 more correctly classified stump sprouts that were dominant or codominant at year 15 than those that were no longer dominant or codominant at year 15. This observation was supported by the magnitude of sensitivity (73.2 percent), compared with that of specificity (62.7 percent). False positive and false negative rates were 27.6 percent and 36.4 percent, respectively.

Scarlet oak stump sprouts present at year 1 had much higher probabilities that they would be dominant or codominant at year 15 than did northern red or black oak (fig. 4). Scarlet oak's probabilities ranged from 95 percent (10 cms stump diameter, 18 m site index) to 59 percent (70 cms stump diameter, 22 m site index) compared to 77 percent and 20 percent for the combined northern red and black oak over the same range. Stump sprouts on lower quality sites had higher probabilities for dominance or codominance than those on higher quality sites. As with the white oak group (fig. 3A), red oak group stump sprouts (fig. 4) were able to better compete on the lower quality sites than on the higher quality sites.

**Year 5**—Scarlet oak differed significantly ( $p < 0.05$ ) from black and northern red oaks. The other significant predictor ( $p < 0.05$ ) was the interaction of site index with the natural log of site index (model 7 in table 2).

The overall significance of model 7 reached a Likelihood Ratio chi-square value of 50.3936, which is significant at  $p < 0.0001$  with 2 degrees of freedom. The goodness-of-fit of model 7 was

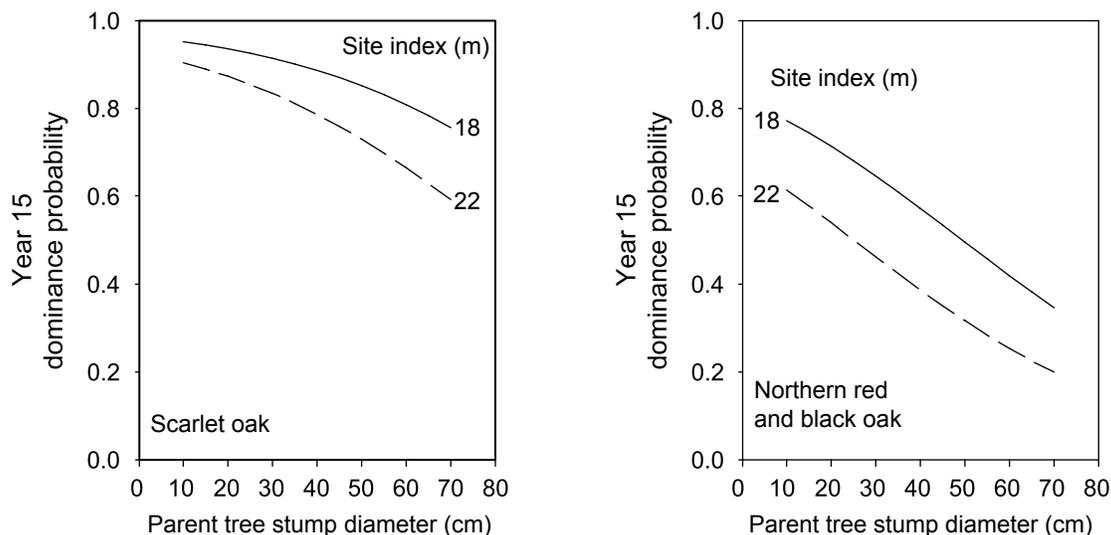


Figure 4—Estimated dominance probability that either a northern red oak or black oak stump sprout, or a scarlet oak stump sprout that is present at year 1 will produce a sprout that is either dominant or codominant 15 years after the parent tree is cut in a clearcut regeneration harvest based on parent tree stump diameter and site index.

confirmed by the insignificant H-L test (chi-square = 12.0004,  $p = 0.1005$ ) (table 2).

The overall correct classification rate based on model 7 was 74.4 percent, which was an improvement over the chance level. Model 7 more correctly classified stump sprouts that were dominant or codominant at year 15 than those that were no longer dominant or codominant at year 15. This observation was supported by the magnitude of sensitivity (87.3 percent), compared with that of specificity (46.7 percent). False positive and false negative rates were 22.2 percent and 36.8 percent, respectively.

With diameter at stump height no longer a significant predictor, the simplified model 7 predicted higher probabilities for scarlet oak than northern red or black oaks combined (table 3). Again, lower quality sites resulted in higher probabilities than higher quality sites.

**Year 10**—As in year 1 and year 5, scarlet oak differed ( $p < 0.05$ ) from black and northern red oak. The other significant predictor ( $p < 0.05$ ) was the interaction of site index with the natural log of site index (model 8 in table 2).

The overall significance of model 8 reached a Likelihood Ratio chi-square value of 40.3735, which is significant at  $p < 0.0001$  with 2 degrees of freedom. The goodness-of-fit of model 8 was confirmed by the insignificant H-L test (chi-square = 2.5005,  $p = 0.9271$ ) (table 2).

The overall correct classification rate based on model 8 was 76.2 percent, which was an improvement over the chance level. Model 8 more correctly classified stump sprouts that were dominant or codominant at year 15 than those that were no longer dominant or codominant at year 15. This observation was supported by the magnitude of sensitivity (87.3 percent), compared with that of specificity (45.8 percent). False positive and false negative rates were 18.5 percent and 43.1 percent, respectively.

Similar to model 7, model 8 was very simple, predicting higher probabilities for scarlet oak than northern red or black oaks combined (table 3). Stump sprouts on lower quality sites performed better than those on higher quality sites. The probabilities for dominance or codominance increased in model 8 from model 7 for any given species and site index. This is a reasonable finding because model 8 was based on a shorter time span than model 7, until year 15. Consequently, the predicted probability that stump sprouts would survive was higher.

**Table 3—The estimated dominance probability that a black, red, or scarlet oak stump sprout present at year 5 or 10 will produce a sprout that is either dominant or codominant 15 years after the parent tree is cut**

Initial year and species	Site index	
	18	22
Year 5		
scarlet oak	0.927	0.805
northern red & black oaks	0.785	0.542
Year 10		
scarlet oak	0.942	0.853
northern red & black oaks	0.810	0.601

## DISCUSSION

The eight models presented in this paper are valuable for predicting the contribution of stump sprouts to forest regeneration. The models allow forest managers to predict the percent of competitive oak stump sprouts 15 years after an even-aged timber harvest. Models 1 and 2 can be used to predict the likelihood of dominant and codominant stump sprouts 15 years after clearcut harvest based on preharvest information. This also permits forest managers to assess the contribution of stump sprouts to the desired stocking of oak advanced reproduction and to adjust stand prescriptions to promote oak advance reproduction by reducing the vigor and abundance of major woody competitors. This analysis highlights the need for developing a prescription for oak underplanting to supplement natural oak advance reproduction where needed (Johnson and others 1986; Weigel and Johnson 1998a, 1998b, 2000).

The remaining six models, models 3 to 8, predict the likelihood of dominant and codominant stump sprouts at year 15 based on their presence at year 1, 5, or 10. Forest managers are then able to assess the need for crop tree release or another type of precommercial thinning to maintain desired stocking of oak. Forest modelers can use these models to better predict and describe the influence of oak stump sprouts on future stands and stand stocking.

Our study differs from many other stump sprout studies by using logistic regression to predict the contribution of stump sprouts to the future stand and hence the sustainability of oak in that stand. This integrates whether a stump produces sprouts, whether those sprouts survive and grow, and how competitive these sprouts are relative to competing vegetation. Another unique quality of this study is that it provides a long-term understanding of stump sprouts. Many other reports are for the first 5 to 10 years. Here we examined the fate of oak stump sprouts at age 15, when crown closure and differentiation are occurring, providing a better indication of the reproduction assuming dominance.

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## LITERATURE CITED

- Bruggink, J.L. 1988. Oak stump sprouting potential on outwash ecosystems of northern lower Michigan. East Lansing, MI: Michigan State University. 109 p. M.S. thesis.
- Carmean, W.H.; Hahn, J.T.; Jacobs, R.R. 1989. Site index curves for forest tree species in the eastern United States. Gen. Tech. Rep. NC-128. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 142 p.
- Dey, D.C.; Johnson, P.S.; Garrett, H.E. 1996. Modeling the regeneration of oak stands in the Missouri Ozark Highlands. Canadian Journal of Forest Research. 26: 573-583.
- Hosmer, D.W.; Lemeshow, S. 2000. Applied logistic regression, second edition. New York, NY: John Wiley & Sons, Inc. 375 p.
- Johnson, P.S. 1977. Predicting oak stump sprouting and sprout development in the Missouri Ozarks. Res. Pap. NC-149. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 11 p.

- Johnson, P.S.; Dale, C.D.; Davidson, K.R.; Law, J.R. 1986. Planting northern red oak in the Missouri Ozarks: a prescription. *Northern Journal of Applied Forestry*. 3: 66-68.
- Lorimer, C.G. 1983. Causes of the oak regeneration problem. In: Loftis, D.; McGee, C.E. eds. Oak regeneration: serious problems, practical recommendations. Symposium proceedings. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 14-39.
- Lorimer, C.G. 1989. The oak regeneration problem: new evidence on causes and possible solutions. *Forest Research Bulletin*. Madison, WI: University of Wisconsin. 31 p.
- Mann, L.K. 1984. First-year regeneration in upland hardwoods after two levels of residue removal. *Canadian Journal of Forest Research*. 14: 336-342.
- Roth, E.R.; Hepting, G.H. 1943. Origin and development of oak stump sprouts as affecting their likelihood to decay. *Journal of Forestry*. 41: 27-36.
- Sander, I.L.; Johnson, P.S.; Rogers, R. 1984. Evaluating oak advance reproduction in the Missouri Ozarks. Res. Paper NC-251. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 16 p.
- Sander, I.L.; Johnson, P.S.; Watt, R.F. 1976. A guide for evaluating the adequacy of oak advance reproduction. Gen. Tech. Rep. NC-23. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 7 p.
- SAS Institute Inc. 2004. SAS/STAT 9.1 user's guide. Cary, NC: SAS Institute Inc. [Not paged].
- Smith, D.M.; Larson, B.C.; Kelty, M.J.; Ashton, P.M. 1997. The practice of silviculture: applied forest ecology. New York: John Wiley & Sons, Inc. 537 p.
- Spetich, M.A.; Dey, D.C.; Johnson, P.S.; Graney, D.L. 2002. Competitive capacity of *Quercus rubra* L. planted in Arkansas' Boston Mountains. *Forest Science*. 48(3): 504-517.
- Weigel, D.R.; Johnson, P.S. 1998a. Planting white oak in the Ozark Highlands: a shelterwood prescription. Tech. Brief NC-5. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.
- Weigel, D.R.; Johnson, P.S. 1998b. Planting northern red oak in the Ozark Highlands: a shelterwood prescription. Tech. Brief NC-6. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.
- Weigel, D.R.; Johnson, P.S. 2000. Planting red oak under oak/yellow-poplar shelterwoods; a provisional prescription. Gen. Tech. Rep. NC-210. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 16 p.
- Weigel, D.R.; Peng, C.J. 2002. Predicting stump sprouting and competitive success of five oak species in southern Indiana. *Canadian Journal of Forest Research*. 32: 703-712.

# LONG-TERM SUCCESS OF STUMP SPROUT REGENERATION IN BALDCYPRESS

Richard F. Keim, Jim L. Chambers, Melinda S. Hughes, Emile S. Gardiner,  
William H. Conner, John W. Day, Jr., Stephen P. Faulkner, Kenneth W. McLeod,  
Craig A. Miller, J. Andrew Nyman, Gary P. Shaffer, and Luben D. Dimov<sup>1</sup>

**Abstract**—Baldcypress [*Taxodium distichum* (L.) Rich.] is one of very few conifers that produces stump sprouts capable of becoming full-grown trees. Previous studies have addressed early survival of baldcypress stump sprouts but have not addressed the likelihood of sprouts becoming an important component of mature stands. We surveyed stands throughout south Louisiana, selectively harvested 10 to 41 years ago, to determine whether stump sprouts are an important mechanism of regeneration. At each site we inventoried stumps and measured stump height and diameter, presence and number of sprouts, sprout height, and water depth. We determined age and diameter growth rate for the largest sprout from each stump from increment cores. The majority of stumps did not have surviving sprouts. Sprouts that did survive were generally vigorous, but rot from stumps often appeared to be spreading into the bases of sprouts. Within the stands studied, baldcypress stump sprouts did not appear to be able to consistently produce viable regeneration sufficient for long-term establishment of well-stocked stands.

## INTRODUCTION

Cut stumps of cypress (*Taxodium* spp.) often produce sprouts from latent or adventitious buds and are some of the very few conifers that produce sprouts capable of becoming full-grown trees (Wilhite and Toliver 1990). This mechanism of regeneration is an attractive option in cypress silviculture, because seedling establishment is often not reliable on the frequently flooded sites where it dominates (Conner and others 1981, Conner and Toliver 1990, Conner and others 1986, Wilhite and Toliver 1990).

Coppice regeneration of baldcypress [*T. distichum* (L.) Rich.] and water tupelo (*Nyssa aquatica* L.) is currently of special interest in Louisiana. There are approximately 345,000 ha of baldcypress-tupelo (*Nyssa* spp.) forest in coastal Louisiana, most of which were clearcut from about 1890 to 1930 (Chambers and others 2005, Conner and Toliver 1990) and subsequently regenerated into even-aged stands. Extensive construction of levees, canals, and other water control structures since the initial logging of these swamps has combined with eustatic sea-level rise and land subsidence to create widespread and pervasive changes of hydrological conditions in these forests (Conner and Day 1988, Pezeshki and others 1990, Salinas and others 1986). Thus, although the second-growth baldcypress-tupelo forests are now commercially attractive for harvesting, many stands may not regenerate naturally by seed. The viability of coppice regeneration is therefore important in designing sustainable silvicultural systems for Louisiana baldcypress and water tupelo regeneration.

Both baldcypress and water tupelo readily produce stump sprouts, though sprouting is less prolific from stumps of older (> 60 years) trees (Mattoon 1915) or from stumps of trees cut in the spring or summer (Williston and others 1980). Stump height, felling method, and harvesting level can also influence the viability of stumps and vigor of sprouts (Ewel 1996, Gardiner and others 2000, Hook and DeBell 1970, Kennedy 1982). Although sprouting usually does occur, some investigators have observed poor growth and survival of stump sprouts. Conner and others (1986) reported that 80 percent of baldcypress stumps sprouted after logging, but fewer than 25 percent retained live sprouts 4 years after harvest. Conner (1988), summarizing a number of studies in Louisiana, found 0 to 23 percent of baldcypress stumps with surviving sprouts after 4 to 7 years. Similarly, Ewel (1996) reported only 17 percent survival of pondcypress (*T. ascendens* Brongn.) stump sprouts a few years after harvests in Florida swamps.

The goal of this research was to evaluate potential of harvested stands to regenerate, become established, and remain productive through stump sprouting. Adequate assessment of the viability of coppice regeneration for regenerating baldcypress-tupelo stands in the context of coastal Louisiana's modified hydrological conditions requires better information about survival and growth of stump sprouts beyond the short time scale of previous research. Therefore, we conducted a regeneration survey of sites harvested 10 or more years earlier. The specific objectives were to (1) determine whether stump sprouts in baldcypress and water tupelo continued to experience the high mortality rates characteristic of the first 7

<sup>1</sup> Assistant Professor, Weaver Brothers Professor of Forestry, and Research Associate, respectively, School of Renewable Natural Resources, Louisiana State University AgCenter, Renewable Natural Resources Building, Baton Rouge, LA 70803; Research Forester, Center for Bottomland Hardwoods Research, USDA Forest Service, Stoneville, MS 38776-0227; Professor, Department of Forestry and Natural Resources, Baruch Institute of Coastal Ecology and Forest Science, Clemson University, Georgetown, SC 29442; Professor, Department of Oceanography and Coastal Sciences, Louisiana State University, 1002-Y Energy, Coast and Environment Building, Baton Rouge, LA 70803; Ecologist, USGS National Wetlands Research Center, Lafayette LA 70506; Associate Research Ecologist, Savannah River Ecology Laboratory, University of Georgia, Aiken, SC 29802; Assistant Professor, School of Renewable Natural Resources, Louisiana State University AgCenter, Baton Rouge, LA 70803; Assistant Professor, School of Renewable Natural Resources, Louisiana State University AgCenter, Baton Rouge, LA 70803; Associate Professor, Southeastern Louisiana University Department of Biological Sciences, Hammond, LA 70402-0343; Postdoctoral Associate, School of Renewable Natural Resources, Louisiana State University AgCenter, Baton Rouge, LA 70803, respectively.

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years after harvest, and (2) assess whether surviving sprouts would be sufficient to form viable new stands.

## METHODS

Suitable sites for this survey were in coastal Louisiana, dominated by baldcypress and water tupelo, and harvested nominally 10 to 50 years earlier. Field experience suggested that rot in baldcypress stumps older than 50 years would be so complete as to prevent assessment of stump sprouting rates. We contacted land owners, foresters, and researchers to find sites meeting these criteria and surveyed 18 sites for stump sprout and seedling regeneration (fig. 1). Information about site history, specific silvicultural goals, and logging methods was incomplete for most sites. Harvesting of most sites consisted mainly of diameter-limit cutting of baldcypress with less cutting of other species. Thus, stumps were mainly larger in diameter than were the remaining overstory trees in most stands.

Sampling at each site was done using a series of transects, 12 m wide and 30 m long, placed irregularly to encompass stumps from the previous harvest. We placed at least 5 transects per site or as many additional transects as necessary to sample 30 stumps per site. In each transect, we measured diameter of all trees and tall shrubs (woody vegetation >1 cm d.b.h.) and counted seedlings of baldcypress and water tupelo that were < 1.37-m tall. Measurements at each stump included height and diameter, depth of water adjacent to the stump, number of live sprouts, diameter and height of the largest sprout, and distance from the stump to the nearest-neighbor canopy tree.

We collected cores from several baldcypress with an increment borer to determine ages and historical growth of trees, saplings, and stump sprouts. We assumed all trees were 3 years old at breast height, and we cored all sprouts near the base within what we assumed to be the first year's growth. We dried, mounted, and sanded cores to aid in visual identification of annual growth rings. After identifying false rings (Young and others 1993) and eliminating them from analysis, we used a measuring stage designed for tree core analysis

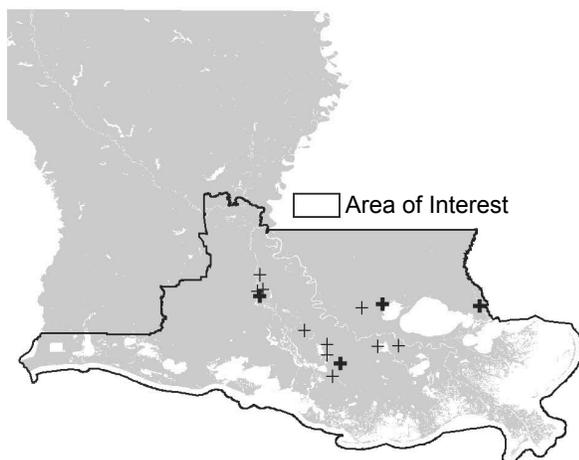


Figure 1—Site locations in south Louisiana for coastal baldcypress–tupelo stump sprouting survey. Bold crosses represent the location of two sites.

under 10 to 100 power magnification to measure ring width to  $\pm 0.1$  mm.

There was a substantial variety of conditions in the sampled sites. Soils were of mineral and organic origin, and hydrological regimes ranged from permanent flooding to seasonal, riverine flooding. Most sites were in blackwater backswamp areas flooded mainly by rain water, but some were near river fronts. Understory vegetation, an indicator of growing-season flooding, ranged from bare ground to thick, emergent aquatic vegetation characteristic of treeless marshes (table 1).

## RESULTS

Across the sites, relative basal area of standing baldcypress ranged from 6.7 to 97.5 percent, and water tupelo ranged from 0 to 93.2 percent (table 1). Baldcypress and tupelo together represented 66 to 100 percent of the stand basal area and exceeded 75 percent on 15 of the 18 sites. Other common woody species included green ash (*Fraxinus pennsylvanica* Marsh.), pumpkin ash (*F. profunda* Bush), swamp red maple [*Acer rubrum* var. *drummondii* (Hook. & Arn. ex Nutt.) Sarg.], buttonbush (*Cephalanthus occidentalis* L.), swamp privet [*Forestiera acuminata* (Michx.) Poir.], Virginia-willow (*Itea virginica* L.), and waxmyrtle [*Morella cerifera* (L.) Small]. A few sites were in mixed cypress-tupelo-bottomland hardwood forests, where common overstory species also included water hickory [*Carya aquatica* (Michx. F.) Nutt.], sugarberry (*Celtis laevigata* Willd.), water locust (*Gleditsia aquatica* Marsh.), water-elm (*Planera aquatica* J.F. Gmel.), black willow (*Salix nigra* Marsh.), and Chinese tallow [*Triadica sebifera* (L.) Small].

Stumps of water tupelo were characteristically too degraded for assessment of stump sprouting potential; the few non-sprouting stumps remaining were barely recognizable and impossible to measure. Additionally, we found live tupelo sprouts at only 2 adjacent sites (16 and 17). Because site history was largely unknown, it was not always clear whether the absence of water tupelo stumps was because (1) it was absent from the stand at the time of logging, (2) it was not cut during logging, or (3) sprout mortality and stump decomposition were rapid. In contrast, baldcypress stumps were intact, easily recognizable, and amenable to analysis for long-term stump sprout survival and growth.

The proportion of baldcypress stumps having live sprouts ranged from 0 to 72 percent by site (median 10 percent; table 2). However, only 2 of the 18 sites had live sprouts on more than 20 percent of stumps. On four sites, no stumps had live sprouts. There was no relationship between time since harvest and sprout survival ( $R^2 = 0.06$ ). The spatial distribution of surviving stump sprouts was uneven, so that some sites had surviving stump sprouts on only one or two sampling transects. We were unable to determine the reason for such variability.

The average diameter of the largest live sprout per stump across all sites was 10 cm, while the average height was 6.8 m. Normalized for sprout age, site-average diameter mean annual increment (MAI) ranged from 0.17 to 0.99 cm yr<sup>-1</sup>, and site-average height MAI ranged from 0.15 to 0.82 m yr<sup>-1</sup>. Site-average stump sprout MAI was moderately correlated to proportional survival ( $R^2 = 0.56$  for height and 0.49 for diameter) (fig. 2A). Sprout MAI was also negatively (but slightly) correlated with age ( $R^2 = 0.37$  for height and 0.27 for diameter; fig. 2B).

**Table 1—Characteristics of the surveyed stands in south Louisiana**

Site	Harvest <sup>a</sup>	Age <sup>b</sup>	Tree	Trees	Rel. basal area <sup>d</sup>		Cypress seedlings	Aquatic vegetation
			basal area		cypress	tupelo		
			(m <sup>2</sup> ha <sup>-1</sup> ) <sup>c</sup>	(ha <sup>-1</sup> ) <sup>c</sup>	----- % -----		ha <sup>-1</sup>	
1	I	20	54.3	331	91	9	953	Scattered
2	P	20	68.9	511	94	4	267	Heavy
3	P	19	50.2	459	68	31	0	Light
4	P	18	74.3	573	88	10	0	Heavy
5	P	24	93.7	1,067	98	3	0	None
6	C	11	47.8	578	75	24	0	Heavy
7	P	11	48.0	729	62	37	0	Heavy
8	P	10	26.5	553	57	9	0	Scattered
9	P	10	52.8	531	67	4	0	None
10	P	24	43.9	457	59	37	40	Light
11	P	17	63.0	852	79	2	0	None
12	P	9	29.2	514	66	0	109	None
13	P	8	57.8	420	78	0	0	None
14	P	1	80.8	694	87	0	0	None
15	P	8	66.0	531	83	1	0	None
16 <sup>e</sup>	C	18	97.5	872	7	93	27	None
17 <sup>e</sup>	I	22	50.9	674	16	85	54	None
18	P	41	58.7	766	56	24	0	None

<sup>a</sup>I=improvement cut; silvicultural thinning. P = partial cut; diameter-limit cut. C = clearcut.

<sup>b</sup>Time between harvest and sampling in 2004.

<sup>c</sup>Includes all currently standing trees and baldcypress cut stumps.

<sup>d</sup>Relative basal area of standing trees only.

<sup>e</sup>Sites dominated by water tupelo; too few baldcypress stumps for analysis.

**Table 2—Baldcypress stump and sprout characteristics for the surveyed stand in south Louisiana**

Site	Harvest <sup>a</sup>	Age <sup>b</sup>	Total	Baldcypress stumps		Sprout MAI	
				with sprouts	%sprouts	Diameter	Height
						cm yr <sup>-1</sup>	m yr <sup>-1</sup>
1	I	20	29	2	6.9	0.46	0.16
2	P	20	30	5	16.7	0.58	0.50
3	P	19	31	6	19.4	0.67	0.46
4	P	18	35	6	17.1	0.92	0.53
5	P	24	64	3	4.7	0.17	0.15
6	C	11	33	24	72.7	0.99	0.75
7	P	11	22	14	63.6	0.99	0.82
8	P	10	25	0	0.0		
9	P	10	36	1	2.8	0.71	0.50
10	P	24	32	2	6.2	0.39	0.33
11	P	17	30	3	10.0	0.81	0.60
12	P	9	30	3	10.0	0.40	0.37
13	P	8	31	4	12.9	0.70	0.56
14	P	11	36	0	0.0		
15	P	8	30	0	0.0		
18	P	41	30	0	0.0		

<sup>a</sup>I = improvement cut; silvicultural thinning. P = partial cut; diameter-limit cut. C = clearcut.

<sup>b</sup>Time between harvest and sampling in 2004.

Time series of annual increment calculated using tree rings show that basal area growth of sprouts greatly exceeded that of trees from the study sites at similar ages (fig. 3A). Mean basal area of sprouts at age 10 was equal to mean basal area of trees currently in the overstory at age 28 and larger than understory trees of seed origin are likely to reach before at

least age 80 (fig. 3B). However, it is important to remember that most of the largest trees were removed from the sites in diameter-limit cuts, so estimates of tree growth from the current overstory likely underestimate trees originating from seed in open-grown stands.

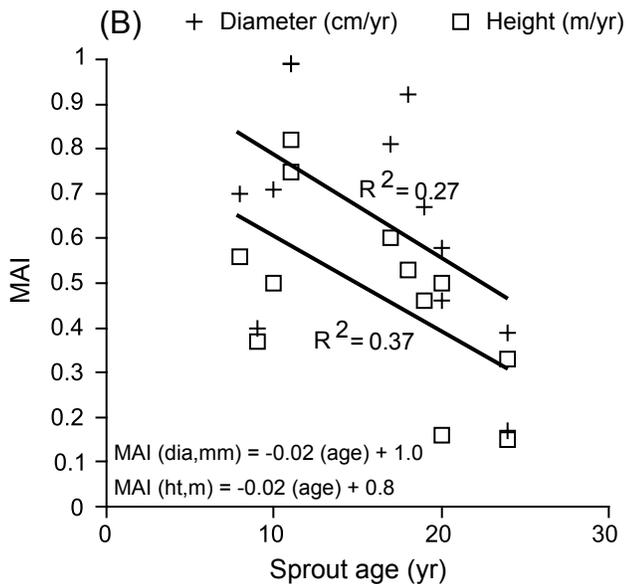
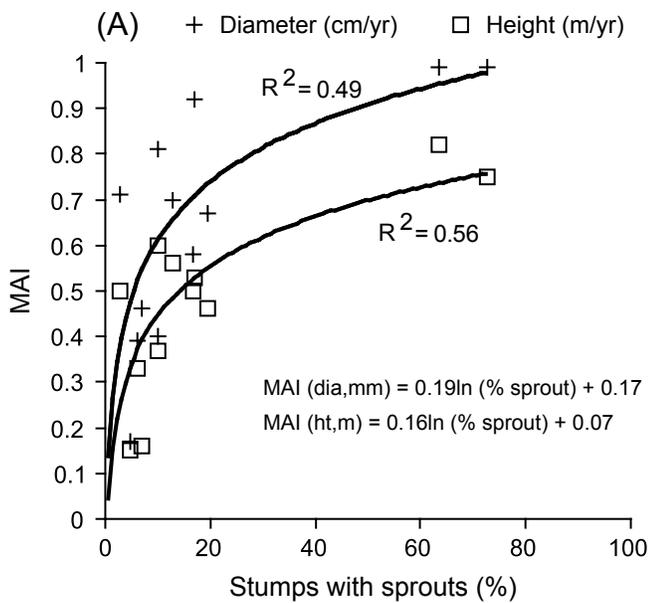


Figure 2—Relationship of baldcypress stump sprout mean annual growth increment (MAI) to stump sprout occurrence (A) and age (B).

Most stumps were at least 40 cm in diameter ( $50 \pm 14$  cm) and nearly 1 m high ( $89 \pm 26$  cm). Within this narrow range of sizes, there were no strong relationships between characteristics of stumps and their sprouting. Bivariate correlation analysis did not reveal strong relationships between stump sprout survival or size and water depth or other site factors.

The condition of the live sprouts was highly variable. However most sprouts were present on stumps with poor callus tissue formation (wound-covering tissue), and many stumps had advanced decay. In many instances, decay was observed in the base of the sprouts themselves. The hollow nature of some sprouts, the narrow band of living tissue on stumps near sprouts, and the position of sprout-stump interface (usually about 1 m above the ground) suggested that some sprouts would likely not survive to be mature trees. In a few cases,

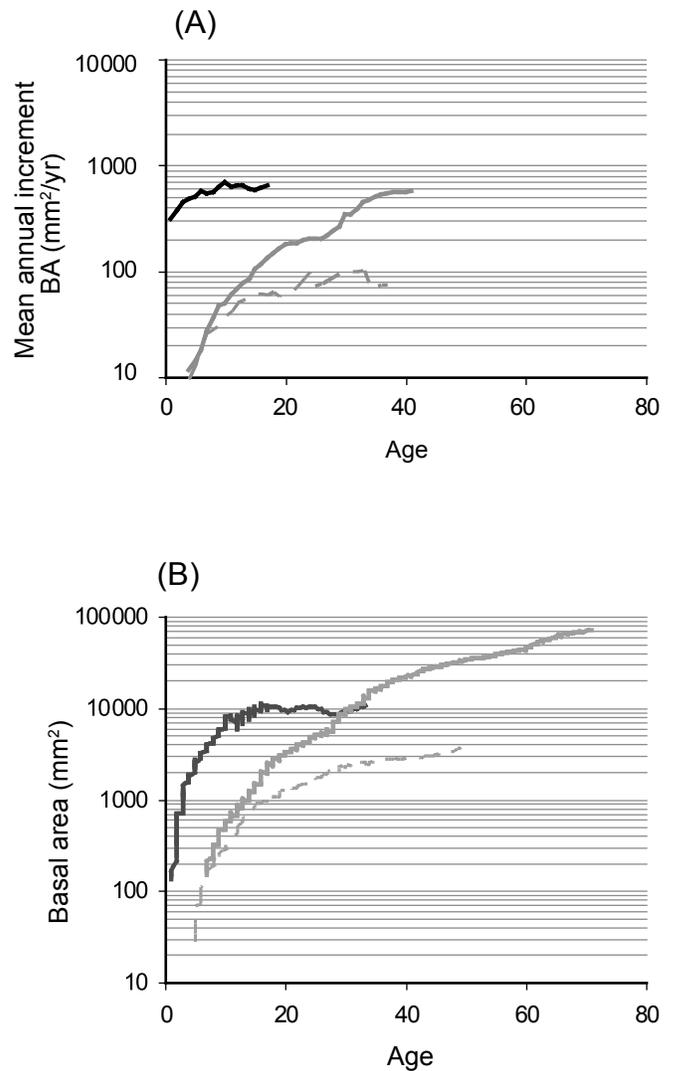


Figure 3—Study mean growth of stump sprouts (black line), overstory trees (solid gray line) and understory trees (dashed gray line) determined from tree ring analyses: (A) basal area mean annual increment; (B) basal area.

almost the entire stump had callused over and, despite minor decay, the sprouts appeared likely to survive to become mature trees.

The number of baldcypress seedlings at each site ranged from 0 to 953 ha<sup>-1</sup> (table 1). Seedlings at permanently flooded sites 1, 2, and 10 were rooted in unconsolidated, floating organic substrates, and we judged them to be ephemeral and unlikely to survive. Seedlings at sites 12, 16, and 17 were rooted in mineral substrates at sites with riverine flooding and may survive. We observed water tupelo seedlings only at sites 16 (44 ha<sup>-1</sup>) and 17 (119 ha<sup>-1</sup>). Overall, seedling regeneration was currently not sufficient for regeneration of any of the sites to baldcypress or water tupelo.

## DISCUSSION

The proportion of baldcypress stumps with surviving sprouts did not change with age since cutting for the range of ages in our data (10 to 41 years). Also, our study-wide median of 10 percent sprout survival is comparable to the range of 0 to 23

percent survival across several sites in Louisiana at ages 4 to 7 reported by Conner (1988). Thus, it appears the mortality rate of sprouts after age 10 is low.

Low and spatially discontinuous sprout survival indicates stump sprouts cannot generally be considered sufficient to establish a new stand or to effectively enhance regeneration. However, this interpretation has several limitations. First, the diameter-limit cutting that dominated our sites is probably not suited to produce either coppice or seedling regeneration of baldcypress or water tupelo, because the amount of light reaching the ground often remained relatively low. Second, the trees cut were primarily sawtimber-sized baldcypress trees of relatively large diameter. Although we found no simple correlation between stump size and sprouting, large stumps have been found elsewhere to be less successful at producing vigorous sprouts compared to smaller stumps.

The high growth rates of sprouts up to age 20 suggests that surviving stump sprouts are capable of producing overstory trees. However, it is not clear whether decay originating in the stumps will allow large sprouts to remain wind firm. We saw no breakage of sprouts, but most sprouts in our study were not in a dominant or open-grown condition that would expose them to high winds.

The poor coppice regeneration and lack of seedlings across the sites suggests that successional processes will move species composition on many of the surveyed stands away from domination by baldcypress and water tupelo. If a site is not excessively flooded during the growing season, it will likely become dominated by shade-tolerant species (Conner and Day 1976). For example, red maple and ash appear poised to dominate the overstory of the somewhat drier survey sites, but with poor quality trees. Preferential harvesting of baldcypress or water tupelo without specific provisions for regeneration will likely accelerate species conversion. Diameter-limit cutting, which was the dominant harvest type on sites we visited, is therefore high-grading and a poor silvicultural practice. The preferred approach is group selection or clearcutting, possibly with preparatory cuts to establish advance regeneration (Meadows and Stanturf 1997, Wilhite and Toliver 1990). The permanent flooding on many of the sites may preclude any natural regeneration, regardless of silvicultural treatment. More research is needed to design effective silvicultural systems for these sites.

## CONCLUSIONS

Regeneration from stump sprouting was insufficient to regenerate the surveyed stands, but mortality of sprouts appeared low after 10 years. Although surviving stump sprouts were vigorous, they were not regularly distributed within stands, and we found no variable to explain variation in stump sprout survival or vigor. The surveyed sites generally were not regenerating to baldcypress–water tupelo forest, either because diameter-limit cutting maintained an overstory sufficient to suppress seedling regeneration or because flooding prevented germination. Silvicultural prescriptions for baldcypress–water tupelo forests must therefore include plans for obtaining natural seedling or artificial regeneration.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Chambers, J.L.; Conner, W.H.; Day, J.W., Jr. [and others]. 2005. Conservation, protection and utilization of Louisiana's coastal wetland forests, final report to the Governor of Louisiana from the science working group on coastal wetland forest conservation and use. 102 p.
- Conner, W.H. 1988. Natural and artificial regeneration of baldcypress [*Taxodium distichum* (L.) Rich.] in the Barataria Basins of Louisiana. Baton Rouge, LA: Louisiana State University. 148 p. Ph.D. dissertation.
- Conner, W.H.; Day, J.W., Jr. 1976. Productivity and composition of a baldcypress–water tupelo site and a bottomland hardwood site in a Louisiana swamp. *American Journal of Botany*. 63: 1354-1364.
- Conner, W.H.; Day, J.W., Jr. 1988. Rising water levels in coastal Louisiana: implications for two forested wetland areas in Louisiana. *Journal of Coastal Research*. 4: 589-596.
- Conner, W.H.; Toliver, J.R. 1990. Long term trends in the bald-cypress (*Taxodium distichum*) resource in Louisiana (U.S.A.). *Forest Ecology and Management*. 33/34: 543-557.
- Conner, W.H.; Gosselink, J.G.; Parrondo, R.T. 1981. Comparison of the vegetation of three Louisiana swamp sites with different flooding regimes. *American Journal of Botany*. 68: 320-331.
- Conner, W.H.; Toliver, J.R.; Sklar, F.H. 1986. Natural regeneration of baldcypress [*Taxodium distichum* (L.) Rich.] in a Louisiana swamp. *Forest Ecology and Management*. 14: 305-317.
- Ewel, K.C. 1996. Sprouting by pondcypress (*Taxodium distichum* var. *nutans*) after logging. *Southern Journal of Applied Forestry*. 20: 209-213.
- Gardiner, E.S.; Russell, D.R., Jr.; Hodges, J.D.; Fristoe, T.C. 2000. Impacts of mechanical tree felling on development of water tupelo regeneration in the Mobile Delta, Alabama. *Southern Journal of Applied Forestry*. 24: 65-69.
- Hook, D.D.; DeBell, D.S. 1970. Factors influencing stump sprouting of swamp and water tupelo seedlings. Res. Pap. SE-57. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 9 p.
- Kennedy, H.E., Jr. 1982. Growth and survival of water tupelo coppice regeneration after six growing seasons. *Southern Journal of Applied Forestry*. 6: 133-135.
- Mattoon, W.R. 1915. The southern cypress. *Agric. Bull.* 272. Washington, DC: U.S. Department of Agriculture. 74 p.
- Meadows, J.S.; Stanturf, J.A. 1997. Silvicultural systems for southern bottomland hardwood forests. *Forest Ecology and Management*. 90: 127-140.
- Pezeshki, S.R.; DeLaune, R.D.; Patrick, W.H., Jr. 1990. Flooding and saltwater intrusion: potential effects on survival and productivity of wetland forests along the U.S. Gulf Coast. *Forest Ecology and Management*. 33/34: 287-301.
- Salinas, L.M.; DeLaune, R.D.; Patrick, W.H., Jr. 1986. Changes occurring along a rapidly submerging coastal area: Louisiana, USA. *Journal of Coastal Research*. 2: 269-284.
- Wilhite, L.P.; Toliver, J.R. 1990. *Taxodium distichum* (L.) Rich. Baldcypress. In: Burns, R.M.; Honkala, B.H., tech. coords. *Silvics of North America*, vol. 1. Conifers. *Agric. Handb.* 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 563-572.
- Williston, H.L.; Shropshire, F.W.; Balmer, W.E. 1980. Cypress management: a forgotten opportunity. *Forestry Report SA-FR 8*. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southeastern Area. 8 p.
- Young, P.J.; Megonigal, P.; Sharitz, R.R.; Day, F.P. 1993. False ring formation in baldcypress (*Taxodium distichum*) saplings under two flooding regimes. *Wetlands*. 13: 293-298.

# A STUDY OF THE EARLY FRUIT CHARACTERISTICS OF PONDBERRY

K.F. Connor,<sup>1</sup> G.M. Schafer, J. Donahoo,<sup>2</sup> M. Devall, E. Gardiner, T. Leininger, D. Wilson, N. Schiff, P. Hamel,<sup>3</sup> and C. Echt<sup>4</sup>

**Abstract**—Pondberry [*Lindera melissifolia* (Walt.) Blume] is an endangered, dioecious, clonal shrub that grows in forested wetlands in the Southeastern United States. Because pondberry is endangered, presence of this plant could limit silvicultural options available to managers of public lands. Interest in pondberry has focused on the clonal nature of this species, and little has been published about the early physical and biochemical characteristics of the fruit as they mature. Four fruits from each of 40 plants were subsampled on a 30-day schedule after flower anthesis. Three months (90 days) after flowering, a complete seed had formed within the fruit. Of the total fruit weight (average 0.228 g), seed tissue accounted for 33 percent of the mass gained from 2 months (60 days) after flowering. Preliminary lipid analysis revealed the presence of myristic, palmitic, stearic, oleic, linoleic, and linolenic fatty acids; lauric acid was not found in any of the early seed samples but was plentiful at later stages in seed development. Preliminary results from seed longevity and persistence studies indicate that seeds without pulp and seeds left on the soil surface germinate more rapidly than buried seeds or those with the pulp intact.

## INTRODUCTION

Pondberry [*Lindera melissifolia* (Walt.) Blume] is an endangered, dioecious, deciduous shrub that grows in southeastern forested wetlands in seasonally flooded areas, or along the margins of sinks and ponds. Stands consist of numerous stems (Devall 2004). The species has probably always been fairly rare in occurrence (Radford and others 1968). Pondberry stems can flower when only 2 or 3 years of age. Female plants can produce many bright red fruits, but it is commonly stated that seeds are of little or no value in stand formation because there is little evidence of new seedling establishment (Tucker 1984). Information on the ecology of the species is sparse, and little is known about the development and biochemistry of fruit and seed or of the fate of pondberry seeds once shed from the plant. Preliminary tests have shown that pondberry seeds are orthodox, and that excellent germination can be achieved when laboratory germinators are set on a cycle of 35 °C for 16 hours with light and 30 °C for 8 hours without light. We have used this information to begin our next series of studies, the purpose of which is to document fruit and seed growth rates, changes in fruit and seed biochemistry, and seed longevity and persistence in the field.

## MATERIALS AND METHODS

Fruit collection and seed longevity and persistence studies were conducted at two sites within the Delta National Forest, MS. In fruit and seed longevity and persistence studies, both entire (with pulp) and peeled drupes were used as treatments.

### Fruit and Seed Morphological and Biochemical Development

The length and diameter of drupes were measured with digital calipers (model CD 6"CS, Mitutoyo America Corporation) within 3 hours after drupes were removed from the plants from April through October. After removal of the pulp, seed diameter was measured. Samples of pulp and seed material were freeze dried, ground in a Wiley mill, and stored in liquid nitrogen pending lipid analysis. Lipids were later extracted from

seed and pulp by first stirring the seed tissue for 30 minutes in a mixture consisting of two parts chloroform and one part methanol. The mixture was filtered, and the filtrate was measured volumetrically, washed, and purified in the manner described by Folch and others (1957) using one wash of 0.9 percent NaCl in distilled water and two washes of a 1:1 mixture of methanol and 0.9 percent NaCl in distilled water. Lipids were esterified using 1.5 percent concentrated H<sub>2</sub>SO<sub>4</sub> in methanol (Christie 1990). Samples were placed in a 50 °C water-bath overnight, cooled, and vortexed for 15 seconds with 3 ml water and 2 ml hexane (Murrieta and others 2003). The hexane phase was removed, dried over anhydrous Na<sub>2</sub>SO<sub>4</sub>, and analyzed on a Hewlett-Packard® 5890 gas chromatograph using an HP-5 column. The initial oven temperature, for 5.2 minutes, was 110 °C. Oven temperature was then increased at 30 °C per minute to 140 °C and held for 22 minutes; temperature was then increased 30 °C per minute to 170 °C and held for 18 minutes. Total run time was 47.2 minutes. Injector and detector temperatures were 200 °C. Response factors were calculated from injections of low erucic rapeseed oil and AOCS oil reference mix number 3 (Sigma Chemical Co., St. Louis, MO).

### Fruit and Seed Longevity

For this study, seed longevity is defined as the longest period of time that a seed will remain viable in the field. In September 2004, we installed a study to examine the longevity of seeds with and without pulp. Seeds were bagged in plastic screen. The bags were attached to wire flags (to aid location) and buried approximately 5 cm below the soil surface. Each bag held 25 seeds and counted as one replicate. Four bags of each treatment (100 seeds total) were to be collected after 1, 2, 4, 6, 12, 18, and 24 months of burial in the soil. After the seeds were brought into the lab, they were examined to determine if any had germinated in the field. Those that were ungerminated were rinsed free of dirt and placed in a germinator for 16 weeks to determine if they would germinate. Seeds were germinated in a Stultz® germination cabinet set

<sup>1</sup> Project Leader, USDA Forest Service, Southern Research Station, Auburn, AL 36849.

<sup>2</sup> Technicians, USDA Forest Service, Southern Research Station, Starkville, MS 39762.

<sup>3</sup> Scientists, USDA Forest Service, Southern Research Station, Stoneville, MS 38776.

<sup>4</sup> Scientist, USDA Forest Service, Southern Research Station, Saucier, MS 39574.

at 35 °C for 16 hours with light and 30 °C for 8 hours without light. We report here on the 1- and 2-month collections.

### Fruit and Seed Persistence

Persistence is a measure of the fate of seeds that have been dispersed. The persistence study was established at the same time as the longevity study. Both peeled and entire drupes were put in mesh bags. As before, each bag (replicate) contained 25 seeds and was attached to a wire flag. Each flag marked the location of both a bag of seeds with pulp and a bag of seeds without pulp. The bags rested on the soil surface. Four bags of seeds both with and without pulp were to be sampled after 1, 2, 4, 6, 12, 18, and 24 months of exposure. We report here on the 1- and 2-month collections. Sample seeds were germinated as above.

## RESULTS AND DISCUSSION

### Fruit and Seed Morphological and Biochemical Development

Pondberry drupes reached their mature size by July. While the average dimensions were larger for August, the difference was not significant. The fruits collected in July averaged 10.9 mm in length and 8.1 mm in diameter. The seeds reached their mature size by August. Seeds were, on average, 6.6 mm in diameter and weighed 0.18 g at that time. Lauric acid was the dominant fatty acid in the pondberry seeds (fig. 1A). Although none of this acid was found in earlier seed samples, concentrations reached 231 mg/g dry seed tissue by August. Oleic and linoleic acids were also found in fairly large quantities, and traces of palmitic, stearic, and linolenic fatty acids were present (fig. 1B). The fruit pulp is very low in lauric acid

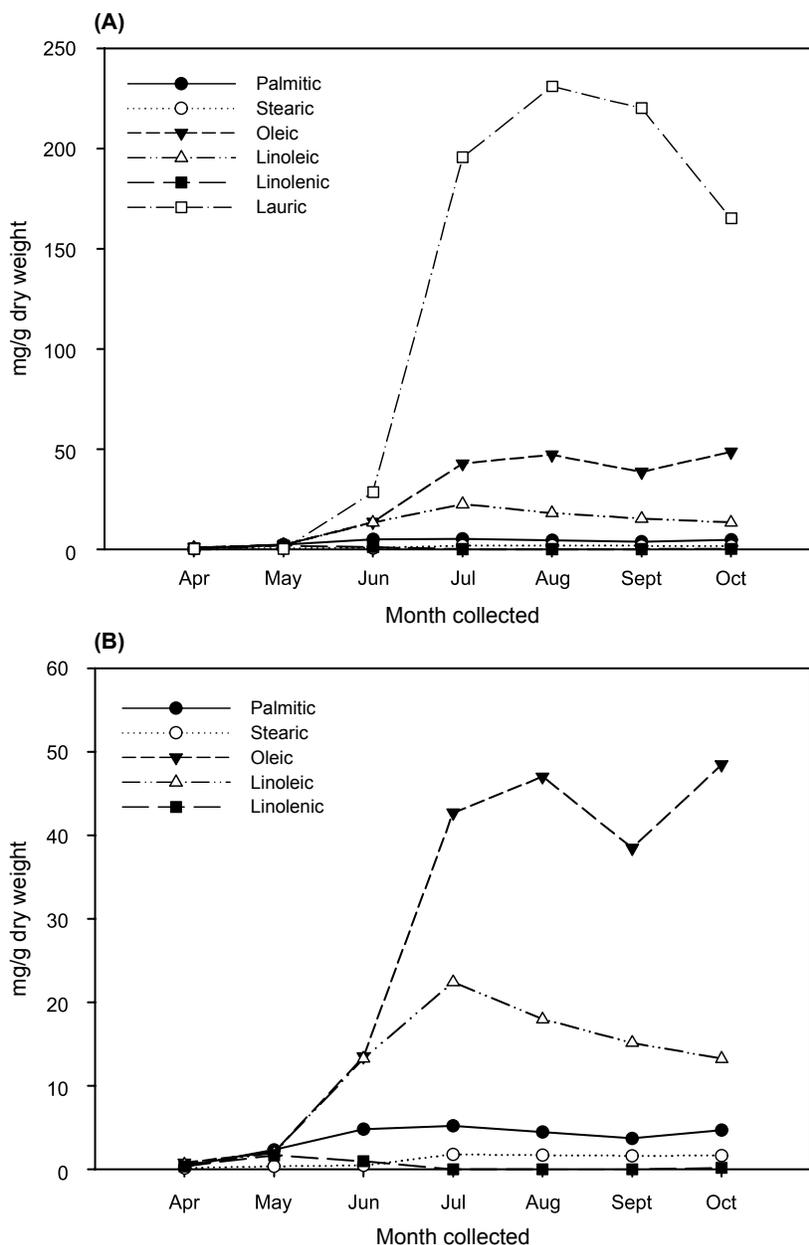


Figure 1—Pondberry seed collected from the Delta National Forest, MS: (A) Fatty acid profile. (B) Fatty acid profile without lauric acid.

throughout its development. Figure 2 profiles the fatty acids that were present in the pulp; oleic acid was the most prevalent, reaching > 300 mg/g dry seed tissue in October. Small amounts of octanoic acid were found in pulp but were absent from seed tissue.

### Fruit and Seed Longevity

Seeds with pulp, buried for 1 month and kept in a germinator for 9 weeks, had a germination rate of 0 percent (fig. 3A). Seeds with pulp, buried for 2 months and kept in a germinator for 6 weeks, had 39 percent germination (fig. 3B). Also, the percentage of seeds that rotted was lower for seeds that were buried for 2 months than for those that were buried for 1 month. Seeds without pulp, buried for 1 month and kept in a germinator for 9 weeks, had 18 percent germination (fig. 4A). Those buried for 2 months and kept in an incubator for 6 weeks had

53 percent germination (fig. 4B). There was a 4 percent reduction in rotten seeds. These results show that, in the laboratory, seeds without pulp have a higher viability than seeds with pulp, and we would expect that they would move out of the seed bank faster than those with pulp left intact. Among the unknowns, however, are the mechanism by which intact pulp may affect seed decay, how flooding will affect seed viability, and how long seed will remain viable in the remaining field samples.

### Fruit and Seed Persistence

Fresh seeds with pulp intact that were deposited directly on the litter layer and remained there for 1 month had 6 percent germination after 9 weeks in the germinator (fig. 5A). Those that remained on the litter layer for 2 months had 59 percent germination after 6 weeks in the germinator (fig. 5B). The

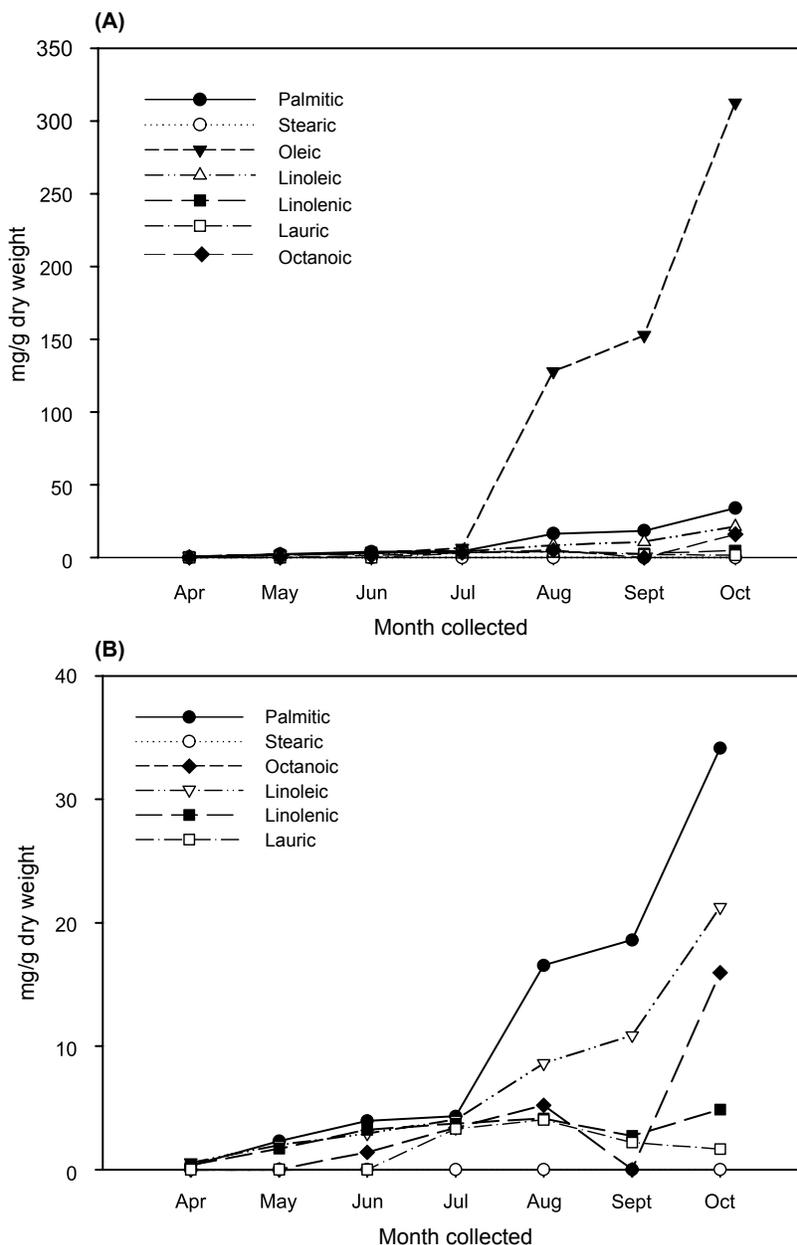


Figure 2.—Pongberry fruit pulp collected from the Delta National Forest, MS: (A) Fatty acid profile. (B) Fatty acid profile without oleic acid.

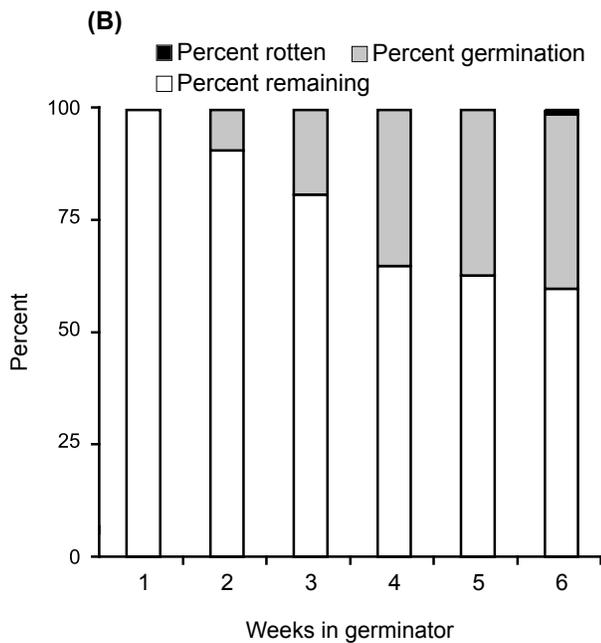
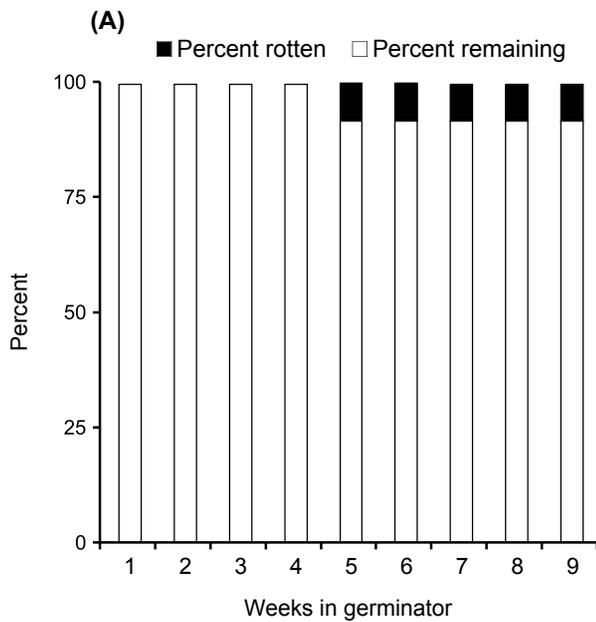


Figure 3—Seed with pulp from the pondberry longevity study after (A) 1 month and (B) 2 months in the field.

proportion of rotten seeds was 3 percent for each group (figs. 5A and 5B). Seeds without pulp that were deposited directly on the litter layer and remained there for 1 month had 20 percent germination after 9 weeks (fig. 6A). Those that remained on the litter layer for 2 months had 90 percent germination after 6 weeks (fig. 6B). One percent of the pulpless seeds that remained in place 1 month rotted, and none of the pulpless seeds that remained in place for 2 months rotted (figs. 6A and 6B). These preliminary laboratory results suggest that seeds on the soil surface might germinate faster than buried seeds and move out of the seed bank faster than buried seeds. Seeds without pulp also have a higher germination percentage than seeds with pulp.

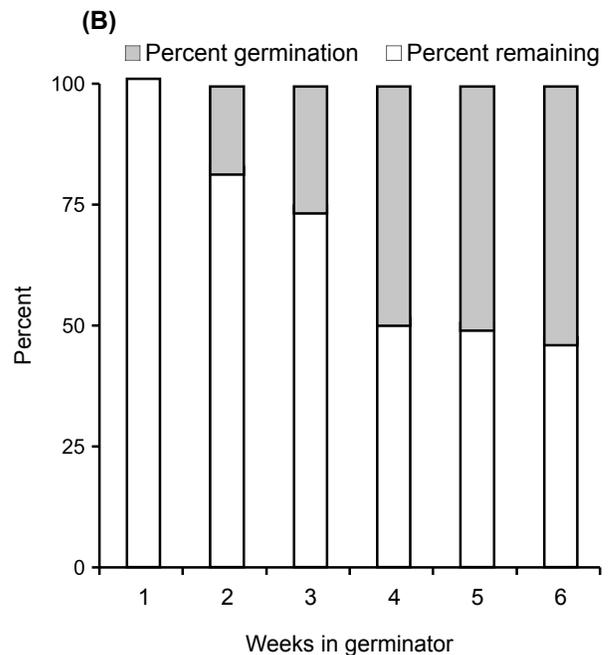
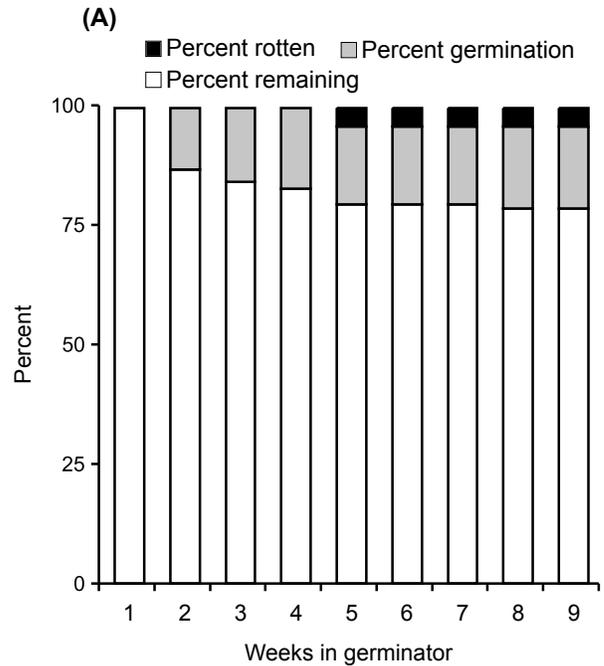


Figure 4—Seed without pulp from the pondberry longevity study after (A) 1 month and (B) 2 months in the field.

Both the longevity and persistence studies show that seeds freshly deposited in the field do not germinate immediately. This study is still in progress, and although seeds are doing well in the laboratory germinators, we have yet to see any germination in the field. Conclusions are pending completion of the study.

#### ACKNOWLEDGMENTS

Pondberry seeds were collected under permit number 43680-02003 issued by the U.S. Fish and Wildlife Service. Funding for the study was provided by the U.S. Army Corps of Engineers.

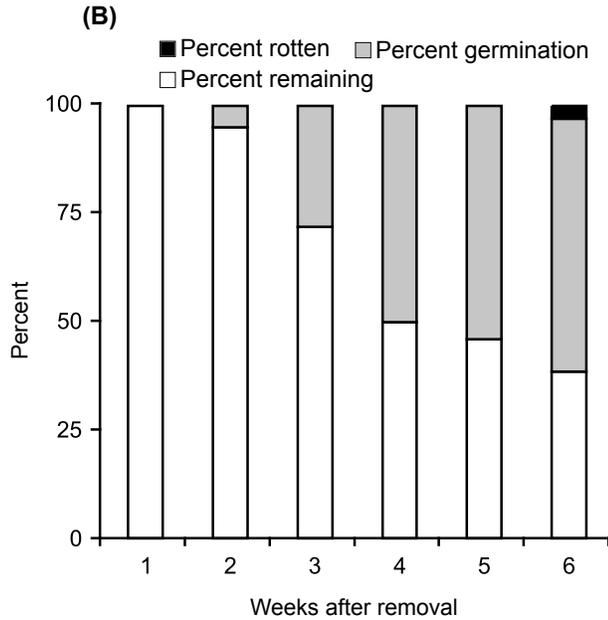
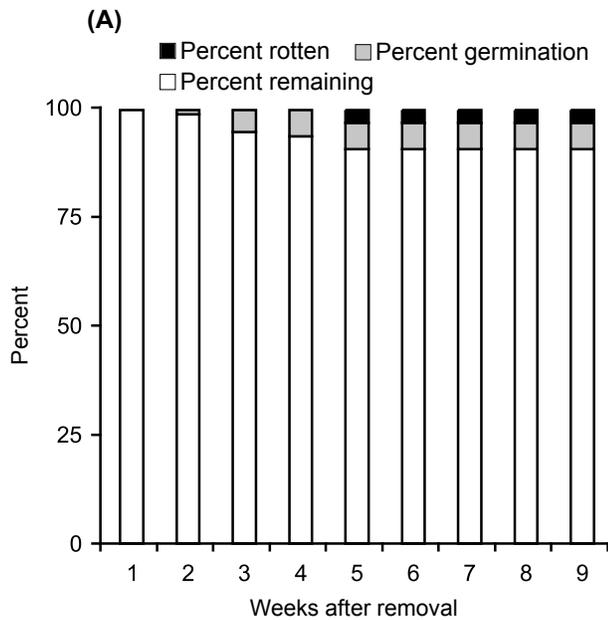


Figure 5—Seed with pulp from the pondberry persistence study after (A) 1 month and (B) 2 months in the field.

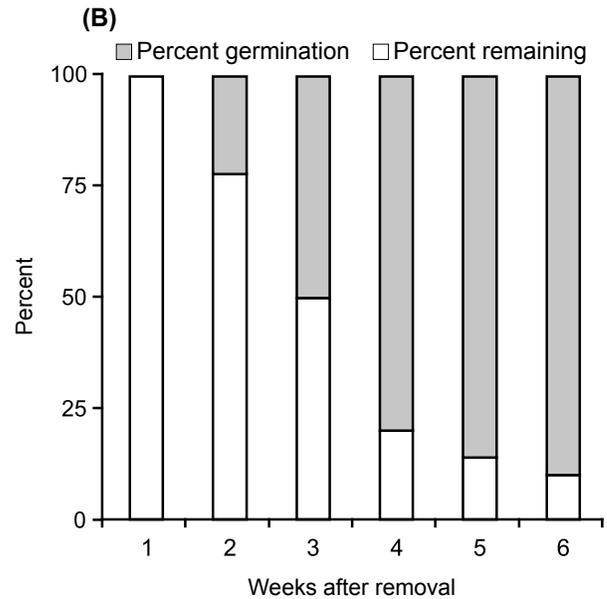
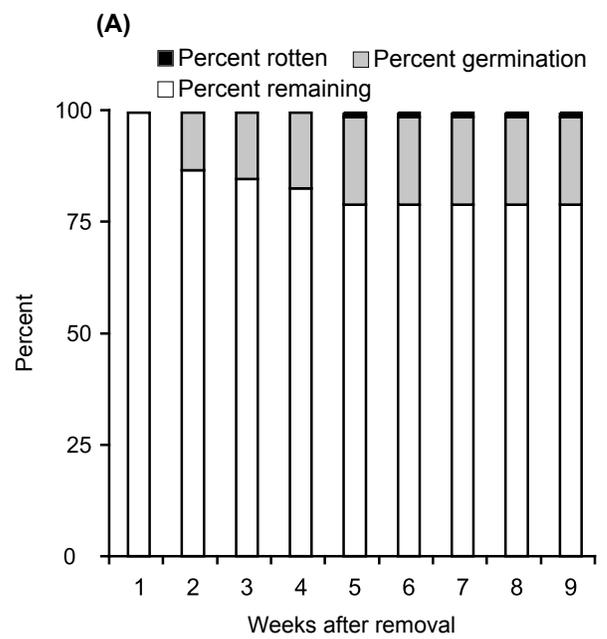


Figure 6—Seed without pulp from the pondberry persistence study after (A) 1 month and (B) 2 months in the field.

**LITERATURE CITED**

Christie, M.M. 1990. Preparation of methyl esters – part I. Lipid Technology. 2(2): 48-49.

Devall, M. 2004. *Lindera lissifolia* (Walt.) Blume. Pondberry. In: Francis, J.K., ed. Wildland shrubs of the United States and its territories: thamnoid descriptions. Gen. Tech. Rep. IITF-26. San Juan, PR: U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry, and Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 830 p. Vol. 1.

Folch, J.; Lees, M.; Sloane Stanley, G.H. 1957. A simple method for the isolation and purification of total lipides from animal tissues. Journal of Biological Chemistry. 226: 497-501.

Murrieta, C.M.; Hess, B.W.; Rule, D.C. 2003. Comparison of acidic and alkaline catalysts for preparation of fatty acid methyl esters from ovine muscle with emphasis on conjugated linoleic acid. Meat Science. 65: 523-529.

Radford, A.E.; Ahles, H.E.; Bell, C.R. 1968. Manual of vascular flora of the Carolinas. Chapel Hill, NC: University of North Carolina. 1183 p.

Tucker, G.E. 1984. Status report on *Lindera melissifolia* (Walt.) Blume. Atlanta, GA: U.S. Fish and Wildlife Service, Southeast Region. 41 p.

# ALLOMETRY AND BIOMASS OF POLLARDED BLACK LOCUST

David M. Burner, Daniel H. Pote, and Adrian Ares<sup>1</sup>

## POSTER SUMMARY

Climatic constraints can cause forage deficits in the summer in west-central Arkansas, necessitating expensive, supplemental hay feeding. Black locust could be used for summer browse, but the temporal distribution of foliar biomass has not been adequately tested. Our objective was to determine effects of harvest date, fertilization (0 and 600 kg P ha<sup>-1</sup> yr<sup>-1</sup>), and pollard height (stems cut at 5, 50, and 100 cm above ground) on foliar and shoot allometry of black locust. The test was conducted on a naturally regenerated 2-year-old black locust stand (15,000 trees ha<sup>-1</sup>). Basal shoot diameter and foliar yield were measured monthly in June to October 2002 and 2003. Yield (Y) of foliar and shoot dry matter was estimated from basal shoot diameter (D) by the function  $Y=aD^b$ , with regression explaining at least 95 percent of variance.

Allometry of foliar yield was affected by harvest date (fig. 1), increasing at a significantly ( $P<0.05$ ) greater rate with D in September ( $Y=0.0126D^{3.0142}$ ) than in June ( $Y=9.4976D^{0.6638}$ ) or July ( $Y=0.5769D^{1.9305}$ ), but not by pollard height or P fertilization. Allometry of shoot dry matter was unaffected by cultural practice,  $Y=0.0427D^{2.8709}$ . Biomass was greater when trees were pollarded at 50 or 100 cm, with or without P, than at 5 cm. Foliar biomass in August was 5.3 Mg dry matter ha<sup>-1</sup>, a competitive yield compared to herbaceous forage. Allometry of shoot dry matter was unaffected by harvest date, pollard height, or P fertilization. Black locust should be considered for rotational livestock browse in summer when climatic stresses induce semi-dormancy of herbaceous forages. Yield of black locust pollards can be estimated from basal shoot diameter with reasonable accuracy.

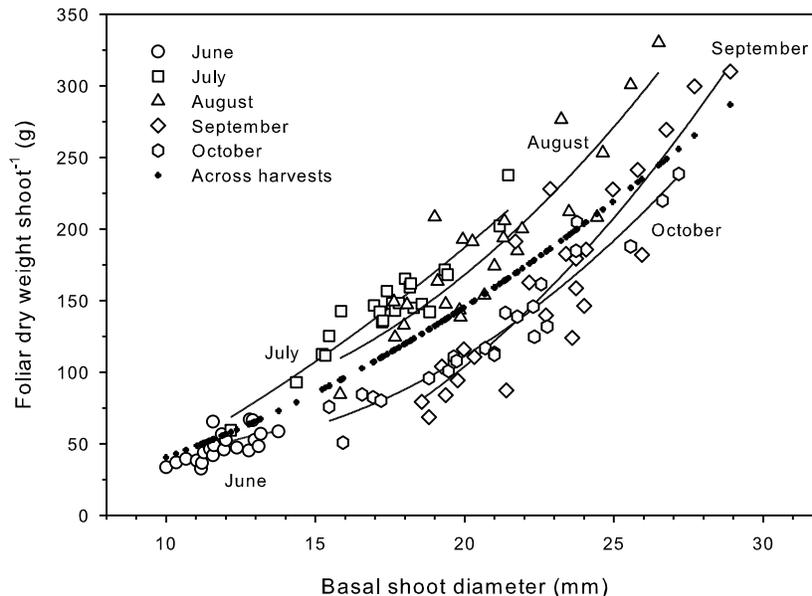


Figure 1—Relationship of foliar dry weight to basal shoot diameter for June through October harvests, and combined across harvests, for black locust in Arkansas, U.S.A.

<sup>1</sup> Research Agronomist and Research Soil Scientist, respectively, U.S. Department of Agriculture, Agricultural Research Service, Dale Bumpers Small Farms Research Center, Booneville, Arkansas 72927; and Research Scientist, Weyerhaeuser Company, Centralia, Washington 98531.

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# SPECIES-SITE RELATIONSHIPS IN A NORTHERN ARKANSAS UPLAND FOREST

Eric Heitzman, Michael G. Shelton, and Ruth Ann Chapman<sup>1</sup>

**Abstract**—Phytosociological aspects of the forest vegetation were described for a 780-ha area on the Sylamore Experimental Forest in northern Arkansas. Pronounced changes in species composition occurred with topographic position in this deeply dissected area. For the overstory, oaks and pines dominated the upper slope positions, while other tree species dominated the lower slopes and hollows. However, other tree species dominated the understory and reproduction strata of all topographic positions. Species diversity was highest in the hollows and declined going upslope for the overstory and understory, but diversity was lowest in the hollows for reproduction, which probably reflected the dominance of several shrub species. Some variation in species composition could also be attributed to aspect. The described gradients in species composition have implications for the silvicultural ease of obtaining reproduction of targeted species within the area.

## INTRODUCTION

The structure of forest vegetation is a function of past disturbance, gradients in environmental factors (e.g., elevation, soils), and life history strategies of tree species. In highly dissected landscapes of the southern and eastern United States, a number of studies have documented that the environmental conditions associated with different topographic positions and aspects greatly influence forest composition (Collins and Carson 2004, Desta and others 2004, Elliott and others 1999, Rubino and McCarthy 2003). However, we are unaware of any study that reports species-site relationships in the Ozark Mountains of Arkansas.

The Sylamore Experimental Forest (SEF) is a 1,740-ha tract on the Ozark-St. Francis National Forest in northern Arkansas. It was established in 1934 by the USDA Forest Service and represented forest conditions typical of the Ozark Mountains. The region is characterized by steep slopes, narrow valleys, and very stony soils (Ward 1983). The SEF was the center of a wide-ranging silvicultural research program from the 1930s through the 1950s. By the early 1960s, however, research activity on the SEF had decreased dramatically. There has been little research or management on the forest for the past 40 years.

Several years ago, the field data sheets were located for a portion of the 1934 inventory of the SEF. We reinventoried this area in 2002 with an overall goal of determining how the forest vegetation changed over a span of nearly 70 years. In this paper, we have focused on the phytosociological aspects of the forest vegetation existing in 2002.

## METHODS

The 780-ha study site encompassed three sections (Township 16 North, Range 11 West, sections 7, 17, and 18) of the SEF. Transects were established in 2002 that roughly corresponded to the 1934 cruise. Along each transect, sampling locations were established at 122-m intervals for a total of 201 sample points. At each location, overstory trees (>14.0 cm

d.b.h.) were tallied by species and d.b.h. on a 0.04-ha circular plot, understory trees (1.4 to 14.0 cm d.b.h.) were recorded by species and d.b.h. on three 0.004-ha plots, and reproduction (<1.4 cm d.b.h.) was counted by species on three 0.0004-ha plots. Each location was ocularly classified as to relative topographic position (fig. 1). Aspect and percent slope were determined by compass and clinometer.

Species importance values were calculated for each location and stratum based on relative density, basal area (overstory and understory), and frequency of occurrence (Curtis and McIntosh 1951). Diversity indices were calculated from species importance values (Odum 1971). Vegetation data by species and stratum were tested for significant differences among topographic positions or aspects using the non-parametric Kruskal-Wallis test of group comparisons, because the data lacked homogeneity and normality (SAS 1989). Significance was accepted at  $P < 0.05$ .

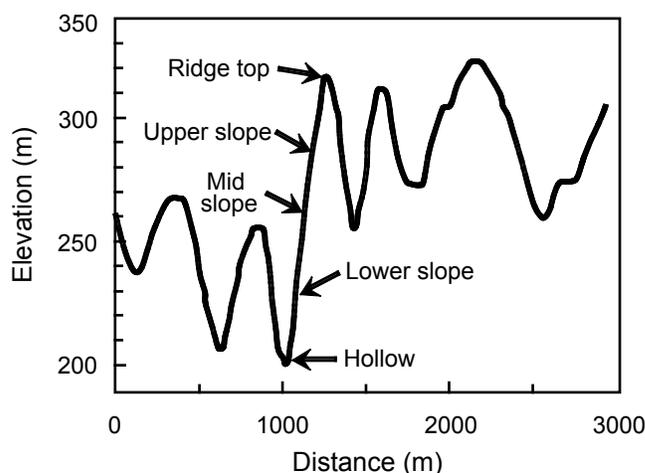


Figure 1—An example of elevations along a typical transect through the Sylamore Experimental Forest showing the five relative topographic positions recognized in the study.

<sup>1</sup> Assistant Professor, University of Arkansas-Monticello, School of Forest Resources, Monticello, AR 71656; Research Scientist, USDA Forest Service, Southern Research Station, Monticello, AR 71656; and Private Lands Biologist, Arkansas Game & Fish Commission, Monticello, AR 71655, respectively.

## RESULTS AND DISCUSSION

### General Terrain and Vegetative Features

The five topographic positions were fairly equally distributed. Hollows (16 percent) and ridge tops (15 percent) were less frequent than the slope positions (lower 23 percent, mid 22 percent, and upper 24 percent). Slopes ranged from 2 to 78 percent. The lowest mean slopes occurred on ridge tops (25 percent) and in hollows (34 percent). Mean slopes for the lower-, middle-, and upper-slope positions were fairly consistent and averaged 39, 40, and 36 percent, respectively. Aspects occurred in every bearing. Northwest and southeast aspects were the least common and together made up 13 percent of the locations. In contrast, east and west aspects were most common and together made up 35 percent of the locations.

The differences in total basal area and stem numbers were fairly minor among topographic positions. For example, overstory basal area totaled 18.1 m<sup>2</sup>/ha in the hollows and 24.1 m<sup>2</sup>/ha on ridge tops ( $P=0.001$ ), whereas total understory basal area was a maximum on mid-slope positions at 4.6 m<sup>2</sup>/ha and declined to about 3 m<sup>2</sup>/ha for both hollows and ridge tops ( $P=0.015$ ). Stem density for reproduction was least in the hollows (14,000 stems/ha) and highest on the ridge tops (22,000 stems/ha) ( $P=0.001$ ).

Composition of forest communities changed dramatically across topographic positions (fig. 2). On ridge tops, the overstory was composed of about equal percentages of red oaks, white oaks, and pines, while other tree species only made up 7 percent of the basal area. In contrast, hollows were 45 percent in other trees, and the contribution of white oaks (33 percent) far exceeded red oaks (13 percent) and pines (9 percent). The understory was mainly composed of other tree species in all topographic positions, with the red oaks, white oaks, and pines only making up 11 to 33 percent of the basal area. For reproduction, red oaks, white oaks, and pines only made up 7 to 14 percent of the total number of stems. The percentage of red oaks increased going up slope, while

shrubs declined. The percentage of pine reproduction was virtually nil on all positions.

### Species-Topographic Relationships

Of the 33 overstory species recorded, 8 species showed significant variation with topographic position. Some species, like *Carya cordiformis* (Wangenh.) K. Koch and *Liquidambar styraciflua* L., were important in hollows but did not occur on ridge tops (table 1). Other species (*Quercus rubra* L. and *Q. velutina* Lam.) occurred on all topographic positions but were most important on upper slopes and ridge tops. *Pinus echinata* Mill. occurred on all positions but was most important on the upper slopes. *Quercus alba* L., the dominant overstory species, did not vary significantly with topographic position ( $P=0.16$ ); importance values were fairly uniform across the landscape, varying only from 22 to 31 percent.

Of the 46 species recorded in the understory, 12 showed significant variation with topographic position. *Carpinus caroliniana* Walt., *Fraxinus americana* L., *Liquidambar styraciflua*, and *Ostrya virginiana* (Mill.) K. Koch decreased in importance going upslope (table 1). In contrast, some species, like *Cornus florida* L., were most important on upper slopes and ridge tops. *Carpinus caroliniana* and *Liquidambar styraciflua* were not observed on ridge tops positions in this stratum.

For reproduction, 16 of the 48 recorded species showed significant variation with slope position. *Carpinus caroliniana* and *Fraxinus americana* decreased in importance going upslope (table 1). In contrast, *Quercus rubra*, *Quercus alba*, and *Sassafras albidum* (Nutt.) Nees increased in importance going upslope.

### Species Diversity

Species diversity for overstory vegetation was highest in the hollows and lowest on the ridge tops (Shannon's Index: 1.4 versus 1.3; richness: 4.9 versus 4.3;  $P<0.01$ ). A similar pattern occurred for understory vegetation (Shannon's Index: 1.6 versus 1.2; richness: 6.2 versus 4.0;  $P<0.01$ ). However, a different

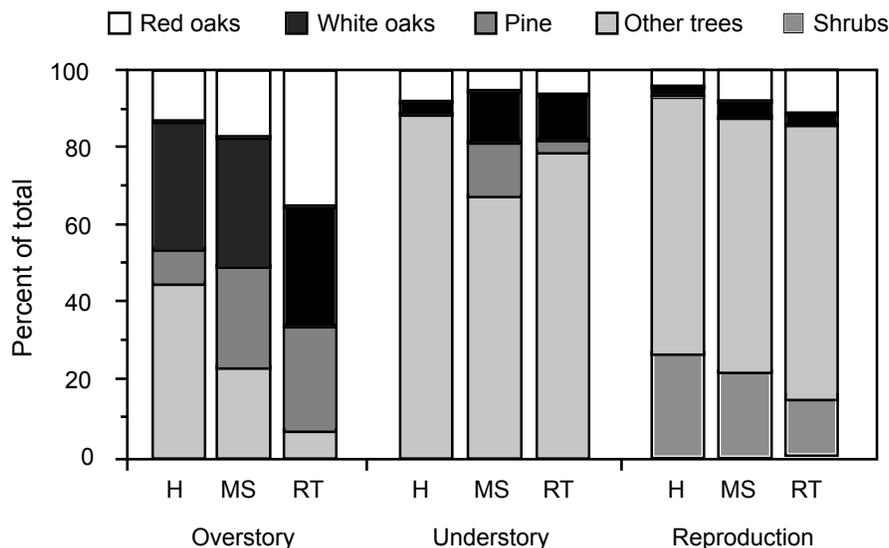


Figure 2—Contribution of species groups to community composition for hollows (H), mid slopes (MS), and ridge tops (RT). Overstory and understory based on basal area, reproduction on numbers.

**Table 1—Importance values (percent) of selected species by topographic position on the Sylamore Experimental Forest in northern Arkansas**

Species <sup>a</sup>	Hollow	Lower slope	Mid slope	Upper slope	Ridge Top	P
----- overstory (>14.0 cm d.b.h.) -----						
<i>Carya cordiformis</i>	4.1	0.2	0.3	0.0	0.0	0.001
<i>Liquidambar styraciflua</i>	15.3	6.6	4.0	0.5	0.0	0.001
<i>Pinus echinata</i>	6.6	11.6	18.1	22.6	17.5	0.007
<i>Quercus rubra</i>	6.8	11.3	7.5	14.6	19.2	0.003
<i>Quercus velutina</i>	2.3	8.7	8.3	15.1	12.3	0.001
----- understory (1.4 to 14.0 cm d.b.h.) -----						
<i>Carpinus caroliniana</i>	10.7	1.7	1.3	0.5	0.0	0.001
<i>Cornus florida</i>	11.8	20.4	16.3	25.0	20.5	0.046
<i>Fraxinus americana</i>	6.0	4.0	1.5	2.5	0.6	0.002
<i>Liquidambar styraciflua</i>	8.9	2.1	1.8	0.4	0.0	0.001
<i>Ostrya virginiana</i>	8.6	10.6	8.8	7.9	3.2	0.010
----- reproduction (<1.4 cm d.b.h.) -----						
<i>Carpinus caroliniana</i>	8.5	3.0	2.5	1.2	1.0	0.001
<i>Fraxinus americana</i>	8.9	7.2	4.1	3.2	4.1	0.006
<i>Quercus rubra</i>	3.7	4.5	4.1	6.8	12.1	0.009
<i>Quercus alba</i>	0.9	3.7	3.6	5.4	4.7	0.037
<i>Sassafras albidum</i>	8.2	17.0	14.1	23.7	24.9	0.001

<sup>a</sup>Limited to the five most important species in each stratum showing a significant difference.

pattern emerged for vegetation in the reproduction-size class, where lower slopes had the highest diversity and hollows the lowest (Shannon's Index: 1.8 versus 1.5; richness: 6.7 versus 5.6;  $P < 0.01$ ). It was interesting that the hollows had the greatest diversity in the overstory and understory but the lowest diversity for reproduction. This may reflect the influence of some dominating shrubs, like *Asimina triloba* (L.) Dunal and *Lindera benzoin* (L.) Blume, which were common in hollows (combined importance value of 16 percent) but rare elsewhere.

### Effect of Aspect

For the combined mid-slope, upper-slope, and ridge-top positions, there were five species that varied significantly with aspect in the overstory, eight in the understory, and five in reproduction. Examples of the patterns are shown for selected species in the overstory and understory in figure 3. *Carya tomentosa* (Poir.) Nutt. was most important on a north-east aspect in the overstory and a southeast aspect in the understory. In contrast, *Pinus echinata* showed highest importance on south aspects in both overstory and understory strata. *Quercus alba* in the overstory was variable in importance with no clear trend, while *Quercus alba* in the

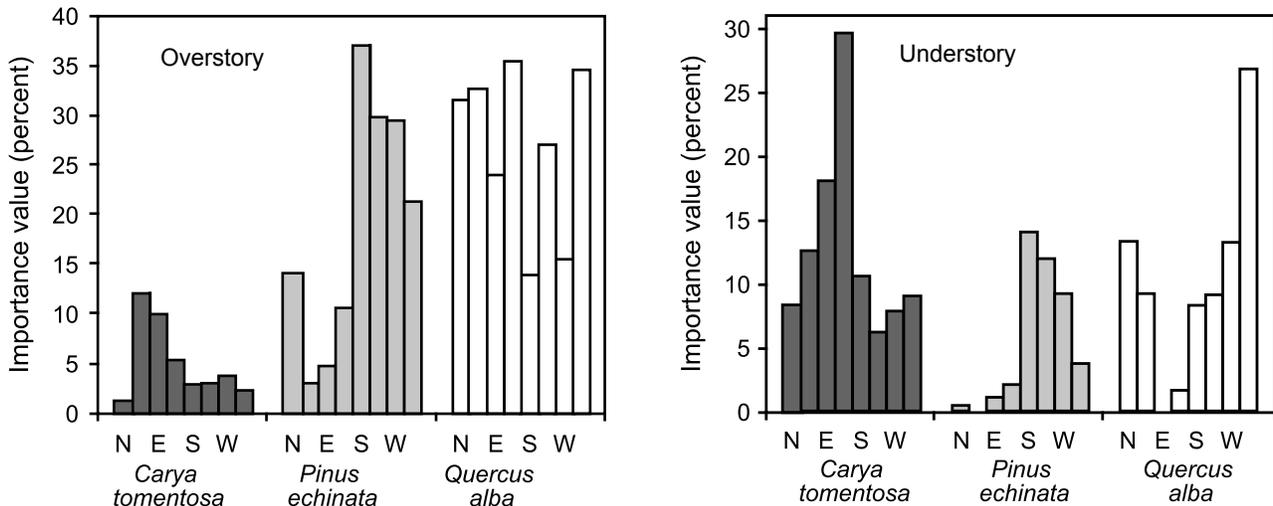


Figure 3—Effects of aspect on importance values of three selected species on mid-slope, upper-slope, and ridge-top positions.

understory was most important on northwest aspects and least important on east aspects. The reproduction of these three important species showed no significant relationship with aspect.

## CONCLUSIONS

The vegetation community existing in a particular location depends on a complex set of factors and their interaction. Our study documents these relationships for a portion of the Ozarks which heretofore has received little attention. In mountainous terrain, topography and aspect are key features of a forest site, because they have a pronounced effect on soils, water, and light. The habitat requirements of species (Burns and Honkala 1990, Lawson 1990) interact with well-known environmental gradients associated with topography and aspect (Geiger 1950) to determine the distribution of vegetation across this study site. Some species, like *Quercus alba*, are generalists and can become established and develop across the entire landscape of the SEF. Other species, like *Carya cordiformis*, are specialists and show a distinctive pattern of occurrence within the landscape (Barnes and others 1998). Competition among plant species for limited resources is also a principal determinant of the observed distribution patterns. For example, the low diversity of the reproduction stratum in hollows was thought to be due to intense competition from two shrubs that were very well adapted to that topographic position.

Some of the observed relationships may reflect the past disturbance history of the SEF, which included the strong influence of fire (Guyette and Spetich 2003). For example, the presence of overstory pines in the hollows suggests a disturbance history in the past far different than that of the present, where pine reproduction was virtually non-existent. Oaks and pines tended to dominate the upper slope positions, while other tree species dominated the hollows and lower slopes. These relationships also have implications about the difficulty of regenerating specific areas to targeted species. Oak and pine reproduction will likely be difficult to secure in hollows and on the lower slopes.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

- Barnes, B.V.; Zak, D.R.; Denton, S.R.; Spurr, S.H. 1998. Forest ecology. 4<sup>th</sup> ed. New York, NY: John Wiley and Sons. 774 p.
- Burns, R.M.; Honkala, B.H., tech. coords. 1990. Silvics of North America, volume 2. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service. 877 p.
- Collins, R.J.; Carson, W.P. 2004. The effects of environment and life stage on *Quercus* abundance in the eastern deciduous forest, USA: are sapling densities most responsive to environmental gradients? *Forest Ecology and Management*. 201: 241-258.
- Curtis, J.T.; McIntosh, R.P. 1951. An upland forest continuum in the prairie-forest border region of Wisconsin. *Ecology*. 32: 476-496.
- Desta, F.; Colbert, J.J.; Rentch, J.S. [and others]. 2004. Aspect induced differences in vegetation, soil, and microclimatic characteristics of an Appalachian watershed. *Castanea*. 69: 92-108.
- Elliott, K.J.; Vose, J.M.; Swank, W.T. [and others]. 1999. Long-term patterns in vegetation-site relationships in a southern Appalachian forest. *Journal of the Torrey Botanical Society*. 126: 320-334.
- Geiger, R. 1950. *The climate near the ground*. Cambridge, MA: Harvard University Press. 611 p.
- Guyette, R.P.; Spetich, M.A. 2003. Fire history of oak-pine forests in the Lower Boston Mountains, Arkansas, USA. *Forest Ecology and Management*. 180: 463-474.
- Lawson, E.R. 1990. *Pinus echinata* Mill. Shortleaf pine. In: Burns, R.M.; Honkala, B.H., tech. coords. Silvics of North America, volume 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 316-326.
- Odum, E.P. 1971. *Fundamentals of ecology*. 3<sup>rd</sup> ed. Philadelphia, PA: W.B. Sanders. 574 p.
- Rubino, D.L.; McCarthy, B.C. 2003. Evaluation of coarse woody debris and forest vegetation across topographic gradients in a southern Ohio forest. *Forest Ecology and Management*. 183: 221-238.
- SAS Institute Inc. 1989. *SAS/STAT user's guide*. Version 6, 4<sup>th</sup> ed., vol. 1. Cary, NC: SAS Institute Inc. 943 p.
- Ward, L.B. 1983. *Soil survey of Stone County, Arkansas*. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 152 p.

# SILVICULTURAL TREATMENTS TO REGENERATE PRINCIPAL SPECIES IN THE FLAT ROCK FOREST COMMUNITY

James E. Johnson, Laura S. Gellerstedt, and David O. Mitchem<sup>1</sup>

**Abstract**—Principal indicator tree species of the Flat Rock Forest Community include Virginia pine (*Pinus virginiana* Mill.), eastern redcedar (*Juniperus virginiana* L.), and post oak (*Quercus stellata* Wangenh.). These species are unusual for forests occurring adjacent to large rivers in the central and southern Appalachian Mountains, but the thin, dry soils typical of the Flat Rock communities preclude other mesic species. As the Flat Rock forests are invaded by riparian tree species such as green ash (*Fraxinus pennsylvanica* Marshall), American sycamore (*Platanus occidentalis* L.), yellow poplar (*Liriodendron tulipifera* L.), and red maple (*Acer rubrum* L.), the indicator species decline. A study was established to determine the effectiveness of cutting, prescribed burning, and herbicide application to create conditions more favorable for the regeneration of the target species and discourage the less desirable riparian vegetation. Treatments were effective in favoring Flat Rock species in the overstory and understory. Over the 2-year study period, seedling numbers increased across all treatments, including controls. This was attributed to above-average precipitation during both growing seasons following treatment.

## INTRODUCTION

The Flat Rock Forest Community is a minor, but locally significant, plant community found in unique locations along major rivers in the Appalachian Mountains (McDonald and Trianosky 1995). Characterized by low biodiversity and harsh sites with little soil over hard sandstone bedrock, these plant communities are maintained by frequent flooding that removes soil rather than deposits sediments. As a result, the plant community is floristically simple, with early successional species dominating. In the absence of flooding, as is the case on the New River below the Bluestone Dam in Summers County, WV, soil accumulates; organic matter, fertility, and water-holding capacity increase; and the site is invaded by both exotic and riparian species. Traditional overstory species in the Flat Rock Forest Community, eastern redcedar (*Juniperus virginiana* L.), Virginia pine (*Pinus virginiana* Mill.), and post oak (*Quercus stellata* Wangenh.), are reduced over time.

Maintaining the Flat Rock Forest Community has become a primary management objective of the National Park Service (NPS) New River Gorge National River. The NPS owns nearly 21,000 ha along the New River in West Virginia (Mahan 2004) and preserving native species and habitats is a primary concern. In light of observed species changes in the Flat Rock Forest Community, the NPS has agreed to test a series of silvicultural practices designed to reduce the overstory and understory composition of upland, riparian, and exotic species. These practices also were designed to facilitate regeneration of the Flat Rock indicator species: eastern redcedar, Virginia pine, and post oak.

## OBJECTIVES

The objectives of this experiment were to evaluate the effects of various silvicultural treatments on overstory and understory composition of key species groups in the Flat Rock Forest Community and to determine the effect of silvicultural treatments on species composition and density of regeneration of key species groups in the Flat Rock Forest Community.

## PROCEDURES

### Study Area

The study was conducted on Brookside Island, located on the New River in Summers County, WV (N 37° 38', W 80° 50'). The New River originates in North Carolina and flows north for approximately 400 km, joining the Gauley River to form the Kanawha River. The New River drains an area of 11,136 km<sup>2</sup>.

### Field Plot Layout and Measurements

The study site was established in the Sub-mesic Virginia Pine Forest Community. This community most resembles the transition from a typical Flat Rock community to a mature riparian forest. Changes in vegetation structure and composition resulting from the applied treatments would be most apparent in this area. Within the Sub-mesic Virginia Pine Forest Community, nine plots were established, each 24 by 24 m in size. All plots were located at least 15 m inland from the New River to avoid exposed bedrock and the influence of high water levels. Each plot is separated by at least an 8-m buffer to prevent any overlap between treatments.

Within each sample plot, overstory trees > 5 m in height were measured for d.b.h. (diameter at breast height) and height. Each overstory plot was divided into a series of nested subplots for understory and regeneration evaluation. Four 6 x 6-m subplots were established for understory assessment, which included trees and shrubs between 1 and 5 m in height. Recorded measurements included species and d.b.h. for trees, while species and number of individuals were recorded for shrubs.

Within each understory subplot, two 1-m<sup>2</sup> sub-subplots were established to sample regeneration, for a total of eight regeneration sub-subplots in each overstory plot. The regeneration stratum was defined as trees and shrubs between 0 and 1 m in height. Regeneration measurements included species and number of individuals.

<sup>1</sup> Professor of Forestry, Graduate Research Assistant, and Forestry Research Specialist, respectively, Department of Forestry, College of Natural Resources, Virginia Polytechnic Institute and State University, 324 Cheatham Hall, Blacksburg, VA 24061.

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## Silvicultural Treatments

Three treatments, each randomly replicated three times, were imposed on the sample plots. The first treatment (light) involved a thinning in which undesired species in the overstory were cut, retaining only eastern redcedar, Virginia pine, post oak, and other species identified by the NPS staff. This treatment was applied to plots 3, 6, and 8. In June of 2001, trees were cut and the slash distributed over the sample plots or relocated to plots scheduled for burning. Two herbicide treatments were also applied to the light treatment. Pathway™ (picloram; 2,4-dichlorophenoxyacetic acid) was applied at a rate of 18.9 L/ha to stumps after cutting to prevent sprouting. Two months later, Brushmaster® [isooctyl (2-ethylhexyl) ester of 2,4-dichlorophenoxyacetic acid; 2-ethylhexyl ester of (+)-R-2-(2,4-dichlorophenoxy) propionic acid; Dicamba] was directly applied to any emerging hardwood species at a rate of 9.5 L/ha.

The second treatment (heavy) included a thinning, an herbicide application as previously described, and a low-intensity prescribed burn, which was applied in April of 2002. This treatment was applied to plots 2, 4, and 7. A prescribed burn plan was prepared by the NPS and used in the implementation of the heavy treatment. This plan provided guidelines for acceptable weather conditions for the day of burning as well as the desired burn characteristics such as rate of spread and flame length. Environmental conditions on the day of burn, including wind speed (km), temperature (°C), wind chill (°C), relative humidity (percent), heat index (°C), and dew-point (°C), are reported in table 1. The specific prescribed burn characteristics for each plot, including duration of burn (min), distance between drip torch lines (m), and flame height by fuel type (m), are presented in table 2.

The third treatment was a control, used for reference, with no active management. The control treatment was assigned to plots 1, 5, and 9.

## Post-Treatment Measurements

Post-treatment vegetation was sampled for each plot during the summers of 2002 and 2003. Overstory assessment included all tree species  $\geq 5$  m in height. D.b.h. (cm) and height (m) were measured for each tree. Basal area/ha (BA/ha) was used to calculate dominance. Density was calculated as the number of stems/ha.

The understory was sampled using trees and shrubs that were 1 to 5 m in height. Dominance and density were calculated by species group for the understory tree stratum. For each understory tree species, diameter was recorded and relative dominance, relative frequency, and relative density were calculated. The regeneration stratum was evaluated by measuring the density of each tree and shrub species. Relative density and relative frequency were also calculated for each species. Importance values (IVs) were calculated by averaging the mean relative dominance, relative density, and relative frequency (Mueller-Dombois and Ellenberg 1974).

## Data Analysis

The effects of the silvicultural treatments, light (thinning/herbicide) and heavy (thinning/herbicide/prescribed burn) as compared to control (no treatment), on the composition and density of tree species were studied by analysis of variance using a completely randomized design. Tree and shrub species

**Table 1—Environmental conditions for prescribed burn applied in April of 2002 on Brookside Island, Summers County, WV**

Environmental condition	Plot		
	2	4	7
Wind (km/h)	6.4	2.3	3.5
Temperature (°C)	19.3	19.5	15.4
Wind chill (°C)	19.8	19	15.3
Relative humidity (%)	18	14	27
Heat index (°C)	18	16.2	13.6
Dew point (°C)	-5	-4.9	-4

**Table 2—Burn characteristics for prescribed burn applied in April of 2002 on Brookside Island, Summers County, WV**

Prescribed burn characteristics	Plot		
	2	4	7
Burn order	3	2	1
Duration of burn (min)	20	30	50
Rate of spread (km/h)	0.072	0.048	0.288
Distance between drip-torch lines (m)	1	1.5-2	N/A <sup>a</sup>
Flame heights (m):			
Grass	0.1-0.4	0.1-0.2	0.08-0.1
Light debris	0.3-1.8	0.3-0.8	0.3-0.38
Heavy debris	0.6-1.2	0.6-1.2	0.6-0.8

<sup>a</sup> Drip-torch lines were sparse due to sufficient fuel loads to carry across plot 7.

were grouped into four categories including riparian, upland, target, and exotic. Each of the three treatments was applied three times at random to the nine plots. Replications from each treatment were compared to determine significant differences, followed by mean separation using the Tukey HSD (honestly significant difference) test (Zar 1999). All percent data were arcsine transformed prior to analysis.

## RESULTS AND DISCUSSION

The effects of silvicultural treatments on the IVs of overstory species groups are presented in table 3. The purpose of the treatments was to promote the target species while discriminating against the other species groups. Two years following treatment, the IVs of target species in both silvicultural treatments were significantly > in the control treatment. IVs for the target species in 2003 averaged 100 percent in the light treatment, 99 percent in the heavy treatment, and 82 percent in the control (table 3). This shift in importance came largely at the expense of the upland species, which were significantly reduced by both treatments.

Similar to the overstory, the applied silvicultural treatments caused significant effects on the IVs of species groups in the understory (table 4). For example, in 2003, 2 years after the treatments, IVs of riparian species in the treated plots were significantly lower than in the control, while the IVs of the target species were significantly higher in the treated plots than

**Table 3—Mean importance value of the three species groups (riparian, target, and upland) in the overstory stratum sampled annually in July of 2000, 2002, and 2003 on Brookside Island, Summers County, WV**

Treatment	Species group	N	Importance value					
			Mean <sup>a</sup>			S.E.		
			2000	2002	2003	2000	2002	2003
----- percent -----								
Control	Riparian	3	2.3 a A	2.4 a A	2.4 a A	1.3	1.2	1.2
	Target	3	83.0 a A	81.0 a A	82.4 a A	6.3	6.9	8.2
	Upland	3	14.7 a A	16.7 a A	15.2 a A	5.0	6.1	7.2
Heavy	Riparian	3	2.6 a A	0.0 a A	0.0 a A	1.3	0.0	0.0
	Target	3	83.6 a A	99.5 b B	99.4 b B	5.6	0.5	0.6
	Upland	3	13.9 a A	0.5 b B	0.6 b B	4.6	0.5	0.6
Light	Riparian	3	0.6 a A	0.0 a A	0.0 a A	0.6	0.0	0.0
	Target	3	75.5 a A	100.0 b B	100.0 b B	7.6	0.0	0.0
	Upland	3	23.9 a A	0.0 b B	0.0 b B	7.8	0.0	0.0

<sup>a</sup> Means followed by the same letter are not significantly different at  $\alpha = 0.1$  level. (Note: a = within each species group and between treatments; A = within each treatment and between years).

**Table 4—Mean importance value of the four species groups (exotic, riparian, target, and upland) in the understory stratum sampled annually in July of 2000, 2002, and 2003 on Brookside Island, Summers County, WV**

Treatment	Species group	N	Importance value					
			Mean <sup>a</sup>			S.E.		
			2000	2002	2003	2000	2002	2003
----- percent -----								
Control	Exotic	3	0.0 a A	0.0 a A	0.0 a A	0.0	0.0	0.0
	Riparian	3	51.2 a A	51.1 a A	55.5 a A	9.5	3.5	11.2
	Target	3	16.4 a A	16.6 a A	18.8 a A	9.2	6.5	12.3
	Upland	3	32.5 a A	32.2 a A	25.6 a A	6.8	3.2	2.4
Heavy	Exotic	3	0.0 a A	0.0 a A	0.0 a A	0.0	0.0	0.0
	Riparian	3	35.1 a A	6.9 b B	9.8 b AB	6.9	6.9	4.9
	Target	3	16.9 a A	88.0 b B	79.1 b B	5.4	12.0	8.6
	Upland	3	48.0 a A	5.1 a B	11.2 a B	8.2	5.1	6.9
Light	Exotic	3	0.0 a A	0.0 a A	2.0 a A	0.0	0.0	2.0
	Riparian	3	32.5 a A	14.4 ab A	9.2 b A	11.4	14.4	4.7
	Target	3	11.9 a A	58.4 b A	68.6 b A	3.3	22.1	16.3
	Upland	3	55.7 a A	27.2 a A	20.3 a A	13.6	14.5	11.4

<sup>a</sup> Means followed by the same letter are not significantly different at  $\alpha = 0.1$  level. (Note: a = within each species group and between treatments; A = within each treatment and between years).

in the control. In the heavy treatment, the pre-treatment IV for target species was 16.9 percent, while 2 years after treatment it was 79.1 percent, a significant increase. Similarly, in the light treatment the IV of the target species increased from 11.9 percent to 68.6 percent (table 4).

The understory shrub stratum was not as diverse as the overstory and understory tree strata, with two species groups identified, exotic species and upland species (table 5). The heavy treatment significantly reduced the importance of the upland shrubs, from 94 percent prior to treatment to 33 percent 2 years post-treatment. The IVs of exotic species did not differ either over time or across treatments. The highest IV for

exotic species was 31 percent in the control treatment in 2003. The shrub stratum was affected by all the silvicultural treatments, including cutting, herbicide application, and fire. Thus, the shrub stratum was the first to show significant differences between the light and heavy treatments.

The effects of silvicultural treatments on IVs and densities of regeneration species groups are shown in tables 6 and 7. The importance values of the dominant species groups, target and upland, were unaffected by the silvicultural treatments (table 6). The treated plots, however, did show a significant increase in the importance of exotic species, from 0 in 2000 to 15 percent in the heavy treatment to 4 percent in the light

**Table 5—Mean importance value of the two species groups (exotic and upland) in the understory shrub stratum sampled annually in July of 2000, 2002, and 2003 on Brookside Island, Summers County, WV (note: riparian shrub species were not present in the understory stratum)**

Treatment	Species group	N	Importance value					
			Mean <sup>a</sup>			S.E.		
			2000	2002	2003	2000	2002	2003
----- percent -----								
Control	Exotic	3	18.4 a A	25.0 a A	30.5 a A	9.4	12.6	15.7
	Upland	3	81.6 a A	75.0 a A	69.5 a A	9.4	12.6	15.7
Heavy	Exotic	3	6.5 a A	0.0 a A	0.0 a A	3.3	0.0	0.0
	Upland	3	93.5 a A	0.0 b B	33.3 a AB	3.3	0.0	33.3
Light	Exotic	3	3.7 a A	0.0 a A	0.0 a A	3.7	0.0	0.0
	Upland	3	63.0 a A	0.0 b A	0.0 a A	31.6	0.0	0.0

<sup>a</sup> Means followed by the same letter are not significantly different at  $\alpha = 0.1$  level. (Note: a = within each species group and between treatments; A = within each treatment and between years).

**Table 6—Mean importance value of the four species groups (exotic, riparian, target, and upland) in the regeneration stratum sampled annually in July of 2000, 2002, and 2003 on Brookside Island, Summers County, WV**

Treatment	Species group	N	Importance value					
			Mean <sup>a</sup>			S.E.		
			2000	2002	2003	2000	2002	2003
----- percent -----								
Control	Exotic	3	0.0 a A	1.6 a A	3.2 a A	0.0	1.6	1.7
	Riparian	3	16.7 a A	13.2 a A	25.0 a A	8.7	5.2	7.8
	Target	3	17.8 a A	35.8 a A	24.2 a A	11.3	3.8	7.9
	Upland	3	65.5 a A	49.3 a AB	47.6 a B	6.9	3.5	1.4
Heavy	Exotic	3	0.0 a A	15.4 b B	5.4 a A	0.0	5.5	0.8
	Riparian	3	19.7 a A	5.6 a A	12.7 a A	17.1	1.1	4.7
	Target	3	26.6 a A	30.3 a A	28.7 a A	1.8	10.2	1.5
	Upland	3	53.7 a A	48.6 a A	53.2 a A	16.9	7.9	4.0
Light	Exotic	3	0.0 a A	4.1 ab B	3.7 a AB	0.0	0.7	2.7
	Riparian	3	17.8 a A	7.3 a A	19.3 a A	13.4	1.8	1.6
	Target	3	24.5 a A	38.2 a A	23.8 a A	8.7	5.0	3.1
	Upland	3	57.7 a A	50.4 a A	53.2 a A	12.1	2.8	4.8

<sup>a</sup> Means followed by the same letter are not significantly different at  $\alpha = 0.1$  level. (Note: a = within each species group and between treatments; A = within each treatment and between years).

treatment in 2001, a significant increase in both cases. Interestingly, the number of seedlings increased significantly in all treatments, including the control, over the course of the study (table 7). For example, in the heavy treatment, target species increased from 15,417 seedlings/ha in 2000 to 49,167 seedlings/ha in 2003, a significant increase. However, during this same time period, the number of seedlings of the upland species also increased significantly, from 18,333/ha to 89,167/ha. In the control plots, the number of riparian and upland seedlings also increased significantly. This increase was attributed to the greater than normal precipitation during the study period, which influences seed abundance and germination and establishment success. The long-term average precipitation for Summers County, WV, is 94 cm per year. However, annual precipitation was 123 cm in 2002 and 133 cm in 2003.

## CONCLUSIONS AND RECOMMENDATIONS

(1) Both thinning and herbicide treatments are effective in favoring desired species over the invading upland and riparian species. (2) Prescribed burning does not appear to significantly improve the responses over thinning and herbicide application alone, although target seedling density increased significantly after burning. (3) Exotic species composition in the regeneration stratum increased, but not significantly. This should be carefully monitored and control strategies implemented if the invasion increases significantly. (4) Numbers of seedlings increased significantly in all treatments, including the controls, over the 2-year study period, due to favorable moisture conditions. It is expected that, due to more favorable light levels in the treated plots, over time survival will be higher in the treated plots.

**Table 7—Mean density of the four species groups (exotic, riparian, target, and upland) in the regeneration stratum sampled annually in July of 2000, 2002, and 2003 on Brookside Island, Summers County, WV**

Treatment	Species group	N	Density					
			Mean <sup>a</sup>			S.E.		
			2000	2002	2003	2000	2002	2003
----- number of stems/ha -----								
Control	Exotic	3	0 a A	1,667 a A	2,500 a A	0	1,667	1,443
	Riparian	3	2,917 a A	6,667 a A	33,750 a B	1,502	2,732	10,777
	Target	3	8,750 a A	36,250 a A	47,083 a A	7,535	6,960	20,276
	Upland	3	19,583 a A	32,917 a A	64,583 a B	5,320	4,229	833
	Total			31,250	77,500	147,917		
Heavy	Exotic	3	0 a A	23,333 a A	7,500 a A	0	18,348	2,165
	Riparian	3	13,750 a A	2,500 a A	16,667 a A	13,130	722	8,427
	Target	3	15,417 a A	34,583 a AB	49,167 a B	3,975	9,419	6,821
	Upland	3	18,333 a A	51,667 a AB	89,167 a B	4,229	18,559	14,866
	Total			47,500	112,083	162,500		
Light	Exotic	3	0 a A	2,500 a A	5,000 a A	0	722	3,819
	Riparian	3	6,667 a A	3,750 a A	19,167 a A	5,465	1,250	5,512
	Target	3	10,417 a A	42,500 a A	34,583 a A	7,372	10,897	11,235
	Upland	3	14,167 a A	34,167 a A	66,250 a B	4,696	4,410	5,204
	Total			31,250	82,917	125,000		

<sup>a</sup> Means followed by the same letter are not significantly different at  $\alpha = 0.1$  level. (Note: a = within each species group and between treatments; A = within each treatment and between years).

**LITERATURE CITED**

Mahan, C.G. 2004. A natural resource assessment for New River Gorge National River. Tech. Rep. NPS/NER/NRTR-2004/002. Philadelphia, PA: U.S. Department of the Interior, National Park Service, Northeast Region. 129 p.

McDonald, B.R.; Trianosky, P. 1995. Assessment of and management recommendations for the plant communities and rare species of Camp Brookside, New River Gorge National River. Tech. Rep. 95-5. Elkins, WV: West Virginia Natural Heritage Program, Division of Natural Resources, and The Nature Conservancy. 26 p.

Mueller-Dombois, D.; Ellenberg, H. 1974. Aims and methods of vegetation ecology. New York, NY: John Wiley and Sons. 547 p.

Zar, J.H. 1999. Biostatistical analysis. Upper Saddle River, NJ: Prentice Hall. 663 p.

# CAN ROOT BIOMASS OF WHITE OAK ADVANCE REGENERATION BE RELIABLY PREDICTED FROM DIAMETER AND HEIGHT?

Benjamin O. Knapp, G. Geoff Wang, Joan L. Walker, and David H. Van Lear<sup>1</sup>

## Poster Summary

The successful regeneration of oak-dominated stands is an issue of concern for foresters today. The size of the root system is directly related to the rate of growth following release and therefore to the chances of establishment of regrowth. The size of the root system is difficult to measure without destructive sampling, but it may be assessed through modeling. The objectives of this study were to test if root biomass of white oak (*Quercus alba* L.) could be predicted from aboveground measurements of diameter and/or height and to determine if disturbance history affected this prediction.

### METHODS

A mature hardwood stand in northwestern South Carolina was chosen for the study. One hundred thirty two seedlings were randomly selected (70 from a burned area and 62 from a control area) for measurement. Diameter measurements were taken at the level of the litter layer (DL), the level of the humus layer (Dh), and at the root collar (RCD). Height (H) was also measured for each seedling and incorporated with diameter measurements in additional variables (DL<sup>2</sup>H, Dh<sup>2</sup>H, RCD<sup>2</sup>H). Linear regression was performed to determine relationships between the log of aboveground measurements and the log of root biomass. F-tests with full and reduced models were used to determine if separate models were needed for the burned vs. unburned sites.

### RESULTS AND DISCUSSION

The results of the F-tests indicate that separate models are needed for all variables except DL, which was additionally modeled separately for comparison purposes. On the burned sites, all the aboveground variables provided adequate prediction of root biomass, with R<sup>2</sup> values ranging from 0.754 to 0.884. On the control site, RCD was the only good diameter measure for root biomass prediction, with an R<sup>2</sup> value of 0.848. The other diameter measures, DL and Dh, were poor predictors of root biomass (R<sup>2</sup> values of 0.553 and 0.531, respectively). On the unburned area, seedling shoots are likely to die back, although they do not resprout synchronously. Additionally, the seedlings are not able to sprout to their full potential until released from competition, therefore not utilizing the entire carbohydrate reserves in the roots. Although the root collar diameter measurement requires digging down into the mineral soil, in our study this was < 1 cm deep, making this a feasible field measurement.

### CONCLUSION

Root biomass can be reliably predicted from aboveground measures, although this differs based on disturbance history. On burned sites, the diameter at the top of the litter is adequate, while on unburned or unknown sites the diameter at the root collar should be used to predict root biomass.

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<sup>1</sup> Graduate Student and Assistant Professor, respectively, Department of Forestry and Natural Resources, 261 Lehotsky Hall, Clemson University, Clemson, SC 29634-0317; Research Ecologist, USDA Forest Service, Southern Research Station, 261 Lehotsky Hall, Clemson University, Clemson, SC 29634-0317; and Bowen Professor of Forest Resources, Clemson University, Department of Forestry and Natural Resources, Clemson, SC 29634-0317.

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# CAN PRESCRIBED FIRES BE USED TO PROMOTE THE RECRUITMENT OF WHITE OAK (*QUERCUS ALBA*) SEEDLINGS?

G. Geoff Wang, David H. Van Lear, and William L. Bauerle<sup>1</sup>

## Poster Summary

Widespread oak replacement by mesophytic tree species, especially on good quality sites, has been occurring across the Eastern United States, because advance oak reproduction is severely limited by the development of heavy midstory and understory. Anecdotal evidence suggests that the development of heavy midstory and understory coincides with the implementation of a fire exclusion policy in the 1920s. Effective fire exclusion over the past 80 years has, therefore, contributed to the current problem of oak regeneration. Using prescribed fire to promote oak regeneration has been successful, but prior studies generally focused on how to use prescribed burning to enhance the relative competitiveness of advance oak regeneration. How does prescribed fire affect the recruitment of new oak seedlings? This important question has not been studied. The objectives of this study were to (1) investigate the effects of prescribed fires on white oak seedling survival and growth during the first growing season following a heavy mast year; and (2) to determine if white oak seedling survival and growth during the first growing season were affected by forest floor depth and understory light intensity.

## METHODS

Three hardwood forest stands dominated by oaks (mainly *Quercus alba* L.), hickories (*Carya* spp.), and yellow-poplar (*Liriodendron tulipifera* L.) were selected in the Clemson University Experimental Forest. White oak had its first heavy mast crop in 2002 since the prescribed fires in 1999 and 2000. In May 2003, 6 to 8 dominant white oak trees were randomly selected in each stand. Four 2-m-radius quadrats were established around each selected tree, and total germinated and surviving seedlings were counted and marked within each quadrat. In August 2003, percent full sunlight was determined at 30 cm above each quadrat, and forest floor depth (litter and duff) was measured at four points and averaged for each quadrat. In October 2003, each quadrat was revisited. White oak seedlings were recounted, and up to three seedlings per quadrat were randomly selected, excavated, and brought back to the laboratory to determine above- and below-ground biomass. Analyses of variance (with stands as blocks, burned vs. non-burned as treatments and trees as replicates) were conducted on white oak seedling measurements and site variables. Nonlinear and linear regression analyses were used to quantify their relationships.

## RESULTS AND DISCUSSION

Burning significantly affected density and biomass but not mortality and root to shoot ratio. Biomass was 58 percent higher in burned plots compared to control. Fire effects on density, forest floor depth, and light intensity varied among stands. With increasing forest floor depth, both seedling density and biomass significantly decreased, following a power relationship. Similarly, both density and biomass significantly increased with increasing understory light intensity. Our study indicated that prescribed fire had a positive effect on both density and biomass of oak seedlings after their first growing season. Effects of burning on density differed greatly among the three stands, suggesting fire behavior may be an important factor to consider when using prescribed fires to promote oak seedling recruitment. It would be beneficial if prescribed fires could be timed to coincide with a good mast year to ensure that acorns have a favorable environment for germination, survival, and growth. More studies are needed to elucidate the effect of fire behavior on initial recruitment and subsequent development of oak seedlings.

## CONCLUSIONS

White oak seedling establishment and growth during the first growing season benefited from prior prescribed fires. The fires reduced forest floor depth and increased understory light intensity, effects that remained significant at the time of the study. Seedling survival and growth were positively related to understory light intensity but negatively related to forest floor depth. For the purpose of promoting white oak seedling recruitment, prescribed fire should be conducted a year or two prior to a good mast year; the fires should be of sufficient intensity/severity to consume the forest floor and kill under- and mid-story competing vegetation.

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<sup>1</sup> Associate Professor and Bowen Professor, respectively, Clemson University, Department of Forestry and Natural Resources, Clemson, SC 29634; and Assistant Professor, Clemson University, Department of Horticulture, Clemson, SC 29634.

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# SOIL PHYSICAL AND CHEMICAL PROPERTIES ASSOCIATED WITH FLAT ROCK AND RIPARIAN FOREST COMMUNITIES

David O. Mitchem, James E. Johnson, and Laura S. Gellerstedt<sup>1</sup>

**Abstract**—Flat Rock forest communities are unique ecosystems found adjacent to some large rivers in the Central and Southern Appalachian Mountains. Characterized by thin, alluvial soils overlying flat, resistant sandstone, these areas are maintained by severe flooding and have unique associated plant systems. With the advent of dams to control flooding in the 20<sup>th</sup> century, many flat rock communities have declined; these areas have been invaded by both exotic species and traditional riparian trees and shrubs. A flat rock forest community and adjacent riparian forest were studied to determine the soil physical and chemical properties associated with each. Vegetation measurements were made of overstory, understory, and regeneration strata and were related to soil characteristics. Based on these measurements, silvicultural treatments to maintain the principal species in the flat rock community were proposed.

## INTRODUCTION

The National Park Service (NPS), New River Gorge National River (NRGRR), has expressed concern about natural plant succession in the riverside flat rock forest community (FRFC) at Camp Brookside, Summers County, WV. Camp Brookside has the largest known concentration of rare plant species within the NRGRR (Rouse and McDonald 1986). Riparian hardwoods, exotic trees, shrubs, and vines are slowly colonizing the lower canopy of this community as natural weathering, organic matter deposition, and plant succession occur. The FRFC was created and maintained by periodic flooding of the New River (Trianosky 1995). However, since the Bluestone Dam was constructed in 1949, flooding waters have been less frequent and less catastrophic, allowing typical riparian forest tree species to become established in the FRFC. The objectives of this study are to assess the current status of the forest communities found on Camp Brookside, provide baseline data for future comparisons of organic matter accumulation and soil development within the FRFC, and provide recommendations for silvicultural treatments to maintain the principal species in the FRFC.

## METHODS

Camp Brookside, a seasonal island, is located on the floodplain of the New River in Summers County, WV. The property is located 10.3 km downstream from Bluestone Dam and is 10.4 ha in size. In the spring of 2000, 10 transects with 44 sample locations were established on the island. A circular 0.04-ha plot was established for overstory sampling at each sample point. Species, diameter at breast height (d.b.h.), and crown class were recorded for all trees > 5 m in height. The plant communities were identified based on the dominant overstory tree species. The dominant overstory trees within the community were identified by having the highest importance values (IVs). One healthy dominant or codominant tree in each plot was cored at breast height to determine age.

Soil and litter samples were collected from four fixed locations along a transect within each sample plot. Soil samples were collected for 2 depths: 0 to 10 cm and 10 to 20 cm.

A composite soil sample for each depth was collected in the field. A composite litter sample was collected from the same four locations where the soil was collected.

## DATA ANALYSIS

IVs were calculated for the overstory and lower canopy trees (Mueller-Dombois and Ellenberg 1974). The overstory and lower canopy tree IVs were calculated by [(relative density + relative dominance + relative frequency)/3] for each species. The Shannon-Weiner diversity index (SWDI) is a measure of the diversity of a community. The SWDI was calculated for each community using the following formula:

$$SWDI = \sum_{i=1}^s (p_i)(\log_e p_i)$$

where

SWDI = index of species diversity

s = number of species

p<sub>i</sub> = proportion of total sample belonging to the i<sup>th</sup> species

log<sub>e</sub> = natural logarithm

## RESULTS

Three distinct plant communities were identified in our study at Camp Brookside. The best expression of the flat rock forest community is the eastern redcedar (*Juniperus virginiana* L.)-white ash (*Fraxinus americana* L.)- Virginia pine (*Pinus virginiana* Mill.) community which occupies 0.8 ha. Vegetation in the flat rock forest community grows in cracks or depressions where soil and organic material have accumulated. Eastern redcedar is the dominant species in the overstory of this community. Eastern redcedar comprised 2.0 m<sup>2</sup>/ha of basal area (57 percent of the total) and had an IV of 49 percent, while Virginia pine comprised 1.4 m<sup>2</sup>/ha of basal area (27 percent of total) and had an IV of 25 percent (table 1). The overstory has a density of 256 stems/ha. The lower canopy is dominated by white ash and eastern redcedar with a cumulative IV of 67 percent (table 2). Overstory tree ages within this

<sup>1</sup> Forestry Research Specialist, Professor of Forestry and Associate Dean of Outreach, and Graduate Research Assistant, respectively, Department of Forestry (0324), Virginia Polytechnic Institute and State University, College of Natural Resources, Blacksburg, VA 24061.

**Table 1—Overstory tree characteristics for the flat rock forest community at Camp Brookside, Summers County, WV**

Species	Average diameter	Average height	Density	Basal area	Relative density	Relative dominance	Relative frequency	Importance value
	<i>cm</i>	<i>m</i>	<i>stems/ha</i>	<i>m<sup>2</sup>/ha</i>	----- percent -----			
Eastern redcedar	17.1	8.6	132	2.9	51.6	57.2	37.5	48.7
White ash	10.7	9.5	66	0.8	25.8	15.8	37.5	26.4
Virginia pine	17.0	9.6	58	1.4	22.6	27.0	25.0	24.9
Total			256	5.1	100.0	100.0	100.0	100.0

**Table 2—Lower canopy tree characteristics for the flat rock forest community at Camp Brookside, Summers County, WV**

Species	Average diameter	Density	Relative density	Relative dominance	Relative frequency	Importance value
	<i>cm</i>	<i>stems/ha</i>	----- percent -----			
White ash	2.0	124	37.5	37.8	37.5	37.6
Eastern redcedar	2.8	82	25.0	39.0	25.0	29.7
Virginia pine	1.5	82	25.0	10.1	25.0	20.0
Northern red oak	2.3	41	12.5	13.1	12.5	12.7
Total		329	100.0	100.0	100.0	100.0

community ranged from 25 to 60 years. This community has a SWDI of 1.5. A complete list of common and scientific names for all trees and shrubs found within the sample plots is located in the appendix.

Soil physical and chemical properties for each of the three communities can be found in table 3. The FRFC had the shallowest soil on the island, with a mean soil depth of 1.8 cm. The textural classification for this community is loamy sand. The soil had a pH of 3.91, a total carbon content of 12.42 percent, and a nitrogen content of 0.62 percent. These values for nitrogen and carbon are much higher than would be expected for a site that would be considered infertile. Reasons for these high values include slow decomposition rates due to acidic soils, pine needles high in lignin, and very dry conditions.

The xeric pine forest community is dominated by Virginia pine, eastern redcedar, and white ash. This community is also a FRPC but is undergoing succession toward more tolerant, riparian forest vegetation. This community occupies 1.4 ha. Virginia pine is the dominant overstory tree in this community;

it comprised 11.1 m<sup>2</sup>/ha of basal area (56 percent of total) and had an IV of 35 percent, while eastern redcedar comprised 3.7 m<sup>2</sup>/ha of basal area (10 percent of total) and had an IV of 22 percent (table 4). Twenty-six percent of the basal area in this community is comprised of deciduous species, mostly riparian in nature. The overstory has a density of 893 stems/ha. Twenty-seven tree species were found in the lower canopy. Fringetree (*Chioanthus virginicus* L.), eastern redcedar, and northern hackberry (*Celtis occidentalis* L.) are the prominent tree species growing in the lower canopy, with a cumulative IV of 44 percent (table 5). Overstory tree ages within this community ranged from 34 to 104 years. This community has a SWDI of 2.8. The xeric pine community has a mean soil depth of 17.6 cm. The texture classification for this community is loamy sand. The soil has a pH of 4.61, a total carbon content of 5.83, and a nitrogen content of 0.25 (table 3).

The largest forest community on Camp Brookside is a riparian forest which occupies 3.7 ha. Yellow poplar (*Liriodendron tulipifera* L.), Carolina silverbell (*Halesia carolina* L.), and white ash are the dominant species found in this community.

**Table 3—Soil physical and chemical properties by plant community at Camp Brookside, Summers County, WV**

Plant community	Soil depth	Coarse fragments	Texture classification	Total carbon	Total nitrogen
	<i>cm</i>	<i>percent</i>		--- percent ---	
Riparian forest	48.5	4.6	Loamy sand	4.12	0.18
Xeric pine forest	17.6	14.1	Loamy sand	5.83	0.25
Flat rock forest	1.8	5.1	Loamy sand	12.42	0.62

**Table 4—Overstory tree characteristics for the xeric pine forest community at Camp Brookside, Summers County, WV**

Species	Average dbh	Average height	Density	Basal area	Relative density	Relative dominance	Relative frequency	Importance value
	<i>cm</i>	<i>m</i>	<i>stems/ha</i>	<i>m<sup>2</sup>/ha</i>	----- percent -----			
Virginia pine	23.4	13.0	301	11.1	33.8	55.3	14.9	34.7
Eastern redcedar	13.6	9.9	280	3.7	31.4	18.4	14.9	21.6
White ash	15.4	11.5	110	2.6	12.4	13.2	13.9	13.1
Post oak	11.6	10.4	35	0.5	3.9	2.6	8.9	5.1
Sugar maple	14.2	11.7	38	0.7	4.3	3.7	5.9	4.6
Downy serviceberry	10.3	9.7	21	0.3	2.4	1.5	7.9	3.9
Northern red oak	10.4	12.6	12	0.1	1.3	0.7	4.0	2.0
Eastern hornbeam	6.0	7.6	8	0.02	0.9	0.1	4.0	1.7
Fringetree	5.2	9.2	10	0.02	1.1	0.1	3.0	1.4
American basswood	6.5	9.4	15	0.05	1.7	0.2	2.0	1.3
Black cherry	5.7	9.2	7	0.02	0.7	0.1	3.0	1.3
Ironwood	5.5	7.4	8	0.02	0.9	0.1	2.0	1.0
Black locust	11.9	10.7	5	0.08	0.6	0.4	2.0	1.0
Bitternut hickory	13.7	13.6	10	0.15	1.1	0.7	1.0	0.9
Red maple	20.7	12.3	7	0.20	0.7	1.1	1.0	0.9
Mockernut hickory	8.6	10.9	5	0.03	0.6	0.1	2.0	0.9
Chestnut oak	8.5	8.4	3	0.02	0.4	0.1	2.0	0.8
White oak	35.7	14.5	2	0.17	0.2	0.8	1.0	0.7
Pawpaw	9.8	4.1	3	0.02	0.4	0.1	1.0	0.5
American elm	17.5	15.1	2	0.04	0.2	0.2	1.0	0.5
American sycamore	15.0	15.3	2	0.03	0.2	0.2	1.0	0.5
Sweet birch	14.7	11.4	2	0.03	0.2	0.1	1.0	0.4
Slippery elm	13.0	11.5	2	0.02	0.2	0.1	1.0	0.4
Shagbark hickory	3.9	7.0	2	0.01	0.2	0.1	1.0	0.4
Tree-of-heaven	4.0	8.7	3	0.01	0.2	0.02	1.0	0.4
Total			893	19.9	100.0	100.0	100.0	100.0

Yellow poplar comprised 8.7 m<sup>2</sup>/ha of basal area (38 percent of total) and had an IV of 20 percent (table 6). Carolina silverbell comprised 2.0 m<sup>2</sup>/ha of basal area (8 percent of total) and had an IV of 13 percent, while white ash comprised 2.0 m<sup>2</sup>/ha of basal area (8 percent of total) and had an IV of 11 percent. Bitternut hickory [*Carya cordiformis* (Wang.) K. Koch], American sycamore (*Platanus occidentalis* L.), black cherry (*Prunus serotina* Ehrh.), and sugar maple (*Acer saccharum* Marsh.) are the primary canopy associates in this community. The overstory has a density of 634 stems/ha. Carolina silverbell, sugar maple, white ash, and northern hackberry are the prominent tree species growing in the lower canopy, with a cumulative IV of 50 percent (table 7). Overstory tree ages within this community ranged from 34 to 83 years. It had a SWDI of 3.0, which is the highest of all of the communities on the island. This community had the deepest soil on the island, with a mean soil depth of 48.5 cm; the texture classification is loamy sand. The soil has a pH of 5.56, a total carbon content of 4.12, and a nitrogen content of 0.18 (table 3).

## DISCUSSION

Today the FRFC is in fair condition but is declining. The community is considered to be in fair condition due to the large areas within it that are still bare to almost bare sandstone with sparse vegetation. The establishment of white ash within

the overstory and white ash's dominance in the lower canopy is evidence that the community is in decline. Honeysuckle (*Lonicera japonica*), a known invasive species, can be found along the community edges. Historically, a large part of the xeric pine forest community was considered to be a FRFC. The xeric pine forest community gives us a glimpse of what the FRFC will look like in the future if no disturbance regime is implemented to preserve it. Soil will continue to develop and deepen, and there will be an increase in the diversity of species within the overstory, lower canopy, and regeneration strata. Flooding the island is no longer an option due to the damage it would cause to the surrounding community, and fire is not a practical management tool due to the lack of adequate fuel on the site and the sensitivity of eastern redcedar and Virginia pine to fire.

## RECOMMENDATIONS

The manual removal of mesic species and the use of direct herbicide application are practical management tools in maintaining the FRFC at Camp Brookside. This area will need to be monitored by NPS personnel to determine when this disturbance regime will need to be periodically implemented.

**Table 5—Lower canopy tree characteristics for the xeric pine forest community at Camp Brookside, Summers County, WV**

Species	Average dbh	Density	Relative density	Relative dominance	Relative frequency	Importance value
	<i>cm</i>	<i>stems/ha</i>	----- percent -----			
Fringetree	1.8	914	21.1	19.4	12.2	17.6
Eastern redcedar	2.3	445	10.3	25.6	11.7	15.9
Northern hackberry	1.3	610	14.1	9.0	8.3	10.5
White ash	1.5	453	10.5	7.8	6.7	8.3
Downy serviceberry	1.8	173	4.0	4.9	7.2	5.4
Smooth blackhaw	2.0	214	5.0	3.8	7.2	5.3
Redbud	2.0	214	5.0	5.9	5.0	5.3
Sugar maple	1.5	288	6.7	2.9	5.6	5.1
Black cherry	1.0	148	3.4	1.2	5.0	3.2
Bitternut hickory	1.8	107	2.5	2.1	5.0	3.2
Ironwood	1.8	156	3.6	2.2	3.3	3.0
Northern red oak	2.3	82	1.9	3.1	3.3	2.8
Post oak	3.1	82	1.9	3.1	2.8	2.6
Virginia pine	3.1	82	1.9	2.9	2.8	2.5
American elm	1.5	49	1.1	0.7	2.2	1.3
Tree of heaven	1.5	74	1.7	0.9	1.1	1.2
Mockernut hickory	1.8	33	0.8	0.7	2.2	1.2
Carolina silverbell	1.3	41	1.0	0.4	1.7	1.0
Eastern hornbeam	2.3	41	1.0	0.9	1.1	1.0
Sassafras	1.8	33	0.8	0.6	0.6	0.7
Black locust	4.8	8	0.2	1.1	0.6	0.6
Red maple	0.8	25	0.6	0.1	1.1	0.6
Shagbark hickory	1.0	16	0.4	0.1	1.1	0.5
Chestnut oak	2.5	8	0.2	0.3	0.6	0.4
American basswood	2.3	8	0.2	0.3	0.6	0.3
Red mulberry	1.0	8	0.2	0.05	0.6	0.3
Slippery elm	0.5	8	0.2	0.01	0.6	0.2
Total		4,321	100.0	100.0	100.0	100.0

**Table 6—Overstory tree characteristics for the riparian forest community at Camp Brookside, Summers County, WV**

Species	Average dbh	Average height	Density	Basal area	Relative density	Relative dominance	Relative frequency	Importance value
	<i>cm</i>	<i>m</i>	<i>stems/ha</i>	<i>m<sup>2</sup>/ha</i>	----- percent -----			
Yellow poplar	30.7	14.9	94	8.65	14.8	37.5	8.4	20.2
Carolina silverbell	14.6	12.6	142	2.02	22.3	8.7	9.1	13.4
White ash	17.0	12.9	84	1.95	13.2	8.5	10.5	10.7
Bitternut hickory	14.6	12.4	41	0.72	6.4	3.1	7.7	5.7
American sycamore	40.6	14.8	13	1.92	2.0	8.3	4.9	5.1
Black cherry	17.1	10.6	25	0.84	3.9	3.6	4.9	4.1
Sugar maple	18.7	11.4	26	0.76	4.1	3.3	4.9	4.1
Ironwood	10.0	9.7	35	0.25	5.5	1.1	5.6	4.1
Virginia pine	26.2	15.6	22	1.07	3.3	4.6	3.5	3.8
Redbud	8.6	8.6	23	0.20	3.7	0.9	4.9	3.2
American basswood	12.3	11.0	23	0.40	3.7	1.7	3.5	3.0
Northern red oak	18.7	12.7	15	0.44	2.3	1.9	3.5	2.6
Black locust	25.0	12.9	9	0.58	1.4	2.5	3.5	2.5
Eastern redcedar	18.5	12.2	15	0.36	2.3	2.1	2.8	2.4
Sassafras	22.3	14.6	7	0.30	1.1	1.3	2.8	1.7
River birch	39.4	16.4	6	0.71	0.9	3.1	0.7	1.6
White oak	27.7	12.7	4	0.39	0.7	1.7	2.1	1.5
American elm	14.2	11.0	7	0.14	1.1	0.6	2.1	1.3
Persimmon	14.8	11.5	7	0.14	1.1	0.6	1.4	1.0
Black walnut	65.6	15.9	1	0.49	0.2	2.1	0.7	1.0
American beech	27.0	14.6	3	0.26	0.5	1.1	1.4	1.0
Slippery elm	10.5	10.0	9	0.08	1.4	0.3	0.7	0.8
Post oak	13.5	13.6	4	0.06	0.7	0.2	1.4	0.8
Cucumber magnolia	16.4	8.2	3	0.08	0.5	0.3	1.4	0.8
Boxelder	7.0	5.5	4	0.02	0.7	0.1	1.4	0.7
Flowering dogwood	6.2	7.0	3	0.01	0.5	0.04	1.4	0.7
Shagbark hickory	17.6	14.5	3	0.07	0.5	0.31	0.7	0.5
Black oak	31.5	17.1	1	0.11	0.2	0.50	0.7	0.5
Honeylocust	9.1	12.2	1	0.01	0.2	0.04	0.7	0.3
Pawpaw	3.0	5.6	1	0.01	0.2	0.04	0.7	0.3
Mockernut hickory	5.0	7.7	1	0.00	0.2	0.02	0.7	0.3
Red maple	6.0	8.6	1	0.00	0.2	0.02	0.7	0.3
Red mulberry	6.6	7.6	1	0.00	0.2	0.02	0.7	0.3
Total			634	23.05	100.0	100.0	100.0	100.0

**Table 7—Lower canopy tree characteristics for the riparian forest community at Camp Brookside, Summers County, WV**

Species	Average dbh	Density	Relative density	Relative dominance	Relative frequency	Importance value
	<i>cm</i>	<i>stems/ha</i>	----- percent -----			
Carolina silverbell	2.3	676	18.1	19.6	12.6	16.8
Sugar maple	1.5	509	13.6	8.6	11.7	11.3
White ash	2.3	363	9.7	10.8	10.7	10.4
Northern hackberry	2.0	538	14.4	11.6	9.2	11.7
Redbud	2.3	225	6.0	7.2	6.3	6.5
Fringetree	4.8	87	2.3	10.8	2.4	5.2
Black cherry	1.5	174	4.7	2.7	7.3	4.9
Pawpaw	1.3	320	8.6	2.9	2.9	4.8
Ironwood	2.5	116	3.1	4.5	4.4	4.0
Bitternut hickory	1.3	153	4.1	2.1	5.3	3.8
Smooth blackhaw	1.5	116	3.1	2.2	3.9	3.1
Eastern redcedar	2.8	65	1.8	4.1	3.4	3.1
American basswood	2.5	58	1.6	2.2	2.4	2.1
American elm	1.5	58	1.6	0.8	2.9	1.8
Downy serviceberry	2.5	29	0.8	1.3	1.9	1.3
Northern red oak	1.3	44	1.2	0.9	1.9	1.3
White oak	2.0	29	0.8	1.2	1.9	1.3
Yellow poplar	4.1	15	0.4	2.0	1.0	1.1
Sassafras	2.0	29	0.8	0.6	1.5	1.0
Chestnut oak	1.3	36	1.0	0.3	0.5	0.6
Slippery elm	5.1	7	0.2	1.1	0.5	0.6
Flowering dogwood	0.5	15	0.4	.03	1.0	0.5
Black locust	2.5	15	0.4	0.5	0.5	0.5
Sweet cherry	3.3	7	0.2	0.4	0.5	0.4
Hawthorne	3.1	7	0.2	0.4	0.5	0.4
Eastern hornbeam	3.6	7	0.2	0.5	0.5	0.4
Post oak	2.8	7	0.2	0.3	0.5	0.3
Osage orange	2.0	7	0.2	0.2	0.5	0.3
Black gum	1.5	7	0.2	0.1	0.5	0.3
Red maple	1.0	7	0.2	0.1	0.5	0.3
Black walnut	0.8	7	0.2	0.03	0.5	0.2
Total		3,733	100.0	100.0	100.0	100.0

**LITERATURE CITED**

Mueller-Dombois, D.; Ellenberg, H. 1974. Aims and methods of vegetation ecology. New York: John Wiley and Sons. 547 p.

Rouse, G.D.; McDonald, B.R. 1986. Rare vascular plant survey, New River Gorge National River. Final report to the Mid-Atlantic Region, National Park Service. 55 p.

Trianosky, P. 1995. Assessment of and management recommendations for the plant communities and rare species of Camp Brookside, New River Gorge National River. Technical Report 95-5. Charleston, WV: West Virginia Natural Heritage Program. 3-21.

Appendix—Forest tree and shrub list for Camp Brookside, Summers County, WV

Common name	Genus, species	Common name	Genus, species
American basswood	<i>Tilia americana</i> L.	Mockernut hickory	<i>Carya tomentosa</i> (Poir.) Nutt.
American beech	<i>Fagus grandifolia</i> Ehrh.	Multiflora rose	<i>Rosa multiflora</i> Thunb.
American elm	<i>Ulmus americana</i> L.	Northern red oak	<i>Quercus rubra</i> L.
American syacmore	<i>Platanus occidentalis</i> L.	Northern hackberry	<i>Celtis occidentalis</i> L.
Autumn olive	<i>Elaeagnus umbellata</i> Thunb.	Osage orange	<i>Maclura pomifera</i> (Raf.) Schneid.
Bitternut hickory	<i>Carya cordiformis</i> (Wang.) K. Koch	Pawpaw	<i>Asimina triloba</i> (L.) Dunal
Black birch	<i>Betula lenta</i> L.	Persimmon	<i>Diospyros virginiana</i> L.
Black cherry	<i>Prunus serotina</i> Ehrh.	Post oak	<i>Quercus stellata</i> Wangenh.
Black gum	<i>Nyssa sylvatica</i> Marsh.	Privet	<i>Ligustrum</i> spp. L.
Black locust	<i>Robinia pseudoacacia</i> L.	Red maple	<i>Acer rubrum</i> L.
Black oak	<i>Quercus velutina</i> Lam.	Red mulberry	<i>Morus rubra</i> L.
Black walnut	<i>Juglans nigra</i> L.	Redbud	<i>Cercis canadensis</i> L.
Black willow	<i>Salix nigra</i> Marsh.	River birch	<i>Betula nigra</i> L.
Blueberry	<i>Vaccinium</i> spp.	Sassafras	<i>Sassafras albidum</i> (Nutt.) Nees
Boxelder	<i>Acer negundo</i> L.	Shagbark hickory	<i>Carya ovata</i> (Mill.) K. Koch
Carolina silverbell	<i>Halesia carolina</i> L.	Silky dogwood	<i>Cornus amomum</i> Mill.
Chestnut oak	<i>Quercus prinus</i> L.	Silver maple	<i>Acer saccharinum</i> L.
Cucumber magnolia	<i>Magnolia acuminata</i> L.	Slippery elm	<i>Ulmus rubra</i> Muhl.
Deerberry	<i>Vaccinium stamineum</i> L.	Smooth blackhaw	<i>Viburnum prunifolium</i> L.
Downy serviceberry	<i>Amelanchier arborea</i> (Michx.f.) Fern	Spicebush	<i>Lindera benzoin</i> (L.) Blume
Eastern hornbeam	<i>Ostrya virginiana</i> (Mill.) K. Koch	St. John's wort	<i>Hypericum</i> spp.
Eastern redcedar	<i>Juniperus virginiana</i> L.	Sugar maple	<i>Acer saccharum</i> Marsh.
Flowering dogwood	<i>Cornus florida</i> L.	Sweet cherry	<i>Prunus avium</i> (L.) L.
Fringetree	<i>Chionanthus virginicus</i> L.	Tree-of-heaven	<i>Ailanthus altissima</i> (Mill.) Swingle
Green ash	<i>Fraxinus pennsylvanica</i> (Vahl) Fern	Virginia pine	<i>Pinus virginiana</i> Mill.
Hawthorne	<i>Crataegus</i> spp.	Weeping willow	<i>Salix babylonica</i> L.
Honeylocust	<i>Gleditsia triacanthos</i> L.	White ash	<i>Fraxinum americana</i> L.
Ironwood	<i>Carpinus caroliniana</i> Walt.	White oak	<i>Quercus alba</i> L.
Japanese honeysuckle	<i>Lonicera japonica</i>	Witch-hazel	<i>Hamamelis virginiana</i> L.
Leatherwood	<i>Dirca palustris</i> L.	Yellow-poplar	<i>Liriodendron tulipifera</i> L.



## **Hardwood Intermediate Treatments**

*Moderator:*

**CALLIE SCHWEITZER**

USDA Forest Service  
Southern Research Station



# LOGGING DAMAGE TO RESIDUAL TREES FOLLOWING COMMERCIAL HARVESTING TO DIFFERENT OVERSTORY RETENTION LEVELS IN A MATURE HARDWOOD STAND IN TENNESSEE

Wayne K. Clatterbuck<sup>1</sup>

**Abstract**—Partial cutting in mature hardwood stands often causes physical damage to residual stems through felling and skidding resulting in a decline in bole quality and subsequent loss of tree value. This study assessed the logging damage to residual trees following commercial harvesting in a fully stocked, mature oak-hickory stand cut to three overstory basal area retention levels: 12.5, 25, and 50 percent. These treatments were replicated three times in north-facing, south-facing, and ridgetop blocks. The logging operation caused widespread damage to residual trees, with more than 76 percent of the trees experiencing some logging damage regardless of treatment and 45 percent of bole-damaged trees rated as severe damage that would ultimately decrease the future value of the tree. More tree damage occurred at the greater basal area retention levels. After 2 years, bole degrade associated with the formation of epicormic branches was much less compared to the bole damage caused by the physical abrasion from the harvesting operation. Potential damage to retention trees should be considered when evaluating silvicultural options where increasing value of retention trees is an objective.

## INTRODUCTION

Public distaste with clearcutting has led forest managers to seek management and regeneration alternatives. One possible alternative is the two-age system where two distinct age classes are maintained for the majority of the rotation (Nyland 1996). The system is initiated by treatments which retain a limited number of canopy or reserve trees from the previous stand along with a cohort of developing, younger stems. These two ages are allowed to develop together to form a two-aged stand (Beck 1986).

Typically, a two-age stand is created by using a partial cut where a limited number of reserve trees, occupying 10 to 30 square feet of basal area (BA) per acre, are retained. These trees have characteristics (good form, greater than average diameter growth, better log grades, and longevity) advantageous to remain for a second rotation and to increase in value without compromising the regeneration or development of the younger cohort (Miller and Schuler 1995). Although this system has often been termed shelterwood with reserves or irregular shelterwood, the term shelterwood is misleading. The reserve or retention trees are not intended to provide any “sheltering” effect to the regeneration (Stringer 2002). The few remaining canopy trees provide an aesthetic alternative to clearcutting, increase in value, remain in place for another rotation, maintain some mast production for wildlife and seed for reproduction, and are widely spaced so that they do not hinder the developing younger age class.

Forest managers often fail to use partial or deferment cuttings in fully stocked hardwood stands because of the potential of logging damage to highly valued retention or leave trees during the harvesting operation. Retention trees are also subject to the development of epicormic branches, which degrades the bole quality (Meadows 1993). Bole quality, as defined by log grade (Rast and others 1973), is the most important factor in determining value of a hardwood log. In general, Stubbs (1986) estimated that USDA Forest Service log grades 1, 2, and 3 have value ratios of approximately 13:7:1, with butt logs much more likely to produce the better log grades than upper logs.

Any damage to the butt log of retention trees during the harvesting operation or with the formation of epicormic branches would likely lower the log grade and its potential value.

To address the concern about potential tree damage associated with logging operations during partial cutting in fully stocked stands, this study evaluated the damage to residual trees 2 years after various partial cutting treatments in upland hardwood stands in eastern Tennessee. Specific objectives were (1) to determine the amount of logging damage and formation of epicormic branches on residual trees retained at three BA retention levels (12.5, 25, and 50 percent), and (2) to assess the severity and type of damage on residual trees associated with the different levels of harvesting.

## METHODS

### Study Area

This study was conducted at the University of Tennessee Forestry Experiment Station in Oak Ridge, TN. It is one of several multi-dimensional studies located on the same area to evaluate effects of different levels of overstory retention on growth and development of regeneration (Barwatt and others 2006, Olson 2003). Treatment blocks were established within a 75-acre oak-hickory forest that had experienced minimal disturbance since 1935. Aerial photography taken in 1935 by the Tennessee Valley Authority (TVA) indicated that the study area was forested at that time. Soils are moderately productive (site index for white oak at 50 years ranges from 65 to 75 feet) and belong to the Fullerton soil series.

### Experimental Design

A randomized complete block design was used in this experiment. Three blocks containing all the treatments were delineated based on stand structure, forest composition, and landscape position. Analysis of variance indicated significant differences in pre-harvest BA among the three blocks ( $P < 0.05$ ), which justified blocking (table 1). Variation between the blocks was primarily due to topographic position and aspect. Treatments were randomly assigned to 4 acre plots and harvesting

<sup>1</sup> Associate Professor, University of Tennessee, Department of Forestry, Wildlife and Fisheries, Knoxville, TN 37996-4563.

**Table 1—Mean basal area for the three replicate blocks for the logging damage study at the University of Tennessee Forestry Experiment Station, Oak Ridge, TN**

Replicates	Basal area <sup>a</sup> <i>ft<sup>2</sup>acre<sup>-1</sup></i>
Rep #1 (north)	126a
Rep #2 (ridge)	112ab
Rep #3 (south)	88b

<sup>a</sup> Means with different letters are significantly different at  $p=0.05$ .

took place in May and June, 2002. Treatments were based on varying degrees of BA retention: 50, 25, and 12.5 percent.

Stands with the 50, 25, and 12.5 percent BA retention were marked for commercial harvest with the general guideline of creating uniformly distributed stands comprised of desirable species. Common overstory species on the study area were white oak (*Quercus alba* L.), chestnut oak (*Q. prinus* L.), yellow-poplar (*Liriodendron tulipifera* L.), hickories (*Carya* spp.), northern red oak (*Q. rubra* L.), black oak (*Q. velutina* Lam.), southern red oak (*Q. falcata* Michx.), red maple (*Acer rubrum* L.), sugar maple (*A. saccharum* Marsh.), American beech (*Fagus grandifolia* Ehrh.), blackgum (*Nyssa sylvatica* Marsh.), and shortleaf pine (*Pinus echinata* Mill.). Guidelines for selecting desirable leave trees included: (1) proper species with capability of growing and surviving for another 50 years (white and chestnut oak and yellow-poplar were preferred), (2) dominant or codominant crown class, and (3) probability of value increase. Trees in the 14 to 18 inch d.b.h. category were favored for retention, but trees in other size classes and perhaps of less desirable species such as hickory and red maple were retained as necessary to maintain an even distribution across all the treatment units (Olson 2003). Blocks one, two, and three were located on a north-facing slope, flat ridge top, and south facing slope, respectively. Plots within blocks were generally arranged in a linear fashion, parallel to the contour of the slope.

### Treatment Implementation

A commercial timber sale using competitive bids was used to harvest the timber. Even though the harvest took place on a research area, we did not try to influence who would submit the successful bid. We wanted to simulate a sale and harvesting procedure that would be common on most private lands in the area. The leave trees were marked, and the timber harvester was responsible for cutting all unmarked trees. The successful buyer subcontracted the timber to a local logging firm who had not harvested timber on the experiment station previously. The loggers were given very little guidance on how to harvest the timber except for where to locate log landings, primary skid trails, and haul roads. The contract specified that best management practices (Tennessee Department of Agriculture, Division of Forestry 2003) be implemented.

### Data Collection

Each leave tree for every treatment for the three blocks or replicates was visited after the harvest during the fall of 2002 to survey for potential tree damage to the bole and the crown. Trees were classified as damaged, destroyed (if tree was dead or pushed over because of logging damage), or unaffected. The type of damage, whether to the bole, crown, or both, was catalogued. The severity of bole damage (severe, moderate, or minor; see definitions in table 2) was noted. We did not measure or quantify the size of the damage. During the winter of 2004, each tree was visited again to verify the damage code collected in 2002 and to count trees which had epicormic branch formation on the lower 16-foot butt log. Epicormic branches were defined as those that had initiated after the timber harvest and were at least 1 foot long and 3/8 inches in diameter at the bark surface (Meadows and Burkhardt 2001).

## RESULTS

### Number of Trees Retained by Treatment

The total number of retention trees remaining after the harvesting operation and sampled in this study (summed for each treatment across blocks) was 62, 159, and 307 for the 12.5, 25, and 50 percent BA retention treatments, respectively (table 2). Mean diameter of the retention trees was essentially the same across treatments at 16 to 17 inches.

### Logging Damage to Residual Trees

The logging operation caused widespread damage to residual trees. More than 43 percent (27/62) of the trees in the 12.5 BA treatment were classified as damaged or destroyed by the harvesting operation (table 2). The remaining trees, 35, were not damaged by logging. However, more damage, approximately 80 percent of the trees, was found in the 25 and 50 percent BA retention treatments. More trees were damaged as the number of trees retained increased. Few trees remained that were not damaged in these two treatments.

### Type of Logging Damage

Excluding the number of destroyed trees, totaling 16, 13, and 11 percent of the trees sampled for the 12.5, 25, and 50 BA retention treatments, most of the damage to trees was associated with the bole (table 2). The percentage of bole-damaged trees ranged from 64 to 72 percent by treatment. Crown damage was much less, averaging about 20 percent of the damaged trees for each treatment. Trees sustaining both bole and crown damage was < 12 percent for each treatment.

### Severity of Logging Damage to Tree Boles

Most of the bole damage ("bole damage" and "both" categories) was rated as severe (reduction of one log grade) with 54, 45, and 44 percent of bole-damaged trees for the 12.5, 25, and 50 percent BA retention treatments, respectively (table 2). About a third of the bole-damaged trees, regardless of treatment, received the minor rating where bole damage did not reduce log grade. The moderate rating ranged from 15 to 23 percent of the bole-damaged trees.

### Formation of Epicormic Branches

Few epicormic branches developed on the butt log of retention trees after 2 years (table 2). Based on the total number of damaged and unaffected retention trees, only 10 percent of the trees had epicormic branches for the 12.5 and 50 percent

**Table 2—Tree damage comparisons at different basal area retention levels summed for each treatment across blocks for the logging damage study at the University of Tennessee Forestry Experiment Station, Oak Ridge, TN**

	Basal area (BA) retention treatment		
	12.5% BA	25% BA	50% BA
Retention trees			
Total number by treatment	62	159	307
Average diameter ( <i>inches</i> )	16.0	17.0	17.1
- - - - - number of trees - - - - -			
Damage classification <sup>a</sup>			
damaged	17	106	214
destroyed	10	21	34
unaffected	35	32	59
Type of damage			
bole	11	76	147
crown	4	19	40
both	2	11	27
Severity of bole damage <sup>b</sup>			
Severe	7	39	77
Moderate	2	20	34
Minor	4	28	63
Epicormic branches after 2 years <sup>c</sup>	5	18	29

<sup>a</sup> Damaged = visible damage of tree crown or bole or both from harvesting operation; destroyed = tree completely lost during harvesting operation; unaffected = no visible damage to tree.

<sup>b</sup> Severe = bole damage causes log grade to decrease by at least one grade; moderate = bole damage has the "potential" to cause log grade to decrease by at least one class, however, log grade does not change at present; minor = slight bole damage that does not change log grade.

<sup>c</sup> Counted on the 16-foot butt log only.

BA retention levels, with 13 percent of the trees for the 25 percent BA retention treatment.

## DISCUSSION

One of the potential difficulties of partial harvesting in any stand is logging damage to residual trees. Some damage is expected and inevitable, especially in mature, fully stocked stands. However, the harvesting operation monitored in this study caused widespread damage to the residual stand, with more than 80 percent of the trees damaged in some manner in the 25 and 50 percent BA retention treatments (table 2). Much of this damage could have been avoided through more careful logging procedures. Most of the bole damage was from skidding when tree-length logs scraped against boles of standing trees on primary and secondary skid trails. Bark was often rubbed off, and roots near the base of the tree were often exposed. Also, better felling procedures, such as directional felling, could have remedied some of the crown damage. Many trees were cut without any regard to where they might fall. More tree damage occurred at the greater BA retention levels. Logging equipment was able to maneuver around widely spaced individual trees in sparsely stocked areas with less tree damage than in areas where trees were more closely spaced.

The number of trees that were destroyed by the harvesting operation ranged from 11 to 16 percent depending on the

treatment. Although this percentage might seem of minor influence, losing more than 10 percent of overstory trees that will comprise the next stand will reduce the total value of the stand and represents an investment loss.

Logging damage was rated as severe for more than 44 percent of the bole-damaged trees in the 25 and 50 percent BA residual treatment and more than 54 percent in the 12.5 percent BA retention treatment. The severe classification represents damage so great that the log grade decreases by one grade on the butt log. The butt log is the most valuable log in the tree. This again devalues the remaining trees in the residual stand because the trees will probably not heal over and increase to a better log grade anytime in the foreseeable future. The logging wounds provide an opportunity for fungi to enter the tree and instigate the spread of wood decay and rot that will diminish the value of the tree (Shigo 1979, 1986). With the extensive damage incurred by these residual trees and their decrease in value by reduction in log grade, trees are devalued in the current stand and in the potential of the future stand. The damage classified as minor probably will not affect the value of the residual trees now or in the future. These wounds should heal over fairly quickly without having an effect on the log grade.

Damage from epicormic branches was not as much of a consideration as the bole or crown damage in this study. Less than 13 percent of the butt logs of residual stems were

damaged by epicormic branching after 2 years regardless of treatment (table 2). Most of the stems with epicormics also had associated crown or bole damage, indications of stress that may have instigated formation of epicormic branches (Meadows and Burkhardt 2001). However, yellow-poplar was one of the desired species featured for residual leave trees, a species that does not have the propensity to form epicormic branches. More epicormics would be expected if more oaks, particularly white oaks, were left as residuals compared to yellow-poplar (Miller 1996).

## CONCLUSIONS

More careful logging would have reduced the amount of residual stem damage associated with partial harvesting in this study. Some damage is acceptable, especially in fully stocked, large diameter stands. However, the greater BA retention levels increased the chance of bole and crown damage to residual trees. Thinnings and partial harvests have many advantages in reducing stand density, favoring certain species, increasing diameter growth, and having more pleasing aesthetics when compared to clearcutting. However, the potential detrimental damage to residual trees should be considered. Residual-tree damage from partial cutting may cause a decline in bole quality and subsequent loss of tree value. Reduction of butt log grade and the loss of potential tree value are prime considerations with long-term effects in the future stand.

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## LITERATURE CITED

Barwatt, B.A.; Buckley, D.S.; Clatterbuck, W.K. 2006. Regeneration microsites and resource levels resulting from a range of silvicultural treatments in Tennessee oak-hickory forests. In: Connor, K.F., ed. Proceedings of the thirteenth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 541-546.

- Beck, D.E. 1986. Management options for southern Appalachian hardwoods: the two-aged stand. In: Phillips, D.R., ed. Proceedings of the fourth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 451-454.
- Meadows, J.S. 1993. Logging damage to residual trees following partial cutting in a green ash-sugarberry stand in the Mississippi Delta. In: Gillespie, A.R.; Parker, G.R.; Pope, P.E.; Rink, G., eds. Proceedings of the ninth central hardwood forest conference. Gen. Tech. Rep. NC-161. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North-Central Forest Experiment Station: 248-260.
- Meadows, J.S.; Burkhardt, E.C. 2001. Epicormic branches affect lumber grade and value in willow oak. *Southern Journal of Applied Forestry*. 25(3): 136-141.
- Miller, G.W. 1996. Epicormic branching on central Appalachian hardwoods 10 years after deferment cutting. Res. Pap. NE-702. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 9 p.
- Miller, G.W.; Schuler, T.M. 1995. Development and quality of reproduction in two-age central Appalachian hardwoods—10-year results. In: Gottschalk, K.W.; Fosbroke, S.L.C., eds. Proceedings of the tenth central hardwood forest conference. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 364-374.
- Nyland, R.D. 1996. Silvicultural concepts and applications. New York, NY: The McGraw-Hill Companies, Inc. 633 p.
- Olson, M.G. 2003. Mechanical damage incurred by underplanted northern red oak (*Quercus rubra*) following six overstory treatments and the development of planted northern red oak seedlings under closed canopy: first-year results. Knoxville, TN: University of Tennessee. 77 p. M.S. Thesis.
- Rast, E.D.; Sonderman, D.L.; Gammon, G.L. 1973. A guide to hardwood log grading. Gen. Tech. Rep. NE-1. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 31 p.
- Shigo, A.L. 1979. Tree decay: an expanded concept. *Agric. Inform. Bull. No. 419*. Washington, DC: U.S. Department of Agriculture, Forest Service. 72 p.
- Shigo, A.L. 1986. A new tree biology: facts, photos and philosophies on trees and their problems and proper care. Durham, NH: Shigo and Trees, Associates. 595 p.
- Stringer, J.W. 2002. Oak regeneration using the two age system. In: Outcalt, K.W., ed. Proceedings of the eleventh biennial silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 370-373.
- Stubbs, J. 1986. Hardwood epicormic branching---small knots but large losses. *Southern Journal of Applied Forestry*. 10: 217-220.
- Tennessee Department of Agriculture, Division of Forestry. 2003. Guide to forestry best management practices. Nashville, TN. 50 p.

# EPICORMIC BRANCHING IN RED OAK CROP TREES FIVE YEARS AFTER THINNING AND FERTILIZER APPLICATION IN A BOTTOMLAND HARDWOOD STAND

Brian Roy Lockhart, Alexander J. Michalek, and Matthew W. Lowe<sup>1</sup>

**Abstract**—Epicormic branches are defined as shoots arising from adventitious or dormant buds on the stem or branch of a woody plant, often following exposure to increased light levels or fire. They are a serious concern to hardwood forest managers because epicormic branches are considered defects and reduce the monetary value of logs and the lumber cut from them. The presence of epicormic branches is also considered a sign of stress in a tree. Recently, hardwood forest managers have considered genetics and tree health, in addition to exposure to sunlight, as causes of epicormic branching. A study was initiated to observe the effects of thinning (crown thinning, low thinning, and no thinning) and fertilizer application on the growth and development of designated red oak (*Quercus* spp.) crop trees in a minor creek flood plain in east Texas. Five years after treatment, there were no treatment differences in the number of epicormic branches on the butt log of crop trees. The mean number of epicormic branches on the butt log of red oak crop trees decreased 79 percent from 1999 to 2003, nearly 100 percent from branches  $\leq 1$  foot in length. This large decrease coincided with the ending of a 3-year drought in east Texas. The prevailing weather conditions and normal stand development patterns in this pin oak flat probably contributed more to epicormic branch reduction than did the thinning and fertilizer treatments.

## INTRODUCTION

Epicormic branches are shoots arising spontaneously from adventitious or dormant buds on stems or branches of woody plants, often following exposure to increased light levels or fire (Helms 1998). Epicormic branches are considered defects on tree boles because they result in undesirable knots on trees, reducing the monetary value of logs and lumber (Stubbs 1986). U.S. Department of Agriculture Forest Service factory log grade guidelines indicate that the size of the epicormic branch, in addition to the number and location of epicormic branches on the log, is important in determining log grades (Rast and others 1973). If an epicormic branch is  $> 3/8$  inch in diameter at the point of origin on the log surface, then it is counted as a full defect; an epicormic branch  $\leq 3/8$  inch in diameter is only counted as a one-half defect on logs  $\geq 14$  inches in scaling diameter (Rast and others 1973). Theoretically, even a single, large epicormic branch ideally positioned on a small log can reduce the grade of the log. Meadows and Burkhardt (2001), in a case study using willow oak (*Quercus phellos* L.) logs, showed that as few as five epicormic branches on a 16-foot log reduced the log grade of trees with an average diameter at breast height (d.b.h.) of 19.1 inches. They also showed that epicormic branches developing on willow oak boles after partial cutting reduced willow oak log grades by 50 percent. The value of the lumber from these logs was reduced 13 percent due to surface knot defects caused by the epicormic branches.

Development of epicormic branches on a tree's bole has long been thought to be a response to bole exposure to increased levels of sunlight following a canopy disturbance such as thinning (Brinkman 1955, Erdmann and Peterson 1972, Huppuch 1961). Other thinking indicates that the cause of epicormic branching in trees is more complicated (Books and Tubbs 1970, Kormanik and Brown 1969, Nicolini and others 2003, Strong and Erdmann 2000). Meadows (1995) proposed that

epicormic branching is the result of three factors working in concert (fig. 1): species, stress, and sunlight. Species refers to both species-to-species differences and genotype-to-genotype differences within individual species. Meadows (1995) developed a classification of bottomland hardwood species susceptibility to epicormic branching based on published information and personal observations. A tree's health is also a major factor in the production of epicormic branches. Healthy trees, that is, trees under little or no stress, are less likely to produce epicormic branches, especially if the species has low inherent susceptibility to epicormic branching. As a species' susceptibility increases, less stress may be needed to induce trees of that species to produce epicormic branches. Finally, sunlight acts as the trigger mechanism, rather than the controlling mechanism as has long been thought, in the production of epicormic branches (Meadows 1995). For example, a vigorous tree of a species with low susceptibility to epicormic

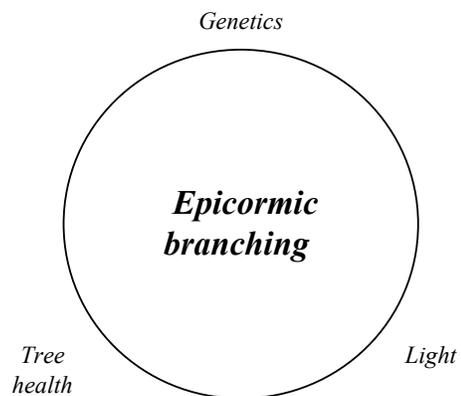


Figure 1—The role of genetics, both within and between species, tree health, and sunlight in the production of epicormic branches.

<sup>1</sup> Research Forester, USDA Forest Service, Southern Research Station, Center for Bottomland Hardwoods Research, Stoneville, MS 38776; District Silviculturist, USDA Forest Service, Kisatchie National Forest, Catahoula Ranger District, Bentley, LA 71407; and Research Project Manager, Temple-Inland Forest Products Corporation, Diboll, TX 75941, respectively.

branching is unlikely to produce epicormic branches if its bole is suddenly exposed to direct sunlight by a thinning operation. A tree with medium vigor, of a species with medium susceptibility to epicormic branching, will probably produce some epicormic branches when suddenly exposed to sunlight, and a tree with low vigor and high species susceptibility to epicormic branching will likely produce many epicormic branches when its bole is suddenly exposed to sunlight. In this last case, the tree will probably have epicormic branches on its bole because of its poor health even without exposure to sunlight.

Forest managers have long sought ways to reduce the production of epicormic branches, or shed current epicormic branches, from trees. Techniques for increasing a tree's vigor involve giving the tree more room to expand its crown, such as through thinnings. But thinnings may also increase the production of epicormic branches, at least in the short term, by suddenly exposing the bole to sunlight, depending on the tree's health and species susceptibility to epicormic branching. Another treatment may include application of fertilizer as a way to quickly increase a tree's vigor, especially when this is done in concert with a thinning treatment. The objective of this study was to determine the effects of thinning and fertilizer application on the production and development of epicormic branches on selected bottomland red oak (*Quercus* spp.) crop trees. Our hypothesis was that crown thinning, combined with fertilizer application, would result in fewest epicormic branches on the butt log of designated red oak crop trees 5 years after treatment.

## MATERIALS AND METHODS

The study site description, treatments, crop tree designation, and study design have been described previously (Lockhart and others 2004, Michalek and others 2004). In summary, the study site was located on the Shawnee Creek flood plain in Angelina County, TX. Soils were Pophers silty clay loam, and site index, base age 50 years, was estimated to be 90 to 95 feet for cherrybark oak (*Q. pagoda* Raf.), water oak (*Q. nigra* L.), and willow oak using the Baker/Broadfoot soil-site evaluation method (Baker and Broadfoot 1979). The stand was about 30 years old at the time of study installation. Three thinning treatments (crown, low, and none) and two fertilizer treatments (none and 200 pounds of nitrogen and 50 pounds of phosphorus per acre) were applied in a 3 by 2 factorial arrangement with four replicates. Crop trees were selected based on desired species (red oaks when possible), healthy crowns, grade 1 butt log or potential to develop a grade 1 butt log, few to no epicormic branches, and free of disease. Thinning was done in February 1999, and fertilization application was done in June 1999.

A total of 261 red oak crop trees, with an average d.b.h. of 11.6 inches, were utilized in this study (162 willow oak, 55 water oak, and 44 cherrybark oak). Epicormic branching was assessed following the 1999 growing season (the first year following thinning and fertilizer treatments). Subsequent measurements were conducted following the 2000, 2001, and 2003 growing seasons. Unfortunately, there was no pretreatment measurement of epicormic branches. Except in 1999, epicormic branches were tallied by 1-foot intervals along the first 17 feet (the butt log) of each of the designated crop trees. In 1999, only epicormic branches in the first 16 feet of each tree's bole were tallied. It was noted whether epicormic branches were  $\leq 1$  foot in length or  $> 1$  foot in length. Our

assumption was that branches  $\leq 1$  foot in length were only 1 year old and that they probably were produced after treatments were installed. Furthermore, epicormic branches  $\leq 1$  foot in length would probably be too small to be considered defects in log grading. Branches  $> 1$  foot in length were considered older branches and may have existed before treatments were installed. Measurements made after the 2000, 2001, and 2003 growing seasons were based on the previous year's tally sheets to ensure consistency with previous measurements.

The numbers of epicormic branches in the 1-foot log sections from 1 foot to 17 feet were summed to obtain total epicormic branches by size class and total epicormic branches. The 0- to 1-foot interval was considered the stump; therefore, branches in this interval were not included in analyses. Analysis of variance was based on a randomized complete block design with four replicates of thinning (high, low, and no thinning) and fertilizer treatments (unfertilized and fertilized). Mean pretreatment d.b.h. was used as a covariate in all analyses. Variables analyzed included mean epicormic branches  $\leq 1$  foot in length, mean epicormic branches  $> 1$  foot in length, and total epicormic branches. Alpha = 0.10 was used to determine the significance of treatment-to-treatment differences.

## RESULTS AND DISCUSSION

No treatment-to-treatment difference was found in the number of epicormic branches  $\leq 1$  foot in length following the 1999 growing season ( $p = 0.6468$ ; fig. 2). Mean numbers of epicormic branches  $\leq 1$  foot ranged from  $9.5 \pm 3.6$  (mean  $\pm$  one standard error) for the crown thin with no fertilizer to  $17.7 \pm 8.2$  for the low thin with fertilizer. A significant difference did exist for epicormic branches  $> 1$  foot, with more branches for the crown thin with fertilizer ( $17.4 \pm 3.6$ ) than for other treatments except low thin with fertilizer ( $p = 0.0368$ ). No significant difference was found among the treatments when numbers of epicormic branches  $\leq 1$  foot and  $> 1$  foot were combined ( $p = 0.2736$ ), but a possible pattern emerges with a greater mean number of epicormic branches in the thinned and fertilized treatments than for the others (fig. 2). Initial tree size had

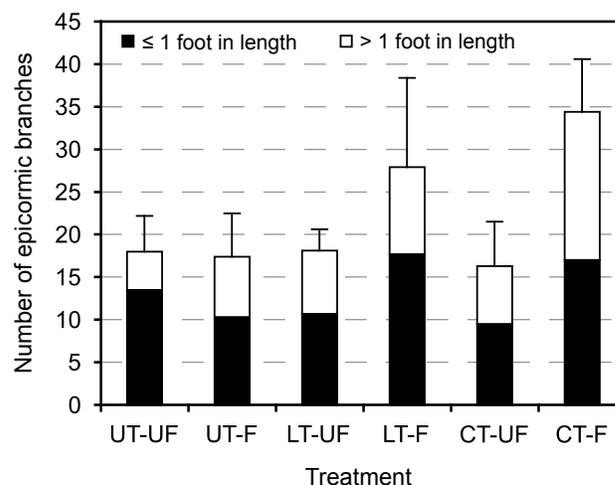


Figure 2—Epicormic branching by treatment after the 1999 growing season, 1 year following thinning and fertilization in an east Texas bottomland hardwood stand. Treatment designations are UT (unthinned), LT (low thinned), CT (crown thinned), UF (unfertilized), and F (fertilized). Solid bars denote epicormic branches  $\leq 1$  foot long; open bars denote epicormic branches  $> 1$  foot long. Lines on top of each bar represent 1 standard error of mean.

no effect on the total number of epicormic branches ( $p = 0.1324$ ).

Epicormic branches were not tallied before treatments were applied, so we do not know how many of the epicormic branches that were tallied following the 1999 growing season (1 year after treatment) may have been produced in response to treatments. The large number of epicormic branches  $\leq 1$  foot in length, even in the unthinned and nonfertilized treatment, probably indicates that the stand was under considerable stress prior to treatment: The stand was overstocked [stocking was 115 percent based on Goelz's (1995) stocking chart for bottomland hardwoods], and a prolonged drought that ended as the study began resulted in understory and some overstory red oak mortality in this and adjacent stands.

The number of epicormic branches dropped considerably following the 2000 growing season (fig. 3). The total number of epicormic branches dropped 46 percent from the previous year, an 86 percent reduction for branches  $\leq 1$  foot in length and an 11 percent increase for branches  $> 1$  foot in length. No treatment-to-treatment difference was found for branches  $\leq 1$  foot in length ( $p = 0.1482$ ), but a significant difference did exist for branches  $> 1$  foot in length ( $p = 0.0101$ ). Crop trees in the crown thinning plus fertilizer treatment had more of these branches,  $18.4 \pm 2.9$ , than did crop trees in the other treatments. The crop trees in the crown thinning plus fertilizer treatment also had more total epicormic branches,  $19.7 \pm 3.3$ , than did crop trees in any other treatment except the low thinning plus fertilizer treatment ( $p = 0.0245$ ).

There are two possible explanations for the sudden decrease in the number of epicormic branches  $\leq 1$  foot in length. The prolonged drought, which lasted for about 3 years, ended during late 1999 or early 2000. Normal rainfall patterns in 2000 probably reduced tree stress and led to high mortality of epicormic branches  $\leq 1$  foot in length. Another possible explanation is measurement error. None of the coauthors was involved in the 1999 epicormic branching surveys; therefore, we cannot

be sure if correct measurements were taken. The 11 percent increase in the number of epicormic branches  $> 1$  foot in length may be ingrowth from the branches  $\leq 1$  foot in length.

No differences were found among treatments for epicormic branches  $\leq 1$  foot in length ( $p = 0.2442$ ),  $> 1$  foot in length ( $p = 0.2412$ ), and total number of epicormic branches ( $p = 0.2581$ ) following the 2003 growing season (fig. 4). Overall, the number of epicormic branches present after the 2003 growing season was down 79 percent from 1999, down 98 percent for branches  $\leq 1$  foot in length and 51 percent for branches  $> 1$  foot in length.

The large decrease in number of epicormic branches from 1999 to 2003 probably represents an overall increase in crop tree vigor. This increase in vigor is probably due more to the weather than to the treatments. Normal to above-normal rainfall resumed during this period, following a 1997 to 1999 drought. The decrease in total epicormic branches ranged from 76 percent in the crown thinning plus fertilizer treatment to 83 percent in the unthinned no fertilizer treatment. These similar percentages across all treatments, including the controls, indicate that the thinning and fertilizer treatments were less important than the weather and possible normal stand development patterns in dense, maturing pin oak flat forests in the production and development (or reduction) of epicormic branches. Kormanik and Brown (1967) noted the short-lived nature of many epicormic branches in species such as yellow-poplar (*Liriodendron tulipifera* L.), sweetgum (*Liquidambar styraciflua* L.), green ash (*Fraxinus pennsylvanica* Marsh.), red maple (*Acer rubrum* L.), water oak, and white oak (*Q. alba* L.).

While epicormic branches have decreased considerably in number from 1999 to 2003, they have left their fingerprints, especially the larger branches. These defects, which will soon be grown over with clear wood, will reappear when the butt logs are harvested and lumber is cut from them. Fortunately, many of these defects are located within the minimum 8- or 10-inch cant that is usually not cut for lumber.

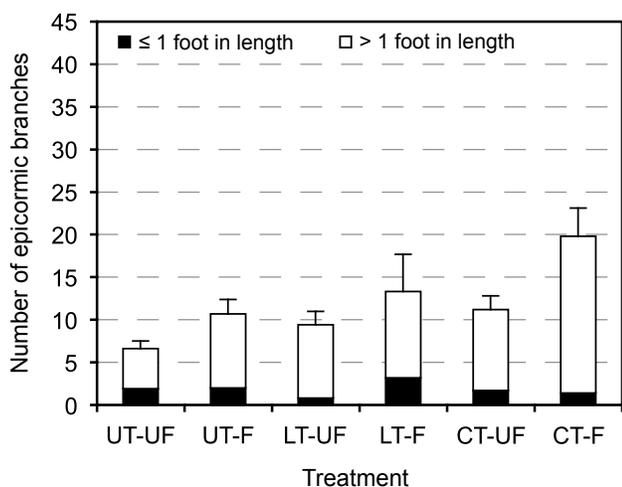


Figure 3—Epicormic branching by treatment after the 2000 growing season, 2 years following thinning and fertilization in an east Texas bottomland hardwood stand. Treatment designations are UT (unthinned), LT (low thinned), CT (crown thinned), UF (unfertilized), and F (fertilized). Solid bars denote epicormic branches  $\leq 1$  foot long; open bars denote epicormic branches  $> 1$  foot long. Lines on top of each bar represent 1 standard error of mean.

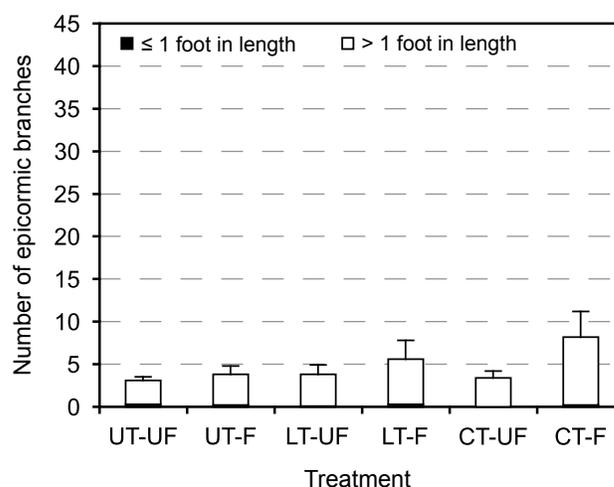


Figure 4—Epicormic branching by treatment after the 2003 growing season, 5 years following thinning and fertilization in an east Texas bottomland hardwood stand. Treatment designations are UT (unthinned), LT (low thinned), CT (crown thinned), UF (unfertilized), and F (fertilized). Solid bars denote epicormic branches  $\leq 1$  foot long; open bars denote epicormic branches  $> 1$  foot long. Lines on top of each bar represent 1 standard error of mean.

Howell and Nix (2002) compared butt-log epicormic branching of bottomland hardwood crop trees in stands that were partially cut 5 years earlier and stands that were not cut. Butt logs of trees in the partial cut stands had twice as many epicormic branches as had those in the uncut controls. In the partially cut stands, the mean number of epicormic branches was about three per tree. Epicormic branch numbers for red oak crop trees were about 4.7 for Shumard oak (*Q. shumardii* Buckl.) and three for cherrybark oak (Howell and Nix 2002), similar to our numbers for willow oak, water oak, and cherrybark oak 5 years following the thinning and fertilizer treatments. Erdmann and Peterson (1972) also found an increase in the number of epicormic branches on yellow birch (*Betula alleghaniensis* Britt.) 3 years following various levels of partial cutting, but the increase was about one extra epicormic branch on the butt log and two to five epicormic branches on the second log. Finally, Meadows and Goelz (2002) found little increase in the number of epicormic branches on the butt logs of red oak crops 4 years after thinning. They concluded that the red oak crop trees (primarily cherrybark oak and water oak) were sufficiently vigorous so that the development of new epicormic branches was inhibited. Undoubtedly, the condition of an individual tree, in addition to its genetically imposed susceptibility, affects the likelihood of producing epicormic branches following thinning or some other type of partial cutting. Results from this study and others indicate that a large increase in the number of epicormic branches following thinning will diminish over time as the vigor of crop trees increases and crop trees become shaded as the canopy closes.

## CONCLUSIONS

Thinning and fertilizer application appeared to have little effect on the production and development of epicormic branches in a bottomland red oak stand on a minor creek flood plain in east-central Texas. The treatments may have triggered the production of epicormic branches in a situation already favorable for their production. First, the study was initiated during the end of a 3-year drought in east Texas. We observed mortality of understory red oaks and even an occasional overstory red oak in the study stand and adjacent stands in the Shawnee Creek flood plain. Second, willow oak dominated the species composition (62 percent), and willow oak is highly susceptible to epicormic branch production (Meadows 1995). Finally, the study stand was highly overstocked (115 percent stocking), a common situation in pin oak flats. The rapid decline in the number of epicormic branches within 2 years after thinning and fertilizer application probably resulted more from improved weather conditions than from these treatments, because the decline was similar in control and treated plots.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

Baker, J.B.; Broadfoot, W.M. 1979. A practical field method of site evaluation for commercially important southern hardwoods. Gen. Tech. Rep. SO-26. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 51 p.

- Books, D.J.; Tubbs, C.H. 1970. Relation of light to epicormic sprouting in sugar maple. Res. Note NC-93. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 2 p.
- Brinkman, K.A. 1955. Epicormic branching on oaks in sprout stands. Tech. Pap. 146. Columbus, OH: U.S. Department of Agriculture, Forest Service, Central States Forest Experiment Station. 8 p.
- Erdmann, G.G.; Peterson, R.M., Jr. 1972. Crown release increases diameter growth and bole sprouting of pole-size yellow birch. Res. Note NC-130. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 4 p.
- Goelz, J.C.G. 1995. A stocking guide for southern bottomland hardwoods. Southern Journal of Applied Forestry. 19: 103-104.
- Helms, J.A. 1998. The dictionary of forestry. Bethesda, MD: Society of American Foresters. 224 p.
- Howell, M.P., III; Nix, L.E. 2002. Early thinning in bottomland hardwoods. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 196-200.
- Huppuch, C.D. 1961. Epicormic branching on sycamore. Res. Note 166. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 1 p.
- Kormanik, P.P.; Brown, C.L. 1967. Adventitious buds on mature trees. Res. Note SE-82. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 7 p.
- Kormanik, P.P.; Brown, C.L. 1969. Origin and development of epicormic branches in sweetgum. Res. Pap. SE-54. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 17 p.
- Lockhart, B.R.; Michalek, A.J.; Lowe, M.W.; Williams, R.A. 2004. Regeneration development 3 years after thinning and fertilization in an east Texas bottomland hardwood stand (to manage or to regenerate: can we do both?). In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 502-508.
- Meadows, J.S. 1995. Epicormic branches and lumber grade of bottomland oak. In: Lowery, G.; Meyer, D., eds. Advances in hardwood utilization: following profitability from the woods through rough dimension: Proceedings of the 23<sup>rd</sup> annual hardwood symposium. Memphis, TN: National Hardwood Lumber Association: 19-25.
- Meadows, J.S.; Burkhardt, E.C. 2001. Epicormic branches affect lumber grade and value in willow oak. Southern Journal of Applied Forestry. 25: 136-141.
- Meadows, J.S.; Goelz, J.C.G. 2002. Fourth-year effects of thinning on growth and epicormic branching in a red oak-sweetgum stand on a minor streambottom site in west-central Alabama. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 201-208.
- Michalek, A.J.; Lockhart, B.R.; Lowe, M.W.; Williams, R.A. 2004. Diameter-growth and epicormic branching response of an east Texas bottomland red oak stand 3 years after thinning and fertilization. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 269-275.
- Nicolini, E.; Caraglio, Y.; Pelissier, R. [and others]. 2003. Epicormic branches: a growth indicator for the tropical forest tree *Dicorynia guianensis* Amshoff (Caesalpinaceae). Annals of Botany. 92: 97-105.
- Rast, E.D.; Sonderman, D.L.; Gammon, G.L. 1973. A guide to hardwood log grading (revised). Gen. Tech. Rep. NE-1. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 31 p.
- Strong, T.R.; Erdmann, G.G. 2000. Effects of residual stand density on growth and volume production in even-aged red maple stands. Canadian Journal of Forest Research. 20: 372-378.
- Stubbs, J. 1986. Hardwood epicormic branching—small knots but large losses. Southern Journal of Applied Forestry. 10: 217-220.

# THIRD-YEAR GROWTH AND BOLE-QUALITY RESPONSES TO THINNING IN A LATE-ROTATION RED OAK-SWEETGUM STAND IN EAST TEXAS

James S. Meadows and Daniel A. Skojac, Jr.<sup>1</sup>

**Abstract**—Three thinning treatments were applied to an 80- to 90-year-old stand dominated by red oaks (*Quercus* spp.) and sweetgum (*Liquidambar styraciflua* L.) along the Neches River in East Texas: (1) unthinned control, (2) light thinning (70 to 75 percent residual stocking), and (3) heavy thinning (50 to 55 percent residual stocking). Three years after treatment, both thinning regimes had significantly increased diameter growth of individual trees, especially the red oaks. Thinning had little effect on the production of epicormic branches on butt logs of residual trees, even among red oaks. Within the range of residual stand density evaluated in this study, we found no differences between light thinning and heavy thinning in either diameter growth or production of epicormic branches by residual red oaks. Residual stand density, at least within fairly broad limits, had little effect on the initial response of individual red oaks to thinning.

## INTRODUCTION

Successful management of hardwood stands for sawtimber production requires satisfactory growth rates, as well as the development and maintenance of high-quality logs. A combination of thinning and improvement cutting often is used in mixed-species bottomland hardwood stands to (1) enhance growth of residual trees, (2) maintain and improve bole quality of residual trees, and (3) improve species composition of the stand (Meadows 1996).

Thinning regulates stand density and increases diameter growth of residual trees. Generally, diameter growth response increases as thinning intensity increases. However, very heavy thinning may reduce residual stand density to the point where stand-level basal area growth and volume growth are greatly diminished, even though diameter growth and volume growth of individual residual trees are greatly enhanced. In heavily thinned stands, density may be so low that the stand is unable to fully occupy the site and therefore cannot achieve its optimum level of production. Earlier research suggests that minimum residual stocking levels necessary to maintain satisfactory stand-level growth after thinning are 46 to 65 percent of maximum full stocking for upland oak stands (Hilt 1979) and 45 to 60 percent of maximum full stocking for Allegheny hardwood stands (Lamson and Smith 1988). No recommended minimum residual stocking levels have been reported for southern bottomland hardwood stands. However, Meadows and Goelz (2001) observed that residual stand density equivalent to 52 percent stocking in a young water oak (*Quercus nigra* L.) plantation appeared to be sufficient to promote adequate stand-level basal area growth following thinning, but that a residual stocking level of 33 percent created such a severely understocked condition that stand-level basal area growth will likely be depressed for many years.

Degradation of bole quality, as a result of increased production of epicormic branches along the boles of residual trees, sometimes may be associated with increased thinning intensity. For example, Sonderman (1984) found that the number and size of both living and dead limbs on the boles of residual upland oak trees increased significantly as residual stocking

decreased. However, this adverse effect of thinning on bole quality most often is related to poorly planned thinning operations. In fact, well-designed hardwood thinning operations tend to favor healthy, sawtimber-sized trees, so that the proportion of dominant and codominant trees in the residual stand typically increases as thinning intensity increases. Vigorous, upper-crown-class trees are much less likely to produce epicormic branches than are less vigorous, lower-crown-class trees (Meadows 1995). Consequently, in well-designed thinning operations, the production of epicormic branches on residual trees may actually decrease as thinning intensity increases (Sonderman and Rast 1988). In fact, carefully planned thinning operations should improve average bole quality throughout the residual stand. In some stands, however, as thinning intensity increases and residual stand density decreases, there may be a trade-off between markedly improved diameter growth and the increased potential for adverse effects on bole quality of residual trees.

This combination of thinning and improvement cutting in mixed-species hardwood stands also is used to improve both species composition and quality of the residual stand (Meadows 1996). Generally, by emphasizing the value or quality of individual trees rather than the density of the residual stand, it is possible to increase the proportion of high-value trees and to decrease the proportion of low-value trees. Trees that are damaged or diseased, have low-quality boles, or are undesirable species are removed; trees that are healthy, have high-quality boles, and are desirable species are retained. Although more important at the time of the first thinning, improvement of both species composition and residual bole quality should be major considerations whenever partial cuttings are performed in mixed-species hardwood stands.

These three components of a well-designed hardwood thinning operation—increased diameter and volume growth of individual trees, enhanced bole quality, and improved species composition—are critically important for the profitable management of hardwood stands for high-quality sawtimber production. Ideally, thinning regimes should be designed to optimize the value of the stand through synthesis of these

<sup>1</sup> Principal Silviculturist and Forestry Technician, respectively, USDA Forest Service, Southern Research Station, P.O. Box 227, Stoneville, MS 38776.

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three components. However, because maximization of all three components is generally not likely, some compromises in expected benefits are often necessary.

Science-based information on thinning in southern bottomland hardwood stands is lacking. Existing guidelines, such as those published by McKnight (1958), Johnson (1981), Meadows (1996), and Goelz and Meadows (1997), are too general and are based more on experience and observation than on specific research results. Effective management of such stands for high-quality sawtimber production requires thinning guidelines that include recommendations for (1) timing of the first and subsequent thinnings, (2) intensity of thinning, and (3) marking rules designed to optimize stand value throughout the rotation.

To address this need for science-based thinning guidelines, we established a series of thinning studies in red oak-sweetgum stands on minor streambottom sites across the South. All of the individual studies within the series use the same study design, treatments, and methods. This study is the fourth in that series. Early results for one of the other studies were reported by Meadows and Goelz (1998, 1999, and 2002). All individual studies within the series are designed to determine how several levels of thinning affect (1) stand-level growth, development, and yield; and (2) growth and bole quality of individual trees. Results from the entire series of studies will be combined to (1) develop practical guidelines for managing stands of southern bottomland hardwoods, (2) evaluate the suitability of various levels of residual stocking across a variety of site and stand conditions, and (3) develop a growth-and-yield model for managed stands of southern bottomland hardwoods.

## METHODS

### Study Area

The study is located near the Neches River in southern Angelina County, near the community of Beulah, in east Texas. The land is owned by Temple-Inland Forest Products Corporation. The site is subject to periodic flooding during the winter and spring, but floodwaters generally recede within a few days.

The study site supports a bottomland hardwood forest dominated by red oaks and sweetgum. Principal red oak species are water oak, cherrybark oak (*Q. pagoda* Raf.), and willow oak (*Q. phellos* L.). The stand was about 80 to 90 years old at the time of study installation. There was no evidence of previous harvesting activity in the stand. We classified the study area as a medium to large sawtimber stand on a medium-quality site, with high initial stocking.

### Plot Design

Plot design followed the recommendations for standard plots for silvicultural research, set forth by the U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station (Marquis and others 1990). We applied each treatment uniformly across a 2.0-acre rectangular treatment plot that measured 4 by 5 chains (264 by 330 feet). One 0.6-acre rectangular measurement plot was established in the center of each treatment plot. Each measurement plot was 2 by 3 chains (132 by 198 feet), providing a 1-chain-wide (66 feet) buffer strip around each measurement plot. The entire study area is 18 acres.

## Treatments

Treatments included three levels of residual stocking, based on a stocking guide developed by Goelz (1995) for southern bottomland hardwoods: (1) an unthinned control, (2) light thinning (70 to 75 percent residual stocking), and (3) heavy thinning (50 to 55 percent residual stocking). Space limitations at this particular study site did not allow us to install a fourth treatment, which was evaluated in all other studies within this series.

A combination of low thinning and improvement cutting removed most of the pulpwood-sized trees, as well as sawtimber-sized trees that were damaged or diseased, had low-quality boles, or were undesirable species. Hardwood tree classes, as originally defined by Putnam and others (1960) and modified by Meadows (1996), formed the cutting priority for each treatment. Trees were removed from the cutting stock and the cull stock classes first and then from the reserve growing stock class, when necessary, until the target residual stocking level for each treatment was met.

Three replications of the three treatments were applied in a randomized complete block design to the nine treatment plots (experimental units) in October 2000. A contract logging crew directionally felled all marked trees with a mechanized feller using a continuously running cutting head. Felled trees were topped and delimbed in the woods. Tree-length logs were removed from the woods with rubber-tired skidders.

## Measurements

A preharvest survey to determine species composition and initial stand density was conducted on each 0.6-acre measurement plot prior to assignment of treatments. Species, diameter at breast height (d.b.h.), crown class, and tree class (Meadows 1996, Putnam and others 1960) were recorded for all trees  $\geq 3.5$  inches d.b.h. Treatment plots were marked for thinning to the target residual stocking prescribed for each treatment. Hardwood tree classes were used to set the cutting priority on each plot. The length and grade of all sawlogs, as defined by Rast and others (1973), and the number of epicormic branches on each 16-foot log section (below the base of the live crown) were recorded on all "leave" trees. Merchantable height, height to the base of the live crown, and total height were measured on a subsample of "leave" trees. Crown class, d.b.h., and the number of epicormic branches on each 16-foot log section were measured annually for the first 3 years after thinning.

## RESULTS AND DISCUSSION

### Stand Conditions Prior to Thinning

The pretreatment stand averaged 147 trees and 118 square feet of basal area per acre, with a quadratic mean diameter of 12.3 inches, among trees  $\geq 3.5$  inches d.b.h. The average stocking of 101 percent exceeded the level of maximum full stocking (100 percent), the point at which thinning is recommended in even-aged southern bottomland hardwood stands (Goelz 1995). There were no significant differences among treatment plots in any of the preharvest characteristics. Although the stand was dense, most of the dominant and codominant trees were healthy and exhibited few symptoms of poor vigor, such as crown deterioration, loss of dominance, or the presence of numerous epicormic branches along the boles. In short, the stand was too dense and needed to be

thinned, but the overstocked conditions were not so severe that overall stand health had begun to deteriorate.

Red oaks and sweetgum together comprised 66 percent of the basal area of the stand prior to thinning. Red oaks (primarily water, cherrybark, and willow oaks) accounted for 39 percent of the basal area, while sweetgum accounted for 27 percent. Red oaks and sweetgum clearly dominated the upper canopy of the stand and had quadratic mean diameters of 16.3 and 16.5 inches, respectively. Nearly all of the very large trees (> 30 inches d.b.h.) scattered throughout the stand were red oaks.

Other species commonly found throughout the stand were mockernut hickory [*Carya tomentosa* (Poir.) Nutt.], shagbark hickory [*C. ovata* (Mill.) K. Koch], American elm (*Ulmus americana* L.), green ash (*Fraxinus pennsylvanica* Marsh.), and black tupelo (*Nyssa sylvatica* Marsh.). Scattered individuals of a wide variety of species, such as sugarberry (*Celtis laevigata* Willd.), water hickory [*Carya aquatica* (Michx. f.) Nutt.], honeylocust (*Gleditsia triacanthos* L.), swamp chestnut oak (*Q. michauxii* Nutt.), and overcup oak (*Q. lyrata* Walt.), also occurred. Collectively, these species accounted for 31 percent of the basal area prior to thinning. Most of these trees were found in the very dense, midcanopy layer of the stand.

Shade-tolerant species, such as American hornbeam (*Carpinus caroliniana* Walt.), American holly (*Ilex opaca* Ait.), dogwood (*Cornus* spp.), eastern hophornbeam [*Ostrya virginiana* (Mill.) K. Koch], hawthorn (*Crataegus* spp.), and red mulberry (*Morus rubra* L.), dominated the lower canopy and understory and accounted for the remaining 3 percent of the basal area prior to thinning. Giant cane [*Arundinaria gigantea* (Walt.) Muhl.] formed a very dense component of the understory throughout the study site.

### Stand Development Following Thinning

Light thinning reduced stand density to 43 trees and 86 square feet of basal area per acre, increased quadratic mean diameter to 19.1 inches, and reduced stocking to 68 percent. It removed 71 percent of the trees and 27 percent of the basal area. Heavy thinning reduced density to 31 trees and 64 square feet of basal area per acre, increased quadratic mean diameter to 19.6 inches, and reduced stocking to 50 percent. It removed 79 percent of the trees and 46 percent of the basal area. Both thinning treatments produced stand characteristics significantly different from the unthinned control. The light thinning and heavy thinning treatments were not significantly different from each other in terms of residual trees per acre or quadratic mean diameter but were significantly different from each other in terms of residual basal area per acre and residual stocking percent.

Mortality during the 3-year period after thinning did not differ significantly among the three treatments (table 1). A few trees died in both the unthinned control plots and in the heavily thinned plots, but none died in the lightly thinned plots. A few trees were destroyed during the logging operation, but most of the mortality occurred as a result of windthrow.

There has been little stand-level growth in any of the treatment plots during the first 3 years following thinning (table 1). Although stand-level basal area growth and an increase in stocking percent may indicate the stand is recovering faster from light thinning than from heavy thinning, these results may be misleading. Failure of the stand to achieve a net increase in basal area following heavy thinning is most likely due to mortality in the heavily thinned plots, resulting in no net basal area growth.

All treatments produced increases in quadratic mean diameter (table 1). In the heavily thinned stand, it increased 1.2 inches during the 3 years following thinning, from 19.6 to 20.8 inches. By contrast, in the unthinned control and the lightly thinned plots, it increased only 0.4 and 0.5 inches, respectively. Again, this relatively large increase in quadratic mean diameter following heavy thinning may be due to mortality in the heavily thinned plots. The trees that died following heavy thinning were smaller than the initial quadratic mean diameter of the stand. Consequently, the calculated increase in quadratic mean diameter of the heavily thinned stand is primarily a reflection of the larger diameters of the surviving trees. Taking all variables into account, changes in stand conditions during the 3 years following thinning are inconclusive.

### Diameter Growth

Heavy thinning significantly increased cumulative diameter growth of residual trees, averaged across all species, during each of the first 3 years following thinning (fig. 1). A significant difference between the heavy thinning treatment and the unthinned control was detected even after the first year. Significant diameter growth responses were not detected until the third year in one of the other thinning studies within the larger series of studies (Meadows and Goelz 1999). By the end of the third year in this study, cumulative diameter growth of residual trees in the heavily thinned plots was 2.5 times greater than the cumulative diameter growth of trees in the unthinned control—0.64 inches and 0.26 inches for the two treatments, respectively. By contrast, cumulative diameter growth of residual trees in the lightly thinned plots was 1.8 times that of trees in the unthinned control, but this difference was not statistically significant. Light thinning also did not differ significantly from heavy thinning in cumulative diameter growth at the end of the third year. The cumulative

**Table 1—Stand conditions 3 years after application of three thinning treatments**

Treatment	Trees <i>no./ac</i>	Cumulative mortality %	Basal area ----- <i>ft<sup>2</sup>/acre</i> -----	Cumulative basal area growth -----	Stocking %	Quadratic mean diameter <i>inches</i>
Unthinned control	144 a	5.9 a	121 a	1 a	103 a	12.5 b
Light thinning	43 b	0.0 a	90 b	4 a	71 b	19.6 a
Heavy thinning	28 b	9.7 a	64 c	0 a	50 c	20.8 a

Means within a column followed by the same letter are not significantly different at the 0.05 level of probability.

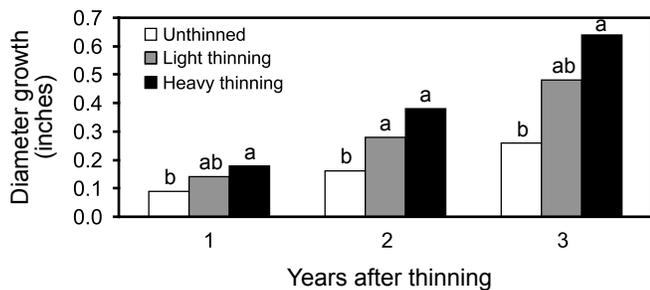


Figure 1—Cumulative diameter growth of residual trees at the end of each of the first 3 years after application of three thinning treatments. Bars within a year followed by the same letter are not significantly different at the 0.05 level of probability.

diameter growth data represent trees of all species and all crown classes within each of the three treatments.

When separating data by species groups, we found that, by the end of the third year, light thinning had increased cumulative diameter growth of red oaks (primarily water, cherrybark, and willow oaks) by 61 percent; heavy thinning had increased cumulative diameter growth of red oaks by 47 percent, relative to the unthinned control (fig. 2). Residual red oaks in the lightly thinned plots grew 0.95 inches in the 3 years following thinning, while residual red oaks in the heavily thinned plots grew 0.87 inches. By contrast, red oaks in the unthinned control plots grew 0.59 inches. Both thinning regimes significantly improved the cumulative diameter growth of sweetgum and other merchantable species (primarily hickory, American elm, green ash, and black tupelo) but not nearly to the same extent as they did in the red oaks.

It is very important to note that, while both thinning regimes significantly improved cumulative diameter growth of residual red oaks relative to the unthinned control, there were no significant differences between the two regimes. In other words, the diameter growth response of residual red oaks was about the same for both light thinning and heavy thinning. Diameter growth response of residual red oaks appeared to be independent of residual stand density, at least within the range of residual densities we evaluated—64 square feet of basal area per acre following heavy thinning to 86 square feet of basal area per acre following light thinning. We found the same trend in other studies in the series (Meadows and Goelz 2002).

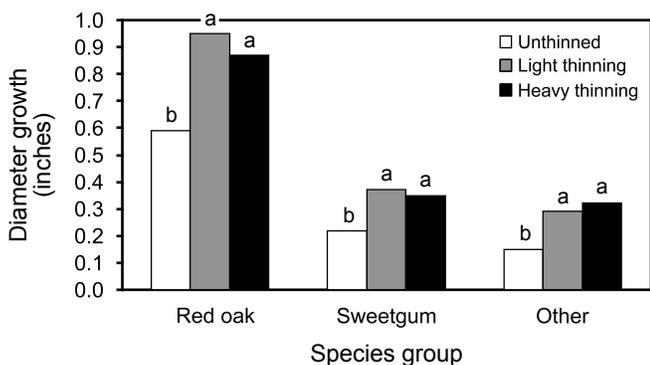


Figure 2—Cumulative diameter growth of residual trees, by species group, 3 years after application of three thinning treatments. Bars within a species group followed by the same letter are not significantly different at the 0.05 level of probability.

When averaged across trees of all species, there appeared to be a favorable cumulative diameter growth response by both dominant and codominant trees to the two thinning regimes (fig. 3). However, the only statistically significant result was that codominant trees in the heavily thinned plots grew more than codominant trees in the unthinned control plots. The cumulative diameter growth rate of codominant trees following heavy thinning was 31 percent greater than it was for codominant trees in the unthinned control plots. Heavy thinning also significantly increased cumulative diameter growth of residual trees in the intermediate crown class by 77 percent. This rapid increase in diameter growth indicates that there may be good growth potential for the smaller trees eventually to develop into valuable sawtimber trees.

Both thinning regimes successfully increased the cumulative diameter growth of residual trees during the first 3 years following treatment. Excellent diameter growth responses were observed for red oaks, particularly in the codominant crown class. Most of the stand's red oaks were classified as crop trees, the most desirable trees in the stand for high-quality sawtimber production. For that reason, both levels of thinning greatly enhanced the value of the stand.

### Epicormic Branching

Thinning operations in hardwood stands, while producing positive effects on diameter growth, also may have negative impacts on bole quality of residual trees, particularly in the form of epicormic branches. The production of epicormic branches along the merchantable boles of residual trees can become a serious problem in thinned hardwood stands. Epicormic branches cause defects in the underlying wood and can reduce both log grade and lumber value. However, well-designed thinning prescriptions with proper marking rules can minimize the production of new epicormic branches in most hardwood stands.

When averaged across all species, thinning had no significant effects on the total number of epicormic branches on butt logs of the residual trees after each of the first 3 years following thinning (fig. 4). It is important to note that, immediately after thinning (year zero), residual trees in the two thinning treatments averaged fewer than two epicormic branches on the butt log, whereas trees in the unthinned control plots averaged four epicormic branches on the butt log, even though these differences among treatments were not statistically significant. Both thinning treatments discriminated against trees

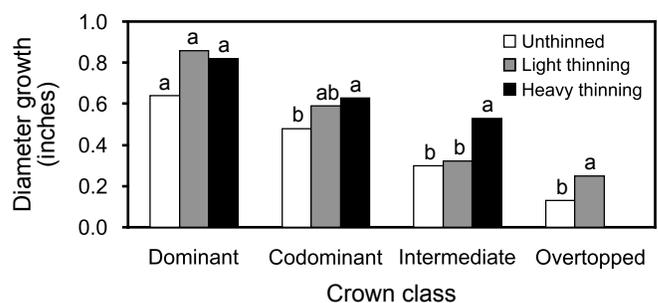


Figure 3—Cumulative diameter growth of residual trees, by crown class, 3 years after application of three thinning treatments. Bars within a crown class followed by the same letter are not significantly different at the 0.05 level of probability.

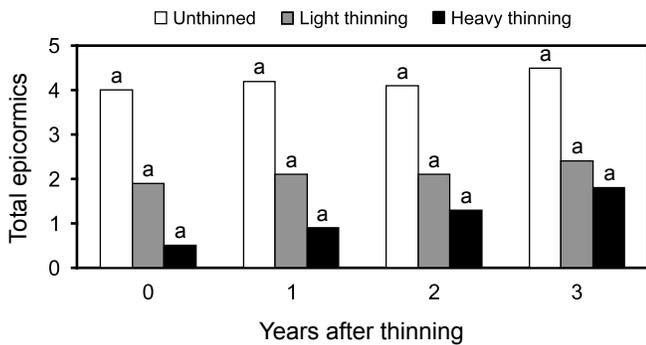


Figure 4—Total number of epicormic branches on the butt logs of residual trees initially and at the end of each of the first 3 years after application of three thinning treatments. Bars within a year followed by the same letter are not significantly different at the 0.05 level of probability.

that had numerous epicormic branches; those trees were removed from the stand during thinning. In the first 3 years following thinning, few changes occurred in the total number of epicormic branches found on the butt logs of residual trees across the three treatments. Because none of the treatment means represented in figure 4 was significantly different in any given year, the two levels of thinning did not negatively affect bole quality, at least when data were averaged across trees of all species. However, production of new epicormic branches on the butt log varied among individual trees. Some trees produced no new branches, while others produced only a few. Most of those trees were highly vigorous and had large, well-shaped crowns with dense foliage. By contrast, some trees produced many new epicormic branches. Those trees expressed relatively low vigor and had small crowns with sparse foliage.

Because hardwood species vary widely in their susceptibility to the production of epicormic branches (Meadows 1995), data were partitioned by species groups (fig. 5). Neither thinning regime affected the production of epicormic branches in residual sweetgum trees or in residual trees of the Other species group. On the other hand, by the end of the third year following thinning, residual red oaks in the lightly thinned plots averaged 1.1 more epicormic branches on the butt log than did red oaks in the unthinned control plots. By contrast, residual red oaks in the heavily thinned plots averaged 1.2 fewer epicormic branches on the butt log than did red oaks in

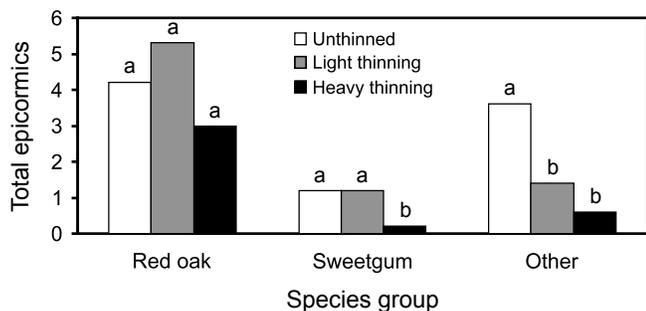


Figure 5—Total number of epicormic branches on the butt logs of residual trees, by species group, 3 years after application of three thinning treatments. Bars within a species group followed by the same letter are not significantly different at the 0.05 level of probability.

the unthinned control plots. These treatment differences were not statistically significant, but it is interesting to note that red oaks in the heavily thinned plots averaged 2.3 fewer epicormic branches on the butt log than did red oaks in the lightly thinned plots.

To maintain the target residual density in the lightly thinned plots, we had to leave some low-vigor trees, which are generally highly susceptible to the production of epicormic branches, especially the red oaks (Meadows 1995). Consequently, strict adherence to residual density targets forced the retention of some less than desirable trees, which resulted in a greater average number of epicormic branches on residual red oaks in the lightly thinned plots than in the heavily thinned plots, although these treatment differences were not statistically significant. At least to some extent, enhancement of overall stand quality in the lightly thinned plots may have suffered.

Production of epicormic branches on the butt logs of residual trees also varied among crown classes, when averaged across trees of all species (fig. 6). Generally, epicormic branches were more numerous on lower-crown-class trees than on upper-crown-class trees, especially those within the unthinned control plots. This observation indicates that epicormic branches often are produced in response to increased stress and reduced vigor, even in undisturbed stands. It is interesting to note that upper-crown-class trees, even though they produced a few new epicormic branches in response to thinning, still averaged fewer than two epicormic branches on the butt log, regardless of treatment.

These results support the hypothesis advanced by Meadows (1995) that the tendency for an individual hardwood tree to produce epicormic branches in response to some type of disturbance or stress is controlled by both the species and the tree's initial vigor. Meadows (1995) observed that hardwood species vary greatly in the likelihood that they will produce epicormic branches; he proposed a classification scheme to categorize the susceptibility of most commercially important bottomland hardwood species to epicormic branching. Meadows (1995) also hypothesized that tree vigor is the primary factor controlling production of epicormic branches when a tree is subjected to a disturbance or stress. This hypothesis further proposes that healthy, vigorous trees, even of susceptible species, are much less likely to produce epicormic branches than are trees in poor health. Observations in this study that the production of epicormic branches varied not

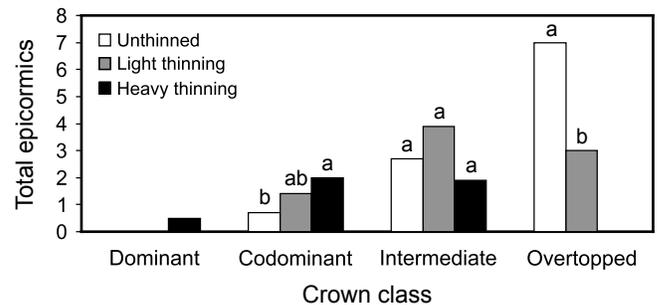


Figure 6—Total number of epicormic branches on the butt logs of residual trees, by crown class, 3 years after application of three thinning treatments. Bars within a crown class followed by the same letter are not significantly different at the 0.05 level of probability.

only by species but also among crown classes strongly support these hypotheses.

When assessing the effects of thinning on the production of epicormic branches, the most important consideration, however, is the total number of epicormic branches found on the butt logs of crop trees, particularly sawtimber-sized red oaks. These trees are favored during the thinning operation because they produce high-quality, high-value sawtimber. Our study showed that neither level of thinning had a significant effect on the total number of epicormic branches found on the butt logs of sawtimber-sized red oaks 3 years after thinning (fig. 7). In fact, sawtimber-sized red oaks in both the lightly thinned plots and the heavily thinned plots averaged < 3.5 epicormic branches on the butt log.

Based on a general rule of thumb that five epicormic branches are sufficient to cause a reduction in the grade of the butt log (Meadows and Burkhardt 2001), it is likely that most of the sawtimber-sized red oaks in our study did not experience a negative impact on overall bole quality due to the production of epicormic branches on the butt log following thinning. Sawtimber-sized red oaks with healthy dominant or codominant crowns are fairly resistant to the production of epicormic branches even after heavy thinning.

Production of epicormic branches on the boles of pulpwood-sized red oaks increased significantly during the 3 years following light thinning (fig. 7). To maintain the target residual stocking of 70 to 75 percent associated with the light thinning treatment, we had to leave numerous pulpwood-sized red oaks with small, sparse crowns. Most of these low-vigor, lower-crown-class red oaks retained in the lightly thinned plots produced many new epicormic branches during the 3 years following thinning. By contrast, because the target residual stocking associated with the heavy thinning treatment was much lower (50 to 55 percent), we were able to retain only the healthiest pulpwood-sized red oaks. These relatively high-vigor trees had dense, well-shaped crowns and produced few new epicormic branches during the 3 years following thinning.

## CONCLUSIONS

Stand-level growth has been negligible, but increases in quadratic mean diameter have been observed through the first 3 years of the study, particularly following the heavy thinning treatment.

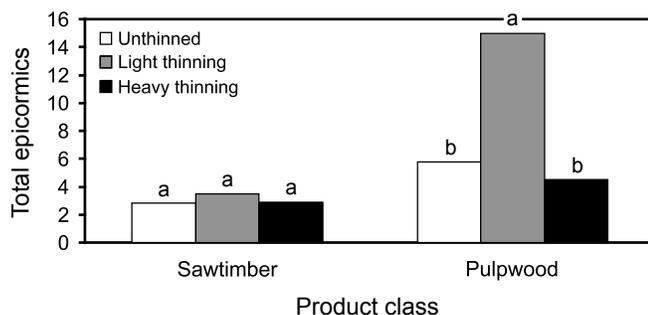


Figure 7—Total number of epicormic branches on the butt logs of residual red oak trees, by product class, 3 years after application of three thinning treatments. Bars within a product class followed by the same letter are not significantly different at the 0.05 level of probability.

Thinning increased cumulative diameter growth of residual trees, when averaged across all species. Diameter growth response varied among species groups, but the most pronounced response was by red oaks. Both levels of thinning increased cumulative diameter growth of residual red oaks by at least 47 percent, but there were no significant differences in diameter growth response between residual red oaks in the lightly thinned plots and in the heavily thinned plots. Heavy thinning also significantly increased diameter growth of codominant trees (by 31 percent), when averaged across all species.

Neither light nor heavy thinning significantly affected the production of epicormic branches on the butt logs of residual trees, even among red oaks, which generally are considered to be highly susceptible to the production of epicormic branches. In fact, across both levels of thinning, sawtimber-sized red oaks averaged a total of < 3.5 epicormic branches on the butt log at the end of the third year. The number of epicormic branches on the butt logs of residual, sawtimber-sized red oaks generally was not enough to cause a reduction in the grade of the butt log.

Most important, within the range of residual stand density evaluated (64 square feet of basal area per acre following heavy thinning to 86 square feet of basal area per acre following light thinning), we found no differences between light and heavy thinning in either cumulative diameter growth or production of epicormic branches by residual red oaks. Residual stand density, at least within fairly broad limits, had little effect on the initial response of individual red oaks to thinning.

## ACKNOWLEDGMENTS

We express deepest appreciation to Temple-Inland Forest Products Corporation for providing the study site and for its cooperation in all phases of study installation and measurement. We specifically thank Matthew Lowe, Jeff Portwood, Kylie Bradley, and Jennifer Smith, all of Temple-Inland Forest Products Corporation, for their continuing assistance in this study. We also thank Andy Ezell and Brian Lockhart for providing helpful suggestions on earlier drafts of this manuscript.

## LITERATURE CITED

- Goelz, J.C.G. 1995. A stocking guide for southern bottomland hardwoods. *Southern Journal of Applied Forestry*. 19(3): 103-104.
- Goelz, J.C.G.; Meadows, J.S. 1997. Stand density management of southern bottomland hardwoods. In: Meyer, D.A., ed. *Proceedings of the 25<sup>th</sup> annual hardwood symposium; 25 years of hardwood silviculture; a look back and a look ahead*. Memphis, TN: National Hardwood Lumber Association: 73-82.
- Hilt, D.E. 1979. Diameter growth of upland oaks after thinning. Res. Pap. NE-437. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.
- Johnson, R.L. 1981. Wetland silvicultural systems. In: Jackson, B.D.; Chambers, J.L., eds. *Timber harvesting in wetlands: 30<sup>th</sup> annual forestry symposium*. Baton Rouge, LA: Louisiana State University, Division of Continuing Education: 63-79.
- Lamson, N.I.; Smith, H.C. 1988. Thinning cherry-maple stands in West Virginia: 5-year results. Res. Pap. NE-615. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.
- Marquis, D.; Smith, C.; Lamson, N. [and others]. 1990. Standard plot layout and data collection procedures for the Stand Establishment and Stand Culture Working Groups, Northeastern Forest Experiment Station. Warren, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 55 p.

- McKnight, J.S. 1958. Thinning stands of water oaks. In: Management of bottomland forests. Proceedings of the seventh annual forestry symposium. Baton Rouge, LA: Louisiana State University, School of Forestry: 46-50.
- Meadows, J.S. 1995. Epicormic branches and lumber grade of bottomland oak. In: Lowery, G.; Meyer, D., eds. Advances in hardwood utilization: following profitability from the woods through rough dimension. Proceedings of the 23<sup>rd</sup> annual hardwood symposium. Memphis, TN: National Hardwood Lumber Association: 19-25.
- Meadows, J.S. 1996. Thinning guidelines for southern bottomland hardwood forests. In: Flynn, K.M., ed. Proceedings of the southern forested wetlands ecology and management conference. Clemson, SC: Clemson University, Consortium for Research on Southern Forested Wetlands: 98-101.
- Meadows, J.S.; Burkhardt, E.C. 2001. Epicormic branches affect lumber grade and value in willow oak. *Southern Journal of Applied Forestry*. 25(3): 136-141.
- Meadows, J.S.; Goelz, J.C.G. 1998. First-year growth and bole quality responses to thinning in a red oak-sweetgum stand on a minor streambottom site. In: Waldrop, T.A., ed. Proceedings of the ninth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 188-193.
- Meadows, J.S.; Goelz, J.C.G. 1999. Third-year growth and bole quality responses to thinning in a red oak-sweetgum stand on a minor streambottom site in west-central Alabama. In: Haywood, J.D., ed. Proceedings of the 10<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 87-93.
- Meadows, J.S.; Goelz, J.C.G. 2001. Fifth-year response to thinning in a water oak plantation in north Louisiana. *Southern Journal of Applied Forestry*. 25(1):31-39.
- Meadows, J.S.; Goelz, J.C.G. 2002. Fourth-year effects of thinning on growth and epicormic branching in a red oak-sweetgum stand on a minor streambottom site in west-central Alabama. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 201-208.
- Putnam, J.A.; Furnival, G.M.; McKnight, J.S. 1960. Management and inventory of southern hardwoods. *Agric. Handb.* 181. Washington, DC: U.S. Department of Agriculture. 102 p.
- Rast, E.D.; Sonderman, D.L.; Gammon, G.L. 1973. A guide to hardwood log grading (revised). Gen. Tech. Rep. NE-1. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 31 p.
- Sonderman, D.L. 1984. Quality response of even-aged 80-year-old white oak trees after thinning. Res. Pap. NE-543. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.
- Sonderman, D.L.; Rast, E.D. 1988. Effect of thinning on mixed-oak stem quality. Res. Pap. NE-618. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

# EFFECTS OF THINNING INTENSITY AND CROWN CLASS ON CHERRYBARK OAK EPICORMIC BRANCHING FIVE YEARS AFTER TREATMENT

Luben D. Dimov, Erika Stelzer, Kristi Wharton, James S. Meadows,  
Jim L. Chambers, Kenny Ribbeck, and E. Barry Moser<sup>1</sup>

**Abstract**—Thinning in oak-dominated stands may have many desirable consequences, including increases in tree growth and mast production. One of the potential disadvantages, however, is the proliferation of epicormic branches, which leads to reduction in lumber quality and value. We assessed the effects of thinning intensity and initial crown class on cherrybark oak (*Quercus pagoda* Raf.) epicormic branching in a 35-year old plantation in east central Louisiana. The thinning regimes were light, with residual stocking (Goelz 1995) of 75 percent, heavy, with 50 percent residual stocking, and an uncut control. The crown classes of all residual trees were classified immediately after treatment with a numeric crown class system (Meadows and others 2001). Five years after treatment, the number of epicormic branches increased across all treatments and crown classes. However, trees with higher crown class scores (the more dominant trees) continued to have fewer epicormics than trees with lower crown class scores.

## INTRODUCTION

Thinning in oak stands achieves a number of objectives, including providing intermediate return on investments and increasing basal area growth of the residual trees. Such objectives are common for the typical landowner. One negative consequence often associated with thinning in oak stands however, is the proliferation of epicormic branches on the boles of some trees. Epicormic branches arise from adventitious or dormant buds and can cause substantial reduction in both lumber value and log grade. Meadows and Burkhardt (2001) reported a reduction in willow oak (*Quercus phellos* L.) lumber value of 13 percent as a result of epicormic branches. The difference in value of hardwood logs grade 1, 2, and 3, other conditions being equal, can be dramatic; Stubbs (1986) reported value ratios between such logs as 13:7:1. Any stem attribute change that results in such a difference in log value deserves special attention of the forest manager and the landowner. Since fertilization (Michalek and others 2004) and pruning (Dwyer and Lowell 1988, Pelkki and Colvin 2004) are not solutions to the reduction in number and size of epicormic branches and lumber quality, proper silvicultural measures need to be taken in managing oak stands.

Cherrybark oak (*Quercus pagoda* Raf.), often considered to be one of the most commercially valuable bottomland hardwood species in the Southeastern United States (Putnam and others 1960), is believed to have medium susceptibility to epicormic branching (Meadows 1995). Production of new epicormic branches in cherrybark oak, as well as in other hardwood tree species, is sometimes observed after thinning and has often been believed to be caused by the increase in the amount of light reaching the tree bole. Proliferation in epicormics, however, occurs even in stands that have not been thinned. Indications from various studies suggest that tree species and vigor may also have an effect on epicormic

sprouting (Meadows 1995), with more dominant trees being less likely to produce new epicormic branches, even after thinning.

In this study, we examined the effects of thinning intensity and crown class on the production of epicormic branches in plantation-grown 35-year-old cherrybark oak trees 5 years after thinning. Crown class was determined using a crown classification system that assigns numeric values to crown attributes and allows the crown condition, and consequently the tree vigor, to be rated in more precise increments.

## MATERIALS AND METHODS

The Red River Wildlife Management Area in southern Concordia Parish, LA, served as the study area. The cherrybark oak plantation used in the study is within 0.5 mile west of the Mississippi River levee, but the site is not subject to flooding. The soils are Commerce silt loam (Aeric Fluvaquents), which are deep and somewhat poorly drained, and Bruin silt loam (Fluvaquentic Eutrudepts), a deep and moderately well-drained soil. The site was planted with several oak species between 1969 and 1972 with cherrybark oak representing 43 percent of the area. The average planting density was approximately 412 trees per acre. Between 1982 and 1985, the area was subjected to timber stand improvement using Tordon injection.

During the 1998 growing season, we established 14 treatment plots 3 chains (1 chain = 66 feet) x 6 chains. The measurement plots were nested within the treatment plots and were 1 chain wide x 4 chains long (0.4 acre). Diameter of all trees > 5 inches in diameter at breast height (d.b.h., 4.5 feet above ground) was measured to determine initial stocking according to the Goelz's (1995) stocking guide for southern bottomland hardwoods. Three thinning treatments were randomly assigned

<sup>1</sup> Postdoctoral Researcher, School of Renewable Natural Resources, Louisiana State University AgCenter, Baton Rouge, LA 70803; Biological Technician, IAP World Services, Inc., U.S. Geological Survey National Wetlands Research Center, Lafayette, LA 70506; Forestry Technician, USDA Forest Service, Southern Research Station, Pineville, LA 71360; Principal Silviculturist, USDA Forest Service, Center for Bottomland Hardwood Research, Stoneville, MS 38776; Forestry Program Leader and Weaver Brothers Professor of Forestry, Louisiana State University AgCenter, Baton Rouge, LA 70803; Biologist Programs Manager, Louisiana Department of Wildlife and Fisheries, Baton Rouge, LA 70898; and Department Head and Professor of Experimental Statistics, Louisiana State University AgCenter, Baton Rouge, LA 70803, respectively.

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to the plots within each block: light thin, where stocking was reduced to 75 percent, heavy thin, with stocking reduced to 50 percent, and uncut control (table 1). The thinning method was “from below”, where trees with low crown class, vigor, and small d.b.h. were preferentially removed until the desired stocking level was achieved. Thinning intensity was assigned randomly to the plots within each block and was applied between September 30, 1998, and February 3, 1999.

Crown class of each residual tree was determined immediately after treatment using the classification system of Meadows and others (2001). This system assigns numeric values to tree crown according to the criteria: (1) proportion of the crown exposed to direct sunlight from above - values from 0 to 10, (2) proportion of the upper half of the crown exposed to direct sunlight from the sides - values from 0 to 10, (3) crown balance - values from 1 to 4 according to the number of quadrants occupied by 20 percent or more of the total crown volume, and (4) relative crown size - values from 1 to 4 assigned for appropriate crown size and density as related to a tree of that diameter and species: One point is assigned if the crown size and density are considered to be severely limiting to growth, two points if limiting to growth, three points if somewhat limiting to growth, and four points if not limiting to growth. All points are then summed up and crown class is assigned in the following manner: 24 to 28 points = dominant, 17 to 23 points = codominant, 10 to 16 points = intermediate, and 2 to 9 points = suppressed.

Epicormic branches were counted immediately after treatment in February, 1999, and then 5 growing seasons later, in March, 2004. We counted all epicormic branches on the first 16-foot log of the cherrybark oak trees larger than 5 inches d.b.h.

We utilized a split-plot model with thinning treatment in the whole plot and crown class in the sub-plot and the MIXED procedure (software SAS v.9) to analyze the 5-year change in number of cherrybark oak epicormic branches. Effects with p-value < 0.05 were considered significant.

**Table 1—Differences in initial stocking necessitated assignment of plots into one of five blocks**

Block number	Plot number	Initial stocking	Thinning intensity
		- - % - -	
1	12	75	Control
	1	76	Light
	2	77	Heavy
2	11	80	Heavy
	6	81	Light
3	14	85	Heavy
	4	87	Light
4	7	90	Control
	8	92	Heavy
	3	95	Control
5	10	96	Light
	18	102	Light
	15	103	Heavy
	5	107	Control

## RESULTS

The overall effects of thinning intensity, initial crown class, and their interaction term were not significant. Therefore, the change in number of epicormic branches did not appear to be influenced by the residual stocking level and by the degree of crown release. The average 5-year increase in number of epicormic branches was 6.5 branches per tree, and the 95 percent confidence interval was from 4.0 to 9.1 branches.

However, the average number of epicormic branches per tree at the end of the fifth growing season was significantly greater than the number of epicormic branches at the beginning of the study in three of the four crown classes (fig. 1) and in each of the individual treatments (fig. 2, table 2). The average increase in number of epicormic branches per tree on the different treatments ranged from 6.0 to 6.8 branches. Trees from more dominant crown classes experienced smaller increase in number of epicormic branches than did trees that were codominant or intermediate. These differences, however, were not significant (table 2). Although the suppressed trees did not experience a very large increase in the number of epicormic branches, at the end of the period they still had more epicormic branches than the trees from the other three crown classes (fig. 1).

With the exception of the trees from the dominant crown class in the Control plots, the increase in epicormic branches

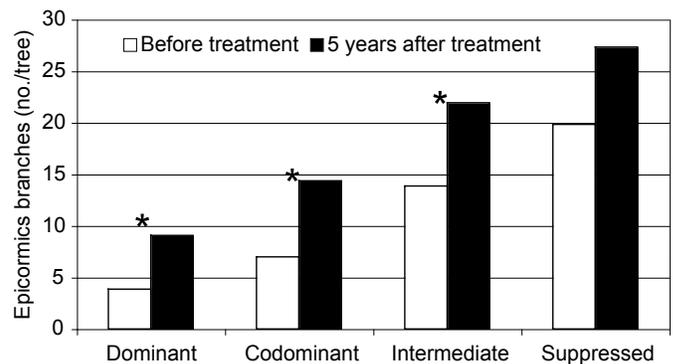


Figure 1—Average number of epicormic branches per crown class before and 5 years after thinning. Asterisks indicate that the increase in number of epicormic branches is significant at the 0.05 level.

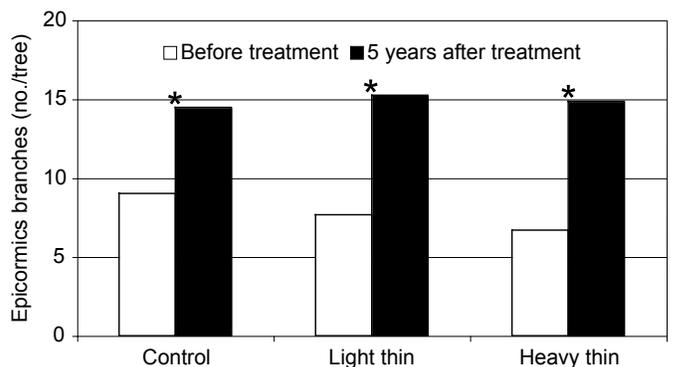


Figure 2—Average number of epicormic branches per treatment before and 5 years after thinning. Asterisks indicate that the increase in number of epicormic branches is significant at the 0.05 level.

was significant for trees within all crown classes in each treatment (table 3; figs. 3 and 4). It should be noted that due to the very small number of suppressed trees in the heavy

and light thin plots (as a result of their preferential removal during the thinning operations), they were not included in table 3.

**Table 2—Five-year mean (least squares means) change in numbers of epicormic branches for each of the three levels of thinning (control-C, light-L, and heavy-H) and four crown classes (dominant-D, codominant-CD, intermediate-I, and suppressed-S). Significant t tests indicate an increase in the number of epicormic branches**

Effect	Thinning (C,L,H)	Crown class (D,CD,I,S)	Estimate	Standard error	DF	t-value	P-value
thinning	C		6.830	1.842	11.1	3.71	0.003
	L		6.782	2.126	29.4	3.19	0.003
	H		5.951	2.425	47.1	2.45	0.018
crown class		D	5.594	1.281	29.8	4.37	<0.001
		CD	7.361	1.137	19.1	6.48	<0.001
		I	8.654	1.630	67.6	5.31	<0.001
		S	4.476	3.200	289.0	1.40	0.163

**Table 3—Five-year mean (least squares means) change in numbers of epicormics for the cell-mean combinations of the three levels of thinning (control-C, light-L, and heavy-H) and four levels of crown class (dominant-D, codominant-CD, intermediate-I, suppressed-S). Significant t tests indicate an increase in the number of epicormic branches**

Effect	Thinning (C,L,H)	Crown class (D,CD,I,S)	Estimate	Standard error	DF	t-value	P-value
thinning by crown class	C	D	3.944	2.307	26.3	1.71	0.099
	C	CD	5.298	2.010	15.6	2.64	0.018
	C	I	7.278	2.328	27.6	3.13	0.004
	C	S	10.801	3.112	78.8	3.47	<0.001
thinning by crown class	L	D	5.163	2.208	34.8	2.34	0.025
	L	CD	7.623	1.831	16.9	4.16	<0.001
	L	I	11.392	2.570	56.9	4.43	<0.001
thinning by crown class	H	D	7.674	2.136	29.7	3.59	0.001
	H	CD	9.162	2.058	26.5	4.45	<0.001
	H	I	7.294	3.449	131	2.11	0.036

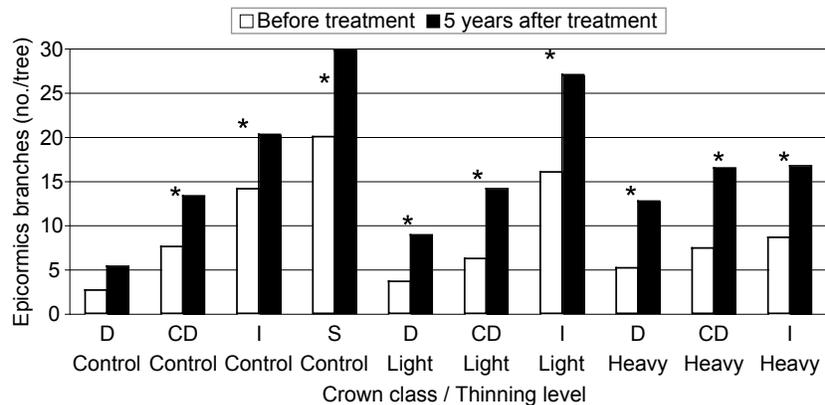


Figure 3—Number of epicormic branches before and 5 years after treatment per crown class (dominant-D, codominant-CD, intermediate-I, suppressed-S) by treatment and ordered by the treatment level. Asterisks indicate that the increase in number of epicormic branches is significant at the 0.05 level.

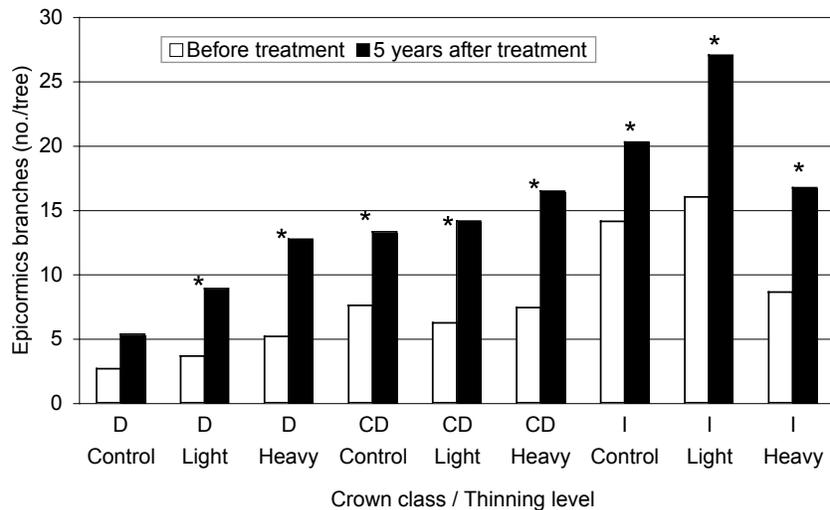


Figure 4—Number of epicormic branches before and 5 years after treatment per crown class (dominant-D, codominant-CD, intermediate-I, suppressed-S) by treatment and ordered by crown class. Asterisks indicate that the increase in number of epicormic branches is significant at the 0.05 level.

## DISCUSSION AND CONCLUSIONS

The observed increase in overall number of epicormic branches on the boles of all trees, regardless of their crown class immediately after thinning and regardless of the thinning intensity, indicates that other factors beyond those examined in the study may also be having an impact on this increase. Tree vigor is one of the factors influencing epicormic branching that forest management can manipulate the easiest. This is carried out through timely release of selected crop trees from the crowding effects of inferior neighbors. If such a release is not provided in a timely manner, even the more competitive trees may have already been subjected to enough competition for resources to experience a decrease in vigor and an increase in propensity to produce epicormic branches. This is certainly a possibility for the plantation described in this study, because stocking was high on most of the plots. Additionally, providing sufficient aboveground growing space may not always be a sufficient measure for improving tree vigor. Environmental factors, including droughts and insect infestations, may reduce tree vigor regardless of the amount of growing space available to the tree. Two of the years (1999 and 2000) during the study period were indeed classified as drier than average and may therefore have contributed to increased tree stress and the overall increase in number of epicormic branches. It appears that the combined effect of delayed thinning and lower-than-average rainfall for part of the study period might have been so strong as to mask the effect of thinning intensity and initial crown class, both of which were not significant effects for the 5-year change in number of epicormic branches. In cases where stands have not yet stagnated and there are no climatic events that cause unusual stress on the residual trees, epicormic branches are generally expected to be less of a problem in red oak species. Meadows and Goelz (2002), for example, report little effect of thinning on the production of new epicormic branches in red oaks in a mixed red oak-sweetgum stand 4 years after thinning.

The lack of significance of the overall increase in epicormic branches in the suppressed trees likely results from the limited number of suppressed trees in the heavy and light

thinned plots, which makes the estimate for this effect less reliable. When the suppressed trees are examined in regard to the individual treatments, then they do follow the general trend of significant increase in number of epicormic branches by the end of the fifth growing season.

It seems possible that the lack of significance in the increase in number of epicormic branches on the dominant trees from the control plots might be caused by the likely much higher average initial vigor of these trees. That is, dominant trees on controls plot quite possibly experienced less competition and reduction in vigor in the past than trees with comparable crown class score that are in the light or heavy thinned plots. This is because the trees on the thinned plot had such scores after the thinning, while on the average, prior to thinning, their scores would have generally been lower than that, i.e., they would have been growing in a more competitive environment.

Despite the overall increase in the number of epicormic branches on the boles of all trees after thinning, such average increase was also present on trees in the unthinned plots, indicating that factors other than thinning also play a crucial role in the process. Although the number of epicormic branches increased on trees from all crown classes, the high-vigor dominant and co-dominant trees still had fewer epicormic branches at the end of the 5-year period than trees from lower crown classes. Therefore, unless the most vigorous trees are favored during thinning, the residual stand is likely to suffer from substantial reduction in average tree quality and value. A typical diameter limit cut, which often amounts to “high-grading”, would certainly result in degrading the stand value and its future potential and should therefore be discouraged and avoided. It is also important to time the thinning operations before the trees in the plantation have gotten so crowded as to jeopardize their future quality.

## ACKNOWLEDGMENTS

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#### LITERATURE CITED

- Dwyer, J.P.; Lowell, K.E. 1988. Long-term effects of thinning and pruning on the quality, quantity, and value of oak lumber. *Northern Journal of Applied Forestry*. 5: 258-260.
- Goelz, J.C.G. 1995. A stocking guide for southern bottomland hardwoods. *Southern Journal of Applied Forestry*. 19: 103-104.
- Meadows, J.S. 1995. Epicormic branches and lumber grade of bottomland oak. In: *Proceedings of the 23rd annual hardwood symposium*. Memphis, TN: National Hardwood Lumber Association: 19-25.
- Meadows, J.S.; Burkhardt, E.C. 2001. Epicormic branches affect lumber grade and value in willow oak. *Southern Journal of Applied Forestry*. 25: 136-141.
- Meadows, J.S.; Burkhardt, E.C.; Johnson, R.L.; Hodges, J.D. 2001. A numerical rating system for crown classes of southern hardwoods. *Southern Journal of Applied Forestry*. 25: 154-158.
- Meadows, J.S.; Goelz, J.C.G. 2002. Fourth-year effects of thinning on growth and epicormic branching in a red oak-sweetgum stand on a minor streambottom in west-central Alabama. In: Outcalt, K.W., ed. *Proceedings of the 11th biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 201-208.
- Michalek, A.J.; Lockhart, B.R.; Lowe, M.W.; Williams, R.A. 2004. Diameter-growth and epicormic branching response of an east Texas bottomland red oak stand 3 years after thinning and fertilization. In: Connor, K.F., ed. *Proceedings of the 12th biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 269-275.
- Pelkki, M.H.; Colvin, R.J. 2004. Effects of thinning in a cherrybark oak plantation. *Southern Journal of Applied Forestry*. 28: 55-58.
- Putnam, J.A.; Furnival, J.M.; McKnight, J.S. 1960. *Management and inventory of southern hardwoods*. Agric. Handb. 181. Washington, DC: U.S. Department of Agriculture, Forest Service. 102 p.
- Stubbs, J. 1986. Hardwood epicormic branching - small knots, but big losses. *Southern Journal of Applied Forestry*. 10: 217-220.

# EARLY RESPONSE OF INTERPLANTED NUTTALL OAK TO RELEASE FROM AN EASTERN COTTONWOOD OVERSTORY

Emile S. Gardiner<sup>1</sup>

**Abstract**—Forest restoration activity in the Lower Mississippi Alluvial Valley has generated a demand for alternative afforestation practices that can accommodate diverse landowner objectives. An alternative afforestation practice now being studied involves rapid establishment of a forest canopy of eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.), followed by interplanting with seedlings of slower-growing bottomland hardwood species. An experiment conducted in Mississippi shows that Nuttall oak (*Quercus nuttallii* Palm.) seedlings can develop into vigorous sapling-sized reproduction when interplanted in the understory of eastern cottonwood, and that the cottonwood overstory can be harvested without adversely affecting the interplanted reproduction. Harvesting damage was minimal, and excellent survival, vigorous sprouting, and adequate growth of Nuttall oak reproduction interplanted beneath eastern cottonwood indicate that Nuttall oak reproduction can be established under and released from an eastern cottonwood overstory.

## INTRODUCTION

Over the past 15 years, a substantial area of cropland in the Lower Mississippi Alluvial Valley (LMAV) has been converted to hardwood forest plantations (Gardiner and Oliver 2005). Due to the extensiveness of afforestation in this region, plantation establishment practices and costs are often minimized, and this conventional approach frequently contributes to poor stocking or slow growth of stands. It has been found that conventional afforestation practices may not be the best means of accomplishing certain landowner objectives (Stanturf and others 2000, Stanturf and others 2001). Recent interest in establishing plantations for objectives such as biodiversity, carbon sequestration, economic sustainability, and water quality has led managers to seek alternative afforestation practices that promote development of complex plantations (Gardiner and others 2002).

In one alternative afforestation system now being tested in the LMAV, rows of bottomland hardwood species of later successional seres, such as Nuttall oak (*Quercus nuttallii* Palm.), are interplanted between previously established rows of eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) (Gardiner and others 2001, Gardiner and others 2004). In this system, the cottonwood stand serves as a nurse for the other hardwood reproduction developing in the understory. At the end of the 10- to 15-year cottonwood rotation, the cottonwood is harvested and the hardwood reproduction that has been established in the understory is released. This alternative has several ecological and economic advantages over conventional afforestation practices in the LMAV. These advantages include more rapid carbon sequestration (Stanturf and others 2003), quicker development of forest bird assemblages (Hamel 2003), earlier economic return on the afforestation investment (Stanturf and Portwood 1999), and favorable stand conditions for regeneration of other bottomland tree and shrub species (Gardiner and others 2004). Thus, this interplanting system can provide for multiple objectives while catalyzing bottomland hardwood ecosystem processes.

Though substantial benefits of this interplanting system have been documented, it has not been demonstrated that the

cottonwood biomass can be harvested without significant damage to the developing reproduction in the understory. Also, it has not been shown that the interplanted Nuttall oak reproduction will respond satisfactorily once the eastern cottonwood overstory is harvested. In this study, a mature plantation of eastern cottonwood interplanted with Nuttall oak was harvested experimentally to address these questions. More specifically, the objectives of this research were to (a) quantify the extent of harvesting damage to interplanted Nuttall oak reproduction when the eastern cottonwood overwood was removed; and (b) quantify sprouting frequency, survival, and growth of interplanted Nuttall oak reproduction following release from the eastern cottonwood overstory.

## METHODS

The study was conducted in a 10-year-old eastern cottonwood plantation adjacent to Steele Bayou on the Fidler Plantation, Issaquena County, MS. Soil on the site is mapped to the Commerce series (fine-silty, mixed, superactive, nonacid, thermic Fluvaquent Endoaquepts) (Wynn and others 1959), and this series is generally well suited for culture of eastern cottonwood. Operational practices described in Gardiner and others (2001) were employed to establish the cottonwood stand on a conventional spacing of 12 by 12 feet in the winter of 1991-92. In the winter of 1993-94, rows of 1-0 bareroot Nuttall oak seedlings were planted between rows of cottonwoods. The oak rows were 24 feet apart, and the oaks were 12 feet apart within rows. Oak seedlings were hand planted and did not receive competition control or other cultural treatments after planting.

Six plots were delineated. Each measured approximately 180 by 240 feet and encompassed 15 rows of eastern cottonwood and 7 rows of Nuttall oak, each row being 240 feet long. We inventoried all Nuttall oak reproduction in each plot, assigning a unique number to each stem. Forty Nuttall oak stems in each plot were randomly selected to serve as sample plants (240 total plants). We measured the height (feet), root-collar diameter (inches), and diameter at breast height (inches) of each sample plant.

<sup>1</sup> Research Forester, USDA Forest Service, Southern Research Station, Center for Bottomland Hardwoods Research, Stoneville, MS 38776.

In November 2001, the plots were harvested with a John Deere 843H feller buncher. There were two harvesting treatments, and these were assigned to plots randomly. Three plots received each harvesting treatment. In one treatment, all cottonwood stems were felled and removed from the site as whole trees with a grapple skidder. In the other treatment, all cottonwood stems were felled, all Nuttall oak stems were severed by the feller buncher, and a grapple skidder was used to skid all harvested cottonwood from the site. The first treatment was designed both to show how much damage a typical harvesting operation might do to Nuttall oak reproduction in a stand of this kind and to determine the growth response to release by the interplanted Nuttall oak reproduction. The second treatment was designed to provide insight into the amount of damage to, and stool viability and growth response of, interplanted Nuttall oak reproduction that was coppiced.

Immediately after the harvest, we assessed physical damage sustained by sample plants. We noted if reproduction had bark removed, a broken shoot, or was uprooted during harvesting. Following three consecutive growing seasons after the harvest, we measured stem height and the number of sprouts on all surviving Nuttall oak sample plants. Analysis of variance for a completely random design was conducted on plot means of stem damage and stem height for each growing season. Tests were conducted at an  $\alpha = 0.05$  level.

## RESULTS AND DISCUSSION

### Logging Damage to Reproduction

Logging damage to Nuttall oak reproduction averaged 6 percent across the study site. Most of the observed logging damage was recorded as leaning or bent stems, and this damage appeared to be caused as cottonwood trees were felled rather than by maneuvering of logging equipment. No uprooting of plants was observed. Previous experience of harvesting operations in other cottonwood stands suggested that the felling and skidding equipment would require about 16 feet to maneuver between trees. The 24-foot spacing between Nuttall oak rows in this study made it possible to maneuver harvesting machinery without significantly damaging reproduction interplanted in the understory.

### Damage to and Sprouting of Nuttall Oak Stumps

In plots that were harvested completely, Nuttall oak stems were clipped about 10 inches above groundline by the feller buncher. Typical logging damage was not observed in these plots because shoots that might have been injured by cottonwood felling were cut during the harvest. However, cutting of the small-diameter Nuttall oak stems with the feller head caused splintering of about 64 percent of the Nuttall oak stumps. Also, nearly 12.5 percent of the stems were not completely severed from the stump but were partially severed and broken over by the feller buncher. The Nuttall oak reproduction remained viable and sprouted readily. After the first growing season, there was an average of  $4.3 \pm 0.7$  sprouts per stump. Mortality within clumps progressed slowly, and stumps supported  $3.8 \pm 0.4$  sprouts 3 years after harvest. At that time, 99 percent of all stumps had live sprouts.

Natural or anthropogenic disturbances in bottomland hardwood stands often kill or remove the shoot of advance oak reproduction. Vigorous oak saplings generally coppice readily following disturbance if the root system and root collar remain

intact (Hodges and Gardiner 1993). Because established oak saplings sprout readily, they typically maintain a high value in regeneration of natural bottomland stands (Belli and others 1999). Our findings are consistent with literature on oak sprouting in natural stands in that Nuttall oak artificially established in the understory of eastern cottonwood coppiced readily and survived well following overstory harvest. Our findings on Nuttall oak coppicing and the lack of logging damage to stumps when only the cottonwood overstory was removed may support interplanting of reproduction in a more dense configuration if desired, e.g., a 12 by 12 foot spacing.

### Height Development of Reproduction

Prior to the harvest, Nuttall oak reproduction averaged  $11.6 \pm 1.1$  feet in height, and mean height did not differ by harvest treatment ( $P = 0.5304$ ) (fig. 1). Saplings released by the cottonwood harvest had not shown an above-ground response by the end of the first growing season when they had an average height of  $11.7 \pm 1.3$  feet. Nuttall oak stump sprouts responded vigorously, growing to almost half of their preharvest height ( $5.7 \pm 0.4$  feet). By the end of the third growing season, reproduction that was not coppiced maintained a 25 percent height advantage over coppiced plants ( $P = 0.036$ ). However, coppice was growing vigorously, averaged  $13.0 \pm 0.7$ -feet tall, and had surpassed its preharvest height (fig. 1).

Height distributions of the released Nuttall oak illustrate the development of each reproduction type into taller height classes (fig. 2). Fifty-five percent of saplings that were not coppiced were in a height class taller than 10 feet prior to harvest. Three years following release, 89 percent had advanced into height classes taller than 10 feet. Sixty-five percent of saplings that were coppiced were in a height class taller than 10 feet prior to harvest, and 87 percent had grown into these taller height classes 3 years after treatment (fig. 2).

Slow above-ground response to release has often been cited as a factor that makes bottomland oak reproduction less competitive than reproduction of more intolerant species following stand disturbance (Hodges and Gardiner 1993, Lockhart and others 2000). Several physiological and morphological factors

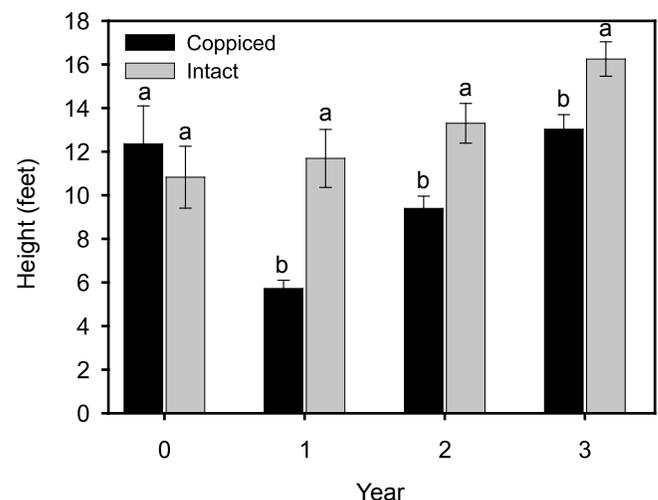


Figure 1—Mean height of coppiced and intact Nuttall oak reproduction interplanted beneath eastern cottonwood. This reproduction was released from the cottonwood overstory following year zero.

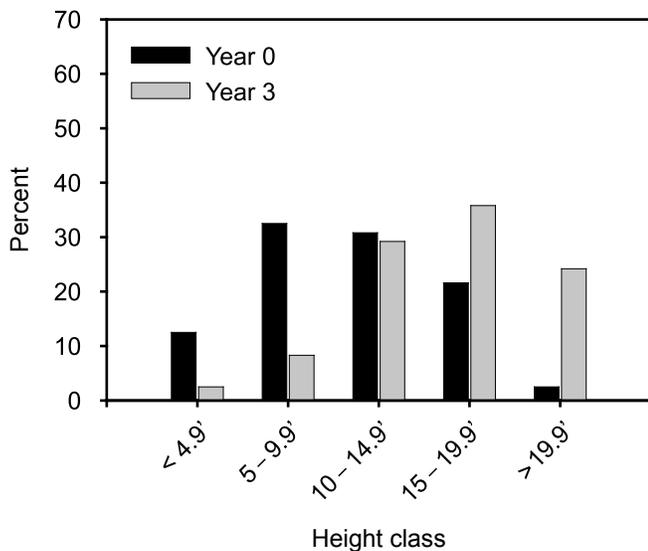
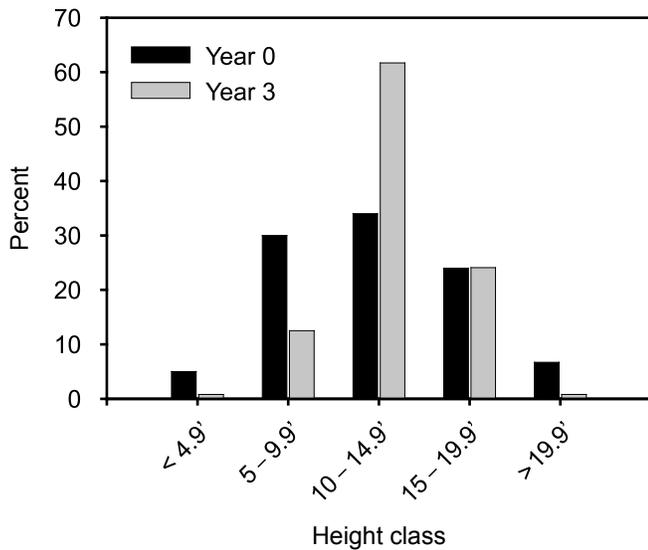


Figure 2—Height distribution of intact (below) and coppiced (above) Nuttall oak reproduction that was interplanted beneath eastern cottonwood. This reproduction was released from the cottonwood overstory following year zero.

characteristic of oak reproduction may contribute to this sluggish response (Hodges and Gardiner 1993), but some authors have suggested the use of shoot clipping or coppicing to rejuvenate above-ground growth of oak reproduction, particularly where this reproduction exhibits poor apical vigor (Deen and others 1993, Gardiner 1998, Janzen and Hodges 1987, Lockhart and others 2000). In this study, established Nuttall oak saplings responded slowly to release from the eastern cottonwood overstory, showing no appreciable height increment the first growing season after harvest. These saplings, however, eventually acclimated to the disturbance and made substantial height growth by the third growing season after harvest. Height growth of Nuttall oak stump sprouts responded rapidly to release, but this growth had not compensated for the reduction in stem length 3 years after clipping. In contrast, Stanturf and Kennedy (1996) demonstrated that the 5-year height of top-pruned cherrybark oak (*Q. pagoda* Raf.) seedlings did not differ from the average height of seedlings that

were not top-pruned. Nevertheless, oak reproduction established in the understory of eastern cottonwood will respond to removal of the canopy on afforestation sites and should attain upper canopy positions in the subsequent stand.

## SUMMARY

A valid concern when designing and establishing interplanted plantations for forest restoration is providing for harvest of the nurse crop and effective release of the understory reproduction. We found that an eastern cottonwood overstory can be harvested with minimal damage to interplanted Nuttall oak reproduction if spacing between and within rows is as it was in this experiment. Mortality of Nuttall oak reproduction was minimal through three growing seasons whether stems remained intact or were severed by felling equipment. Additionally, splintering of the Nuttall oak stumps observed in this study did not reduce coppicing. Our results may support interplanting of reproduction in a more dense configuration if desired, e.g., a 12 by 12 foot spacing. Height development of released Nuttall oak saplings was slow initially, but these saplings eventually acclimated to the open environment and were growing well by year three. Nuttall oak coppice developed rapidly over three growing seasons but still lagged behind saplings that were not coppiced. The lack of harvesting damage and the excellent survival, vigorous sprouting, and adequate growth of Nuttall oak reproduction interplanted beneath eastern cottonwood indicate that reproduction of this species can be interplanted and established under an eastern cottonwood overstory and then released successfully. These results support establishment of more complex plantations to address multiple management objectives when restoring forests on former agricultural land.

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Jackie Henne-Kerr provided invaluable assistance in designing and establishing this experiment and in coordinating and implementing the cottonwood harvest on the Fittler Plantation. Encouragement to conduct this study was provided by Pat Weber of Creative Forestry and Jeff Portwood of Temple-Inland Forest Products Corporation. Bryce Burke, Beth Corbin, Sam Franklin, and Ben Ware provided invaluable assistance in the field.

## LITERATURE CITED

- Belli, K.L.; Hart, C.P.; Hodges, J.D.; Stanturf, J.A. 1999. Assessment of the regeneration potential of red oaks and ash on minor bottoms of Mississippi. *Southern Journal of Applied Forestry*. 23: 133-138.
- Deen, R.T.; Hodges, J.D.; Janzen, G.C. 1993. The influence of mid-story-understory control treatments on regeneration of red oak species following clearcutting. In: Brissette, J.C., ed. *Proceedings of the seventh biennial southern silvicultural research conference*. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 117-121.
- Gardiner, E.S. 1998. Water relations and morphology of Nuttall oak seedling sprouts. In: Waldrop, T.A., ed. *Proceedings of the ninth biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 284-288.
- Gardiner, E.S.; Oliver, J.M. 2005. Restoration of bottomland hardwood forests in the Lower Mississippi Alluvial Valley, U.S.A. In: Stanturf, J.A.; Madsen, P., eds. *Restoration of boreal and temperate forests*. Boca Raton, FL: CRC Press: 235-251.

- Gardiner, E.S.; Russell, D.R.; Oliver, M.; Dorris, L.C., Jr. 2002. Bottomland hardwood afforestation: state of the art. In: Holland, M.M.; Warren, M.L.; Stanturf, J.A., eds. Proceedings of a conference on sustainability of wetlands and water resources: how well can riverine wetlands continue to support society into the 21<sup>st</sup> Century? Gen. Tech. Rep. SRS-50. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 75-86.
- Gardiner, E.S.; Schweitzer, C.J.; Stanturf, J.A. 2001. Photosynthesis of Nuttall oak (*Quercus nuttallii* Palm.) seedlings interplanted beneath an eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) nurse crop. Forest Ecology and Management. 149: 283-294.
- Gardiner, E.S.; Stanturf, J.A.; Schweitzer, C.J. 2004. An afforestation system for restoring bottomland hardwood forests: biomass accumulation of Nuttall oak seedlings interplanted beneath eastern cottonwood. Restoration Ecology. 12: 525-532.
- Hamel, P.B. 2003. Winter bird community differences among methods of bottomland hardwood forest restoration: results after seven growing seasons. Forestry. 76: 189-197.
- Hodges, J.D.; Gardiner, E.S. 1993. Ecology and physiology of oak regeneration. In: Loftis, D.; McGee, C.E., ed. Oak regeneration: serious problems, practical recommendations. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 54-65.
- Janzen, G.C.; Hodges, J.D. 1987. Development of advanced oak regeneration as influenced by removal of midstory and understory vegetation. In: Phillips, D.R., comp. Proceedings of the fourth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 455-461.
- Lockhart, B.R.; Hodges, J.D.; Gardiner, E.S. 2000. Response of advance cherrybark oak reproduction to midstory removal and shoot clipping. Southern Journal of Applied Forestry. 24: 45-50.
- Stanturf, J.A.; Gardiner, E.S.; Hamel, P.B. [and others]. 2000. Restoring bottomland hardwood ecosystems in the Lower Mississippi Alluvial Valley. Journal of Forestry. 98: 10-16.
- Stanturf, J.A.; Gardiner, E.S.; Schoenholtz, S. 2003. Interplanting for bioenergy and riparian restoration in the southern USA. In: Nicholas, I.D., comp. Proceedings of the conference on short rotation crops for bioenergy. [Place of publication unknown]: International Energy Agency, Bioenergy Task. 30: 241-249.
- Stanturf, J.A.; Kennedy, H.E., Jr. 1996. Survival and growth of planted and direct-seeded cherrybark oak in South Carolina. Southern Journal of Applied Forestry. 20: 194-196.
- Stanturf, J.A.; Portwood, C.J. 1999. Economics of afforestation with eastern cottonwood (*Populus deltoides*) on agricultural land in the Lower Mississippi Alluvial Valley. In: Haywood, J.D., ed. Proceedings of the 10<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 66-72.
- Stanturf, J.A.; Schoenholtz, S.H.; Schweitzer, C.J.; Shepard, J.P. 2001. Achieving restoration success: myths in bottomland hardwood forests. Restoration Ecology. 9: 189-200.
- Wynn, A.H., Jr.; Alcorn, D.E.; Parker, R.L. 1959. Soil survey of Issaquena County Mississippi. Series 1959, no. 2. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 42 p.

# THE RESPONSE OF TWO VERY YOUNG NATURALLY REGENERATED UPLAND HARDWOOD STANDS TO WEED CONTROL AND FERTILIZATION

Jamie L. Schuler and Daniel J. Robison<sup>1</sup>

**Abstract**—Two newly regenerated hardwood forest stands in the Piedmont of North Carolina were examined to determine the potential to accelerate productivity in young stands. Factorial combinations of fertilization and vegetation control treatments were applied to 1-year-old and 3-year-old stands. After three growing seasons, fertilization improved growth rates at both sites. The collective species response to NPK fertilization was a doubling of individual seedling volume. Weeding failed to significantly increase growth over nonweeded seedlings, and the combined weeding and fertilization effects were additive (no interaction). Stem densities declined markedly after 3 years. Mortality at the lower end of the initial height distribution was increased on the fertilize-only plots, suggesting that the substantial increase in height in the fertilization treatment was not completely attributable to enhanced growth rates alone. These results highlight that young stands may not be performing up to their potential, and that early stand intervention can be a viable management strategy.

## INTRODUCTION

Southern upland hardwood forests, including the Piedmont region, are often characterized as having low productivity. Most of the Piedmont has suffered from severe soil erosion, and many hardwood stands have been repeatedly subjected to selective harvesting with few if any improvement cuttings. As a result, these stands have average growth rates of about 5 m<sup>3</sup>/ha per year (Roeder and Gardner 1984). With increasing harvests predicted in the Piedmont region because of an expected increased market demand for hardwood roundwood and chips (Prestemon and Abt 2002), many thousands of hectares of newly regenerated stands are being created that will produce mixed species stands starting with 40,000 to 100,000 stems/ha (Schuler and others, in review). Another 3 or 4 decades will typically pass before the next treatment, usually a commercial thinning. By this time, one-third to one-half the rotation may have passed without any attempt to improve productivity or species composition, thereby increasing the likelihood of a continued cycle of sub-optimal productivity and, without timber stand improvement, a high-representation of low-value species.

In young natural hardwood stands, low productivity has been attributed to overstocking (Kellison and others 1981) and the delayed onset of crown closure due to intense competition from competing vegetation (Romagosa and Robison 2003). Managing stem density and competing vegetation has led to positive effects on individual tree growth in young stands (Johnson and others 1998, Pham 1985, Robison and others 2004).

Soil nutrient management has also received substantial attention in the Southern United States. Over 500,000 ha of pine plantations are fertilized annually (NCSFNC 2002). Studies have also shown that fertilization, especially with nitrogen (N) and phosphorus (P), can be very beneficial for hardwood stands by increasing growth rates and accelerating self-thinning (Auchmoody 1985, Haines and Sanderford 1976, Newton and others 2002, Schuler and Robison 2002). Recent economic modeling activities indicate investments upwards of U.S. \$320/ha in year 1 in natural hardwoods are potentially

profitable investments if productivity can rise from 4.7 to 6.9 tons/ha per year due to management activities (assuming IRR=7.3 percent) (Siry and others 2004). These projections indicate that investments such as broadcast weed control and fertilization (Dubios and others 2003) made soon after regeneration treatments (e.g., year 1 to 3) are financially feasible.

The objective of this study was to assess how fertility and competing vegetation affect growth and development of very young mixed species Piedmont stands of naturally-regenerated hardwoods. By manipulating factors that potentially constrain resource availability, opportunities to increase productivity in upland Piedmont stands may be realized.

## METHODS

Two upland sites in the North Carolina Piedmont were studied. One site was on the North Carolina State University Hill Demonstration Forest (Hill), located in Durham Co., NC, and was formerly a natural 2-ha loblolly and Virginia pine (*Pinus taeda* L. and *P. virginiana* Mill., respectively) stand with a lesser component of mixed hardwoods. This site was regenerated through clean clearcutting in winter 1998-1999. Site two was on the Duke University Forest (Duke), located in Orange Co., NC, and was formerly a 5-ha mature natural mixed oak (*Quercus* spp.) stand. This site was regenerated following a salvage clean clearcut operation in the winter 1996-1997 following damage from Hurricane Fran (September 6, 1996). The two sites are approximately 24 km apart.

The Hill site has Georgeville silt loam soils with a mainly north-facing aspect on slopes of < 5 percent (Kirby 1976). The Duke site has Wedowee sandy loam soils with a north-facing aspect on a 2 to 10 percent slope (Personal communication, 2004, Judson Edeburn, Duke Forest Manager, Office of the Duke Forest, Box 90332, Duke University, Durham, NC 27708).

Sixteen 10-m<sup>2</sup> circular plots with an additional 1-m treated border were located on each site with the criteria that each plot contained at least two yellow-poplar (*Liriodendron tulipifera* L.) and two oak stems (putatively seed or seedling-sprout

<sup>1</sup> Assistant Director and Associate Professor/Director, respectively, Hardwood Research Cooperative, North Carolina State University, Department of Forestry and Environmental Resources, Raleigh, NC 27695-8008.

origin), no obvious large stump sprouts, and were not in heavy slash concentrations or on skid trails. For each site, four treatments were replicated in four blocks based on topography. The treatments began in June, 1999, and continued through the end of the 2001 growing season. The study was installed as a 2x2 factorial design with or without the following main factors:

1. Weeding- repeated hand removal of the aboveground portion of all non-arborescent vegetation in years 1 to 3.
2. Fertilization- in June, 1999, with 90 kg N/ha and 100 kg P/ha applied as diammonium phosphate, and in March, 2001, with 100 kg N/ha as urea and 100 kg K/ha as muriate of potash.

Stem heights ( $\pm 1$  cm) and basal diameters ( $\pm 0.1$  mm) were recorded for all arborescent species in spring, 1999, prior to the installation of treatments on all plots. Stem heights and diameters were again measured on all plots at the end of the 2001 growing season and 3 years after treatments were imposed. Stem volumes were calculated as conical volume. Each stem at the Hill Forest site was permanently marked with an aluminum tag embossed with a unique identification number prior to the initiation of treatments. Additional stems that emerged over the duration of the study were tagged at each measurement cycle. The presence and survival of individual stems was used to assess patterns of recruitment and mortality.

Stem densities and stem height, diameter, and volume were analyzed using analysis of variance (ANOVA) (SAS 1990) with the respective initial measurement parameter as a covariate. Therefore, reported means are based on least-squares estimators. Main effects and interactions were evaluated for significance at  $P < 0.1$ . Logarithmic transformations were applied to volume data to correct for heteroscedasticity.

## RESULTS

### Hill Forest

Pretreatment stem densities on these plots averaged 169,750 stems  $ha^{-1}$  with over 20 species represented. No statistical differences were detected in initial stem densities. Species composition was dominated on all plots by yellow-poplar (64 percent of all stems), dogwood (*Cornus florida* L., 5.9 percent), sumac (*Rhus* spp., 5.2 percent), red maple (*Acer rubrum* L., 4.1 percent), river birch (*Betula nigra* L., 3.9 percent) and black cherry (*Prunus serotina* Ehrh., 3.1 percent).

Although species composition varied little throughout the 3-year study, stem densities changed markedly (table 1), mostly as a result of stem mortality. Stem density on control plots increased 21,000 stems  $ha^{-1}$  by the end of the third growing season (3GS). Weeded-only and weeding+fertilization treatment plots had an 18 to 21 percent reduction in initial stem density following year 3. By contrast, stem numbers declined dramatically (>50 percent) by the end of the 3GS on the fertilized-only plots. Stem density was affected by a weeding and fertilization interaction following the 3GS ( $P = 0.049$ ). Stem density after 3 years on fertilize-only plots was significantly less than the control and weeded plots.

The recruitment of new individuals ranged from 18 to 38 stems per plot over 3 years. Fertilized plots had reduced recruitment, although differences were not statistically significant (table 2).

**Table 1—The effect of weeding and fertilization treatments on stem density on a rising 1-year-old (Hill Forest) and on a rising 3-year-old (Duke Forest) naturally-regenerated upland NC Piedmont stand**

Site		Control	Fertilized	Weeded	Weeded + fertilized
----- stems/10 m <sup>2</sup> -----					
Hill Forest	age 0 <sup>a</sup>	130	206	184	159
	age 3	151	87	151	125
Duke Forest	age 3 <sup>b</sup>	79	104	90	87
	age 5	107	94	123	95

<sup>a</sup> At the Hill Forest, age 0 is the pretreatment stem density of a rising 1-year-old stand.

<sup>b</sup> At the Duke Forest, age 3 is the pretreatment stem density of a rising 3-year-old stand.

Net stem mortality (total mortality minus total recruitment) among treatments was 25, 47, 29, and 34 percent of the initial stem density after the 3GS for the control, fertilized, weeded, and weeded+fertilized treatments, respectively. Total mortality among stems present pretreatment was affected by a weeding and fertilization interaction ( $P = 0.086$ ). Three-year mortality averaged 37, 114, 67, and 59 stems per plot on the control, fertilized, weeded, and weeded+fertilized treatment plots, respectively.

Stem mortality among all treatments was generally restricted to the small size classes. The average median initial height for stems that died was 19, 21, 20, and 26 cm for the control, fertilized, weeded, and weeded+fertilized treatments, respectively, and did not differ significantly among treatments. The mean initial height for stems that died was 20, 24, 23, and 30 cm for the control, fertilized, weeded, and weeded+fertilized treatments, respectively. With mortality separated into 20-cm height classes, fertilization increased stem mortality in the 0 to 20 and 21 to 40 cm height classes (fig. 1), but variation was too great to detect statistical differences. Significant treatment differences were found in stem mortality in the 81 to 100 and 101 to 120 cm height classes, but differences amounted to less than 4 stems per plot over the 3-year period.

No significant pretreatment differences were detected for height, diameter, or volume on plots delineated to become control, fertilized, weeded, or weeded+fertilized plots (table 3). Stem height on fertilized plots increased 22 percent, while diameter increased 29 percent over non-fertilized stems. Weeding was effective in increasing stem diameter in both growing seasons following the initial treatment applications but did not significantly affect stem height or volume. Compared to non-weeded plots, the diameter of weeded stems was 29 percent greater.

### Duke Forest

Pretreatment stem densities averaged 90,000 stems  $ha^{-1}$ , with over 20 species recorded. No pretreatment statistical differences existed among plots. Pretreatment species composition was dominated by yellow-poplar (59.4 percent of all stems), white oak (*Quercus alba* L., 20.8 percent), red oak (*Q. rubra* L., 5.7 percent), dogwood (5.9 percent), red maple (2.6 percent), and hickory (*Carya* spp., 2.6 percent).

**Table 2—The number and distribution of newly-recruited stems by height class (cm) and growing season for the Hill forest site on 10 m<sup>2</sup> plots**

Height class	End of 2 <sup>nd</sup> growing season (2-year-old stems) treatments				End of 3 <sup>rd</sup> growing season (3-year-old stems) treatments			
	Control	Fertilized	Weeded	Weed+fert	Control	Fertilized	Weeded	Weed+fert
1 - 20	15.0	4.0	16.0	5.5	0.3	0.0	1.3	0.0
21 - 40	3.3	5.0	8.3	2.0	2.0	0.5	3.0	0.8
41 - 60	3.0	3.5	2.5	1.8	5.0	0.0	1.5	1.0
61 - 80 <sup>a</sup>	2.5	3.0	1.3	0.5	2.3	1.3	0.5	0.3
81 - 100	1.0	1.3	1.0	0.5	1.0	0.8	0.3	0.3
101 - 120	0.3	1.0	0.8	0.5	1.0	0.3	0.0	1.0
121 - 140	0.3	0.5	0.0	0.5	0.3	0.3	0.0	1.0
141 - 160 <sup>a</sup>	0.0	0.3	0.0	0.3	0.0	0.0	0.3	0.5
161 - 180	0.0	0.0	0.0	0.5	0.3	0.3	0.5	0.3
180 - 200	0.0	0.0	0.0	0.3	0.3	0.3	0.0	0.3
201 - 220	0.0	0.5	0.0	0.5	0.0	0.5	0.3	0.0
All	25.3	19.0	29.8	12.8	12.3	4.0	7.5	5.3

<sup>a</sup>Significance at  $P \leq 0.10$  was detected for height class 61-80 for the main effect of weeding, and for height class 141-160 for the main effect of fertilization.

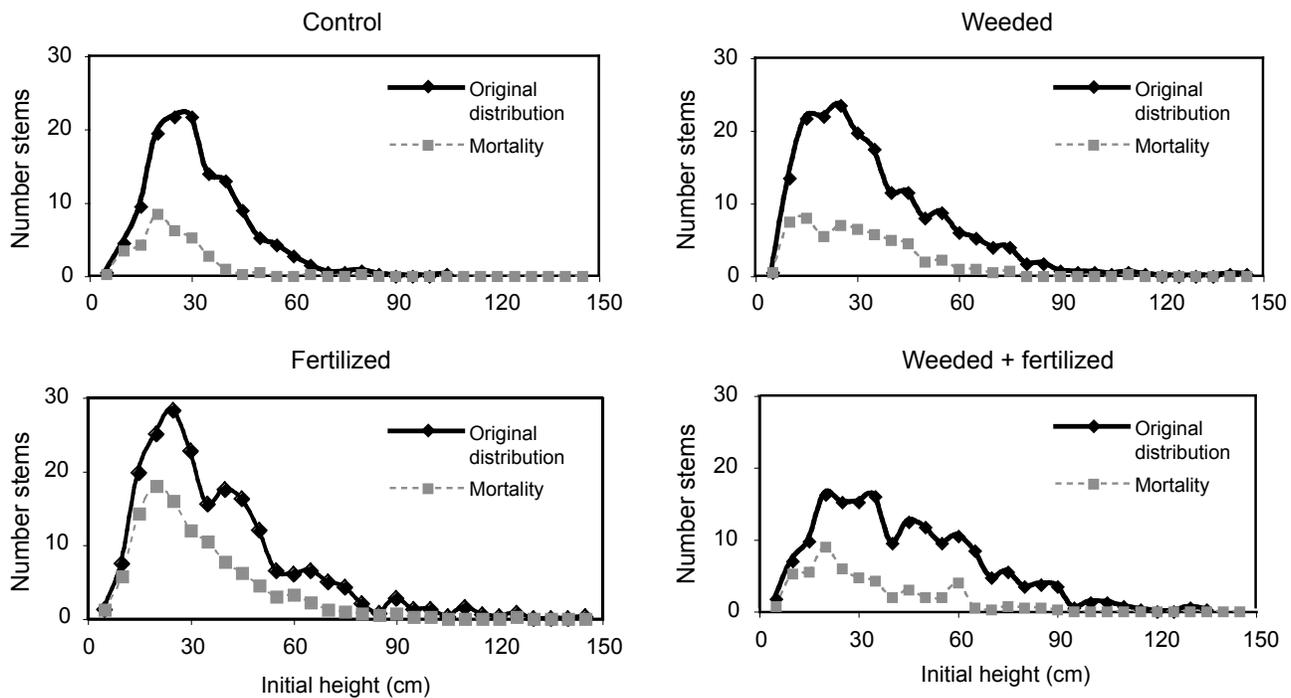


Figure 1—The initial distribution of rising 1-year-old stems (solid black line, by 5-cm height classes) and cumulative mortality (grey dashed lines) after three growing seasons for the Hill Forest site.

Individual stems were not tagged at this site, making it impossible to determine specific recruitment and mortality patterns. Nonetheless, plot inventories revealed stem density patterns associated with the treatments (table 1). Fertilized plots had reduced stem density, and weeded plots had increased stem density 3 years after treatment, although not always significantly. The weed x fertilization interaction was not significant.

Fertilization significantly increased stem growth (table 3). Responses to fertilization for height, diameter, and volume averaged 35, 19, and 86 percent over non-fertilized stems, which averaged 155 cm, 18 mm, and 21 cm<sup>3</sup> for height, diameter, and volume, respectively.

## DISCUSSION

Many natural hardwood stands have been reported to be responsive to a variety of early stand interventions. Site modification treatments have generally focused on improving nutrient availability through fertilization, largely with N and P, and have been beneficial for many species and sites (Auchmoody 1972, Beckjord and others 1983, Demchik and Sharpe 1999, Kolb and others 1990, Newton and others 2002). Vegetation control treatments that remove competing herbaceous and undesirable woody species and/or overtopping residuals have also been beneficial in certain circumstances (Leak 1988, Petruncio and Lea 1985, Romagosa and Robison 2002,

**Table 3—The effect of weeding and fertilization treatments on a rising 1-year-old (Hill Forest) and on a rising 3-year-old (Duke Forest) naturally-regenerated upland NC Piedmont stand for all species combined<sup>a</sup>**

Hill Forest	Treatment	Height		Diameter		Volume	
		Age 0	Age 3	Age 0	Age 3	Age 0	Age 3
		----- cm -----		---- mm ----		--- cm <sup>3</sup> /stem ---	
	Control	29.7	103.2	4.6	10.3	1	14
	Fertilized	32	137.7	4.5	13.5	1	36
	Weeded	31.4	119.2	4.2	12.4	1	28
	Weed + Fert	37.2	133.5	4.6	15.7	1	42
Main Effects (P-value)	Fertilization	—	0.023	—	0.035	—	—
	Weeding	—	—	—	0.015	—	—

Duke Forest	Treatment	Age 3	Age 5	Age 3	Age 5	Age 3	Age 5
	Control	77.2	155.5	10.1	17.6	14	65
	Fertilized	63.5	212.4	8.9	20.8	8	141
	Weeded	63.2	154.2	8.7	19.2	8	76
	Weed + Fert	70.9	205.4	9.3	22.9	12	153
Main Effects (P-value)	Fertilization	—	<0.001	—	0.025	—	<0.001
	Weeding	—	—	—	—	—	—

<sup>a</sup> All volumes were analyzed using log<sub>e</sub> transformed data. The reported least-square means were back-calculated for ease of interruption.

Young and others 1993). Results from this study demonstrate that in North Carolina Piedmont hardwoods, fertilization was very successful in increasing growth and accelerating early stand development (see table 3).

Broadcast fertilization generally produced a large and sustained increase in height, diameter, and volume in the current study. The collective species response to nutrient additions was a 2- to 3-fold increase in individual stem volume. This type of response to fertilization can be expected on many Piedmont sites, which have experienced severe soil erosion over the last century (Daniels and others 1999). Many of the soils are left with only a thin surface horizon overlaying a thicker Bt horizon and consequently are generally low in organic matter, N, and other nutrients (Della-Bianca and Wells 1967).

Concurrent with increased growth, stem densities were reduced on fertilized plots even in the short time span of this study. This suggests other essential growth resources very quickly become limiting (e.g., water and/or light) among tree stems, or that non-arborescent vegetation out-competes trees for these other resources. The data also suggest that the large response to fertilization was due, in part, to mortality at the lower end of the initial height distribution, indicating the expected relationship between competition, growth, and density reductions. For the fertilization-only treatment, a larger proportion of mortality occurred in the smaller height classes (0 to 20 cm) compared to the other treatments (fig. 1). The establishment of new stems, either from seed or sprouts, also appears retarded under fertilization treatments, although the variation among treatments was large. Therefore, the large increase in stem size in the fertilization-only treatments may not be completely attributable to fertilization but rather to enhanced mortality and reduced recruitment of smaller stems, thereby providing more site resources to fewer stems.

Weeding treatments increase the availability of light, water, and nutrients, and allocate these resources that would otherwise

be utilized by competing vegetation to tree stems. The benefits of weeding hardwood plantations have been well documented (e.g., Fitzgerald and others 1975, Nelson 1985, Schuler and others 2004). However, few studies have reported the effects of competing vegetation on young naturally-regenerated hardwood stands (McGill and Brenneman 2002, Romagosa and Robison 2003). In the current study, weeding had a limited effect on stem growth, with a few noted exceptions. It was visually apparent, but not quantified, that the weed biomass at the Hill Forest site was greater and therefore more competitive than at the Duke Forest site, due to the younger age of the Hill stand. The stem height and volume response to weeding treatments reported for this study differed from those of Romagosa and Robison (2003). They reported significant growth responses to weeding-alone on similar sites but with lower initial densities and large shifts in species dominance (Schuler and Robison 2002). No large shift in species composition at the Hill or Duke Forest sites was noted through the 3 years of this study. The effect of weeding treatments is also subject to variation in annual precipitation (wet versus dry years), with the impact of vegetation control generally more pronounced on dry sites and in dry years (Powers and Reynolds 1999). The monthly precipitation patterns for the Hill and Duke Forest sites were normal or slightly above normal during the 2000 and 2001 growing seasons. The 1999 growing season had a 10-cm precipitation deficit in May (based on long-term average) that could have affected growth and survival, especially for small, newly-germinated seedlings with underdeveloped root systems.

## CONCLUSIONS

This study demonstrates that even the youngest naturally-regenerated upland forest stands in the North Carolina Piedmont are not achieving their maximum individual tree growth potential. On these Piedmont sites, young stands are overstocked and growing on soils deficient in soil nutrients. Reducing competing herbaceous vegetation produced a marginal

response for yellow-poplar and oaks. Broadcast fertilization greatly accelerated growth and provided an added benefit of reducing stem density. Although further work on larger study plots will be required to determine whether these responses can be maintained in the future on these upland sites, there do appear to be opportunities to manage regeneration in newly-established stands.

Future work will be needed to assess whether fertilization and vegetation control treatments can modify species composition in a way that favors more desirable species. The use of species-specific fertilizer mixes and rates may be useful if we can show preferential uptake and use among hardwood tree species. Similarly, with target specific herbicides, more species selection opportunities may be available for mixed hardwood stands.

## LITERATURE CITED

- Auchmoody, L.R. 1972. Effects of fertilizer-nutrient interactions on red oak seedling growth. Res. Pap. NE-239. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 5 p.
- Auchmoody, L.R. 1985. Response of young black cherry to thinning and fertilization. In: Dawson, J.O.; Majerus, K.A., eds. Fifth central hardwood forest conference. Urbana-Champaign, Illinois: University of Illinois, Department of Forestry: 53-61.
- Beckjord, P.R.; Melhuish, J.H., Jr.; McIntosh, M.S.; Hacskaylo, E. 1983. Effects of nitrogen fertilization on growth and ectomycorrhizal formation of *Quercus alba*, *Quercus rubra*, *Quercus falcata*, and *Quercus falcata* var. *pagodifolia*. Canadian Journal of Botany. 61: 2507-2514.
- Daniels, R.B.; Boul, S.W.; Kleiss, H.J.; Ditzler, C.A. 1999. Soil systems in North Carolina. Raleigh, NC: North Carolina State University, Department of Soil Science: 118 p.
- Della-Bianca, L.; Wells, C.G. 1967. Some chemical properties of forest soils in the Virginia-Carolina Piedmont. Res. Pap. SE-28. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 16 p.
- Demchik, M.C.; Sharpe, W.E. 1999. Survivorship and growth of natural northern red oak seedlings in response to selected treatments in an extremely acidic forest soil. In: Stringer, J.W.; Loftis, D.L., eds. Proceedings of the 12<sup>th</sup> central hardwood conference. Gen. Tech. Rep. SRS-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 98-102.
- Dubois, M.R.; Straka, T.J.; Crim, S.D.; Robison, L.J. 2003. Costs and cost trends for forestry practices in the South. Forest Landowner. 62(2): 3-8.
- Fitzgerald, C.H.; Richards, R.F.; Selden, C.W.; May, J.T. 1975. Three year effects of herbaceous weed control in a sycamore plantation. Weed Science. 23(1): 32-35.
- Haines, L.W.; Sanderford, S.G. 1976. Biomass response to fertilization in the Piedmont. Washington, DC: Society of American Foresters. Proceedings of the Society of American Foresters: 425-440.
- Johnson, J.E.; Bollig, J.J.; Rathfon, R.A. 1998. Above-ground biomass and nutrient distribution of released and fertilized yellow-poplar trees. Forest Ecology and Management. 105: 231-240.
- Kellison, R.C.; Frederick, D.J.; Gardner, W.E. 1981. A guide for regenerating and managing natural stands of southern hardwoods. No. 463. Raleigh, NC: Bulletin of the North Carolina Agricultural Experiment Station. 24 p.
- Kirby, R.M. 1976. Soil survey of Durham County, North Carolina. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 74 p.
- Kolb, T.E.; Bowersox, T.W.; McCormick, L.H. 1990. Influences of light intensity on weed-induced stresses of tree seedlings. Canadian Journal of Forest Research. 20(5): 503-507.
- Leak, W.B. 1988. Effects of weed species on northern hardwood regeneration in New Hampshire. Northern Journal of Applied Forestry. 5(4): 235-237.
- McGill, D.W.; Brenneman, B.B. 2002. Six-year development of regenerating natural hardwood stands with herbaceous weed control. Northern Journal of Applied Forestry. 19(1): 14-21.
- NCSFNC. 2002. Forest nutrition cooperative 31<sup>st</sup> annual report. Raleigh, NC: North Carolina State University. 21 p.
- Nelson, E.A. 1985. Weed control and fertilization aid sweetgum plantation establishment. In: Dawson, J.O.; Majerus, K.A., eds. Fifth central hardwood forest conference. Urbana-Champaign, Illinois: University of Illinois, Department of Forestry: 68-70.
- Newton, L.P.; Robison, D.J.; Hansen, G.; Allen, H.L. 2002. Fertilization and thinning in a 7 year-old hardwood stand in eastern North Carolina. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 193-195.
- Petruncio, M.; Lea, R. 1985. Natural hardwood regeneration in the Southern Appalachians. In: Shoulders, E., ed. Proceedings of the third biennial southern silvicultural research conference. Gen. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 178-181.
- Pham, C.H. 1985. Thinning of young natural hardwood regeneration in southeastern West Virginia. In: Dawson, J.O., Majerus, K.A., eds. Fifth central hardwood forest conference. Urbana-Champaign, Illinois: University of Illinois, Department of Forestry: 25-34.
- Powers, R.F.; Reynolds, P.E. 1999. Ten-year responses of ponderosa pine plantations to repeated vegetation and nutrient control along an environmental gradient. Canadian Journal of Forest Research. 29(7): 1027-1038.
- Prestemon, R.C.; Abt, R.C. 2002. Timber products supply and demand. In: Wear, D.N.; Greis, J.G., eds. Southern forest resource assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 299-325.
- Robison, D.J.; Schuler, J.L.; Jervis, L. [and others]. 2004. Individual tree release and enrichment planting in young natural upland hardwoods. In: Connor, K.F., ed. Proceedings of the 12<sup>th</sup> biennial southern silvicultural research conference. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 283-286.
- Roeder, K.R.; Gardner, W.E. 1984. Growth estimation of mixed southern hardwood stands. Hardwood Research Cooperative Series No. 3. Raleigh, NC: North Carolina State University, School of Forest Resources. 32 p.
- Romagosa, M.A.; Robison, D.J. 2003. Biological constraints on the growth of hardwood regeneration in upland Piedmont forests. Forest Ecology and Management. 175: 545-561.
- SAS. 1990. SAS/STAT user's guide: version 6, 4th ed. Cary, NC: SAS Institute. 846 p.
- Schuler, J.L.; Robison, D.J. 2002. Response of 1 to 4-yr-old upland hardwood stands to stocking and site manipulations. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 266-269.
- Schuler, J.L.; Robison, D.J.; Myers, R.; Young, M. [In review]. Residual overstory and regenerating stand response of southern hardwoods to even-aged regeneration methods. American Midland Naturalist.
- Schuler, J.L.; Robison, D.J.; Quicke, H.E. 2004. Assessing the use of Chopper<sup>®</sup> herbicide for establishing hardwood plantations on a cutover site. Southern Journal of Applied Forestry. 28(3): 163-170.
- Siry, J.P.; Robison, D.J.; Cabbage, F.W. 2004. Economic returns models for silvicultural investments in young hardwood stands. Southern Journal of Applied Forestry. 28(4): 179-184.
- Young, M.J.; Kellison, R.C.; Kass, D.J. 1993. Effects of residuals on succeeding stand development following clearcutting. In: Brissette, J.C., ed. Proceedings of the seventh biennial southern silvicultural research conference. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 361-365.

# CROP TREES AND QUALITY IN BOTTOMLAND HARDWOODS TEN YEARS AFTER AN EARLY THINNING IN A YOUNG SPROUT-ORIGIN STAND IN SOUTH CAROLINA

Lawrence E. Nix<sup>1</sup>

**Abstract**—A 23-year-old, mostly sprout-origin stand in the Congaree river bottom near Columbia, SC, was commercially thinned in 1994 using three methods of thinning: (1) the “Leave tree”, (2) “Trainer tree”, and (3) “Corridor” methods. The stand was created in 1971 by KG-blade shearing a 90-year-old, heavily cutover bottomland hardwood stand. Before thinning, the stand had 260 to 300 trees averaging 8 to 9 inches d.b.h. and 28 to 31 cords per acre. There were 80 to 100 potential crop trees per acre (30 to 40 percent commercial oaks) of different bottomland species (oaks, sycamore, sweetgum, green ash and red maple). After-thinning, stocking levels were targeted to meet 80 to 100 crop trees per acre. In early 2000 and 2005, the effects of thinnings on residual stand quality were determined by measuring the diameter and number of stems per acre, epicormic sprouts in the first log, logging damage, and residual vine encumbrance, respectively, of residual crop trees. In 2000, the stand had 50 crop trees per acre, averaging 12.4 inches d.b.h. and 2.35 logs merchantable height. In 2005, the stand averaged 45 crop trees per acre, 15.7 inches d.b.h., and 1.8 logs merchantable height. The leave tree thinning resulted in a minor increase in epicormic sprouts, 1.3 in the first log per tree versus 0.33 for the control. All thinnings reduced vine encumbrance of crop trees from 40 to 24 percent, an enhancement in quality. Logging damage was lowest in the trainer tree thinning but is not now appreciable in any of the thinnings. The control has 53 crop trees per acre, the leave tree 46, the trainer tree 41, and the corridor 40, respectively. Diameter is greatest in the leave tree, 16.2 inches, having increased by 3.8 inches since the 2000 measurements.

## INTRODUCTION

Early thinnings in hardwoods provide the landowner with economic return that would normally be lost to mortality (Gingrich 1971, Kellison and others 1988). These thinnings improve stand quality by changing species composition, selecting quality stems, improving tree spacing, and maintaining crown vigor of desired stems (Carvell 1971).

The thinning of bottomlands often favors valuable high quality stems of species such as cherrybark (*Quercus pagoda* Raf) and Shumard (*Q. shumardii* Buckley) oaks (Kennedy and Johnson 1984). Other desirable commercial species favored when they occur are green ash (*Fraxinus pennsylvanica* Marshall), sweetgum (*Liquidambar styraciflua* L.) and sycamore (*Platanus occidentalis*). A crop tree should be selected based on the vigor and quality of the surrounding stems (Clatterbuck and others 1987). However, the removal of too many cull trees can leave the stand understocked; consequently, some type of residual stocking guide should be employed (Gingrich 1971).

Thinning as early as ages 20 to 25 years can increase the growth potential and value of bottomland hardwoods on good sites. The improved market for hardwood pulpwood allows such sites to be commercially thinned at those ages (Kellison and others 1988). However, such early thinnings can be marginally commercial if they result in degrade to residual crop trees (Kennedy and Johnson 1984). In early 1993, a local consulting forester approached us concerning the advisability of early thinning in bottomland hardwoods on the Congaree River near Columbia, SC (Personal communication. 1993. Angus Lafaye, President, Milliken Forestry Company, P.O. Box 23629, Columbia, SC 29224-3629). As a result of this interest, a study was installed to determine the most effective “standard” commercial thinning method relative to its effects

on the future value of residual crop trees in a young sprout origin stand.

## METHODS

### Study Site

The study site is located in a young bottomland hardwood stand on the Congaree River (a red river) near Columbia, SC. The soil type is a well-drained loamy Typic Udifluent of the Congaree series. The stand has a site index (base age 50 years) of 90 to 95 feet for cherrybark oak and has low wet areas interspersed among drier, low broad ridges. The stand was a 23-year-old sprout-origin stand that was KG-blade sheared in 1971. According to the consulting forester (Lafaye 1993), many residual young sapling and pole-sized oaks were left to grow unshaped during the shearing operation.

Before thinning, the stand consisted of 260 to 300 trees per acre, averaging 8 to 9 inches diameter at 4.5 feet height (d.b.h.), 28 to 31 cords per acre, and 80 to 100 potential crop trees per acre (30 to 40 percent commercial oaks) of different bottomland species (oaks, sycamore, sweetgum, and green ash). Many of the crop trees, up to 60 percent in some areas, were infested with grape vines (*Vitis* spp). The criteria for crop trees were that they be a commercial species, have a minimum of one log, be of good bole form, with minimal epicormic sprouting (less than 3 sprouts in the first log), and be a dominant or co-dominant tree not severely infested with grape vines.

### Experimental Design

The thinning methods were done in a randomized complete block design with 4 16-acre blocks containing 4-acre treatments, each of an unthinned control, trainer tree, leave tree, and corridor thinning methods as described by Tinsley and Nix (1998). Each 16-acre block has a main skid trail (20 feet

<sup>1</sup> Professor, Clemson University, Department of Forestry and Natural Resources, Clemson, SC 29634-1331.

wide) marked down the center with treatments on either side. Analysis of variance for a randomized complete block design was performed to test the differences between treatment means (SAS Institute 2002). When the treatment means were different, Tukey's test at the 0.05 level of significance was used to test which means were different.

### Measurements

A 1-acre sampling area was marked in the center of each of the 4-acre treatment plots. The sample trees were marked before measurement to remove bias from the data. In the corridor treatment the sample crop trees were chosen right up to the edge of the cut strip in order to include the influence of the adjacent open area on future quality. For each crop tree, the species, d.b.h., number and grade of logs, the number of epicormic sprouts in the first log, severity of vine infestation, and logging damage were noted.

### Thinning Methods

All thinning methods were marked to be commercial, at least 10 cords per acre were to be removed (about 100 trees per acre averaging 8 inches d.b.h. and 60 feet tall). The trainer tree treatment was designed to leave at least one cull tree near the crop tree to protect it from logging damage and shade out epicormic sprouting on the lower bole. The crop trees were located at approximately 20 by 20 feet spacing where possible, but often a less-than-desirable tree had to be chosen in keeping with the 60 percent residual stocking level suggested for upland hardwoods by Gingrich (1971).

The leave tree method removed all trees except for the crop trees. The same 20 by 20 feet spacing was attempted and all trees other than crop trees were marked to be cut. If a crop tree was not present at 20 feet, then a reasonable crop tree within a 10 foot radius was left.

The corridor treatment removed one-third of the volume per acre (about 100 trees per acre), and felling and skidding was done in the cut strip. The forester marked a 20-foot-wide cut strip and left a 40-foot-wide uncut strip. The cut strips were marked in a 60-degree herringbone pattern to the main skid trail in an attempt to reduce logging damage that results from turning loads.

## RESULTS

### Residual Crop Trees

A total of 720 crop trees were sampled and consisted of 41 percent sweetgum, 24 percent cherrybark oak, 8 percent Shumard oak, and 27 percent others (mostly sycamore). The residual stand has an average of 40 to 50 high quality crop trees per acre, depending on the thinning method. Ten years after thinning, losses to logging damage, butt rot, windthrow, and sprout degrade has resulted in the leave tree thin with 46 crop trees per acre, the trainer tree method with 41, and the corridor thin with 40. The control has 53 crop trees per acre. This is a drastic reduction in the number of crop trees projected before the thinning in 1994 (at least 100 trees per acre were to be left). These losses can be partially explained by the premeasurement rejection of crop trees having profuse epicormic sprouting (more than 6 sprouts in the butt log), logging damage, or other defects. Howell and Nix (2002) found that the number of crop trees in this stand had dropped from 80 to 50 per acre in the first 5 years after the 1994 thinnings.

### Vine Infestation

The number of crop trees with severe vine infestation was reduced by the thinning treatments. The controls had nearly twice as many trees with severe vine infestation than did the thinnings (22.5 versus 12 trees per acre, respectively). The vine infestation in the control is significantly greater than the thinnings (at the 0.05 level), but the thinnings do not differ. In this case, the use of heavy machinery in thinnings silviculturally enhanced the future quality of crop trees by reducing the presence of live vines in the crowns.

### Logging Damage

Logging damage was kept to a minimum by the following factors: (1) good communications, (2) well-designed harvest plan, and (3) reduced stumps values charged the logger for less-productive methods (Tinsley and Nix 1998). Ten years after thinning, logging damage is no longer a significantly visible factor in this stand, but along with butt rot and windthrow, may have caused some mortality of crop trees.

### Epicormic Sprouting

Ten years after the thinnings, epicormic sprouts, though minor, are still significantly greater in the leave tree thinning, 1.3 per tree in the first log, compared to the control, 0.37 per tree (0.05 level). All of the thinnings apparently increased the amount of sunlight in the stand which stimulated epicormic sprouting (Brown and Kormanik 1970). However, the trees in the treatments have sufficiently closed their canopies and reduced the epicormic sprouting to less than 1 in the first log in all but the leave tree thinning.

### Diameter Growth

Ten years after thinning the average d.b.h. of crop trees in the leave tree thinning is 16.2 inches and is significantly greater (0.05 level) than the control (14.8 inches). Crop trees in the leave tree thinning have grown 3.8 inches in d.b.h. since the last measurement in 2000 (Howell and Nix 2002), over an inch more than did those in the controls during the same 5 year period.

## CONCLUSIONS

All thinning methods met the objectives of being a commercial harvest of 10 cords per acre or more and 10 years ago initially left a reasonably stocked stand of 60 to 80 crop trees per acre. The leave tree method was the most productive harvest at 16 cords per acre, and 10 years later it has the most crop trees per acre (46) of the thinnings. The corridor method, which was the most efficient harvest method with its ready-made skidding corridors, has only 40 crop trees per acre left, probably because it cut one third of all trees including the crop trees. All thinning methods were beneficial to the future stand by reducing vine infestation of crop trees with no major increase in epicormic sprouts or logging damage. However, the drastic loss of crop trees (almost 50 percent) in all the stand areas remains a puzzle.

We suspect that the sprout origin of many of the sheared stems dating back to 1971 resulted in an excessive mortality due to butt rot and vine infestation in this often wet stand. Since it floods up to 3 feet height throughout most of the stand each year and there was abundant evidence of washout around the base of many stems, perhaps windthrow was a contributing factor as many of the young crop stems had quite large crowns in 1994.

The corridor and leave tree thins proved to be the best thinning methods in this study, but the decision to use either of these methods should be based on careful consideration of the conditions of the existing stand. If the stand has at least 140 desirable high-quality, well-anchored stems along with at least 100, 8-inch d.b.h. culls per acre, then the corridor method can be used if a target of at least 100 residual crop trees per acre is desired. If the existing stand has at least 110 crop trees per acre with 220 8-inch d.b.h. culls, then the trainer tree method can be used. Because of the initial 12 percent logging damage to crop trees and the 30 percent reduction in crop trees due to epicormic sprouting, the leave tree thinning method should not be used in stands such as these unless at least 100 desirable crop trees per acre can be marked to be left. The effects of thinning on crop tree quality and growth in this study probably will not be monitored again in the future due to the impending retirement of the author.

### ACKNOWLEDGMENTS

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### LITERATURE CITED

- Brown, C.L.; Kormanik, P.P. 1970. The influence of stand disturbance on epicormic branching. In: Linnartz, N.E., ed. Proceedings, silviculture and management of southern hardwoods, 19<sup>th</sup> annual forestry symposium. Baton Rouge, LA: Louisiana State University: 103-112.
- Carvell, K.L. 1971. Silvicultural aspects of intermediate cuttings. In: Doolittle, W.T., ed. Proceedings. Oak symposium. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeast Forest Experiment Station: 60-64.
- Clatterbuck, W.K.; Oliver, C.D.; Burkhardt, E.C. 1987. The silvicultural potential of mixed stands of cherrybark oak and American sycamore: spacing is the key. *Southern Journal of Applied Forestry*. 11(3): 158-161.
- Gingrich, S.F. 1971. Stocking, growth, and yield of oaks stands. In: Doolittle, W.T., ed. Proceedings. Oak symposium. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeast Forest Experiment Station: 65-73.
- Howell, M.P.; Nix, L.E. 2002. Early thinning in bottomland hardwoods. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 196-200.
- Kellison, R.C.; Martin, J.P.; Hansen, G.D.; Lea, R. 1988. Regenerating and managing natural stands of bottomland hardwoods. APA 88-A-6. Bottomland Hardwood Management Taskforce, Southeastern Technical Division, Washington, DC: American Pulpwood Association, Inc. 26 p.
- Kennedy, H.E.; Johnson, R.L. 1984. Silvicultural alternatives in bottomland hardwoods and their impact on stand quality. In: Proceedings of the 14<sup>th</sup> annual southern forest economics workshop. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 6-18.
- SAS Institute 2002. SAS user's guide: Statistical version 8. Carey, NC: SAS Institute, Inc. 484 p.
- Tinsley, M.B.; Nix, L.E. 1998. Early thinnings in a young, sprout-origin, bottomland hardwood stand in South Carolina. In: Waldrop, T.A., ed. Proceedings of the ninth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 170-174.

# THINNING TO IMPROVE GROWTH AND BOLE QUALITY IN AN *INONOTUS HISPIDUS*-INFECTED, RED OAK-SWEETGUM STAND IN THE MISSISSIPPI DELTA: SIXTH-YEAR RESULTS

James S. Meadows, Theodor D. Leininger, and T. Evan Nebeker<sup>1</sup>

**Abstract**—Thinning was applied to a 55-year-old red oak-sweetgum (*Quercus* spp.-*Liquidambar styraciflua* L.) stand in the Delta region of western Mississippi in 1997. Special emphasis was placed on removing all red oaks infected with *Inonotus hispidus* (Bull.) P. Karst, a canker decay fungus that causes serious degrade and cull. Little stand-level growth occurred during the first 6 years after thinning. Thinning significantly increased diameter growth of residual trees, especially among red oaks, but to date, the treatment has not significantly increased quadratic mean diameter. Thinning had no significant effect on the production of new epicormic branches on the butt logs of residual red oaks, but it greatly increased the number of epicormic branches on the butt logs of residual sweetgum trees. Increased numbers of epicormic branches on sweetgum sawtimber trees caused the degradation of many sweetgum logs from grade 2 to grade 3. These reductions increased the proportion of sweetgum volume in grade 3 logs. Because thinning did not increase the number of epicormic branches on red oak sawtimber, the proportion of volume in grade 1 logs increased, and the proportion of red oak volume in grade 3 logs decreased.

## INTRODUCTION

A combination of thinning and improvement cutting often is used in mixed-species forests, not only to enhance the growth of residual trees but also to improve species composition and residual stand quality (Meadows 1996). These three characteristics—growth rate, species composition, and quality—are critically important when managing southern bottomland hardwood stands for high-quality sawtimber production.

Thinning regulates stand density and increases diameter growth of residual trees. Generally, diameter growth response increases as thinning intensity increases. However, very heavy thinning may reduce stand density to such an extent that stand growth is greatly diminished even though individual tree growth is enhanced. Stocking may become so low that potential site productivity is not fully realized. In fact, Meadows and Goelz (2001) showed that thinning to a 33 percent residual stocking level in a relatively young water oak (*Quercus nigra* L.) plantation created such a severely understocked condition that stand-level growth is likely to be depressed for many years. Recommended minimum stocking levels necessary to maintain satisfactory rates of stand-level growth are 46 to 65 percent in upland oaks (Hilt 1979) and 45 to 60 percent in Allegheny hardwoods (Lamson and Smith 1988).

Thinning also may have adverse effects on the bole quality of residual hardwood trees. Production of epicormic branches along the boles of residual trees often is associated with poorly designed thinning operations. However, well-designed hardwood thinning operations tend to favor healthy, sawtimber-sized trees, so that the proportion of dominant and codominant trees in the stand typically increases after thinning. These vigorous, upper-crown-class trees are much less likely to produce epicormic branches than are less vigorous, lower-crown-class trees (Meadows 1995). Consequently, the production of epicormic branches may actually decrease after well-designed thinnings (Sonderman and Rast 1988).

This combination of thinning and improvement cutting in mixed-species hardwood stands also is used to improve both species composition and quality of the residual stand (Meadows 1996). Generally, by emphasizing the value or quality of individual trees rather than the density of the residual stand, it is possible to increase the proportion of high-value trees and to decrease the proportion of low-value trees. Trees that are damaged or diseased, have low-quality boles, or are undesirable species are removed; trees that are healthy, have high-quality boles, and are desirable species are retained. Improvement cuttings often are used to curtail disease-causing fungi in stands that have a high proportion of diseased trees.

Bottomland hardwood stands in the Mississippi Delta region often are infected with *Inonotus hispidus* (Bull.) P. Karst, a canker decay fungus that causes the disease commonly known as hispidus canker. The fungus often is found on willow oak (*Q. phellos* L.) and water oak but also occurs on Nuttall oak (*Q. nuttallii* Palmer) and white oak (*Q. alba* L.). Hispidus canker causes severe degrade and cull in infected trees. The fungus results in formation of a large, spindle-shaped canker usually at the site of an old branch stub 12 to 15 feet or more up the bole of the infected tree (McCracken 1978). The central part of the canker is concave and covered with bark. Damage occurs in the form of heartwood decay, in which the wood behind the canker becomes soft and delignified. In addition to the degrade caused by the heart rot, the hispidus canker greatly increases the possibility of stem breakage at the site of the canker. Improvement cuttings to remove trees with hispidus canker have reduced spore production and dissemination within infested stands, thus minimizing spread of the disease to adjacent trees (McCracken and Toole 1974).

Our study is part of a larger research project investigating relationships between silvicultural practices and insect and disease populations in southern hardwood forests. Specifically, the larger project's goals are (1) to better understand

<sup>1</sup> Principal Silviculturist and Principal Plant Pathologist, respectively, USDA Forest Service, Southern Research Station, P.O. Box 227, Stoneville, MS 38776; and Professor of Entomology, Department of Entomology and Plant Pathology, Mississippi State University, Mississippi State, MS 39762.

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and quantify the effects that stand modification has on insect and disease populations, and (2) to use this knowledge to develop pest management recommendations for use in silvicultural prescriptions.

This paper considers only one study site and addresses only the silvicultural component of the larger project. Our objectives were (1) to determine the effects of thinning on stand growth, development, and yield; and (2) to determine the effects of thinning on tree growth and bole quality.

## METHODS

### Study Area

The study site is on the Delta National Forest in the Delta region of western Mississippi. The study area is adjacent to Ten Mile Bayou, within the floodplain of the Big Sunflower River, in southeastern Sharkey County. The site is nearly flat and is subject to frequent periodic flooding during the winter and spring months. Floodwaters may remain on the site for several weeks.

Soils across most of the area are in the Sharkey series, but smaller areas are interspersed with Alligator soils. Dowling soils also occur in small depressions. All three soils are poorly drained clays that shrink and form wide cracks when dry and expand when wet. These soils formed in fine-textured Mississippi River sediments deposited in slackwater areas of the floodplain. Broadfoot (1976) reported that average site indices of the Sharkey soils are 92 feet at 50 years for willow oak and 91 feet at 50 years for Nuttall oak. Average site index of the Alligator soils is 88 feet at 50 years for both species.

The study site supports an even-aged red oak-sweetgum stand, in which the principal red oak species are willow and Nuttall oaks. In addition to sweetgum, other common species include sugarberry (*Celtis laevigata* Willd.), American elm (*Ulmus americana* L.), common persimmon (*Diospyros virginiana* L.), green ash (*Fraxinus pennsylvanica* Marsh.), and honeylocust (*Gleditsia triacanthos* L.). The stand was 55 years old when we installed the study.

### Plot Design

Plot design was modified from the format for standard silvicultural research plots, as originally recommended by Marquis and others (1990). Each treatment was uniformly applied across a 4.8-acre rectangular treatment plot that measured 6 by 8 chains (396 by 528 feet). We established four 0.6-acre rectangular measurement plots in the center of each treatment plot; each measurement plot was 2 by 3 chains (132 by 198 feet), thus establishing a 1-chain buffer strip around the group of four measurement plots. The entire study site is 9.6 acres.

### Treatments

Only two treatments were applied: (1) an unthinned control, and (2) an operational thinning marked by Delta National Forest personnel. The operation combined low thinning and improvement cutting to remove most of the pulpwood-sized trees as well as those sawtimber-sized trees that were damaged, diseased, had poor bole quality, or were undesirable species. We emphasized removing all red oaks infected with hispidus canker.

Four replications of the two treatments were applied in a randomized complete block design to the eight plots (experimental

units) in August 1997. A mechanized feller with a continuously running cutting head was used to directionally fell all marked trees. Felled trees were topped and delimited in the woods. Rubber-tired skidders were used to remove merchantable products in the form of longwood.

## Measurements

We conducted a preharvest survey to determine species composition and initial stand density on each 0.6-acre measurement plot. Species, diameter at breast height (d.b.h.), crown class, and tree class, as defined by Meadows (1996), were recorded on all trees  $\geq 5.5$  inches d.b.h. The number of epicormic branches on the 16-foot butt log of all "leave" trees was also tallied. Log grade, as defined by Rast and others (1973), of the 16-foot butt log and sawtimber merchantable height were also recorded on "leave" trees  $\geq 13.5$  inches d.b.h. For each of the first 3 years following thinning, we measured crown class, d.b.h., and number of epicormic branches on each 16-foot butt log. These 3-year results were reported by Meadows and others (2002). We measured all variables again at the end of the sixth year after thinning.

## RESULTS AND DISCUSSION

### Stand Conditions Prior to Thinning

The pretreatment study area averaged 98 trees and 125 square feet of basal area per acre, with a quadratic mean diameter of 15.4 inches. The average stocking of 102 percent exceeded the level (100 percent) at which thinning is recommended in even-aged, southern bottomland hardwood stands (Goelz 1995). There were no significant differences among plots in any of these preharvest characteristics. Although the stand was fairly dense, most of the dominant and codominant trees were healthy and exhibited few signs of poor vigor. Hispidus canker was found on about 24 percent of red oaks in the study area; however, many of the infected red oaks were in the intermediate crown class.

The stand was clearly dominated by red oak and sweetgum. Prior to thinning, those species together comprised 91 percent of the stand's basal area. Red oaks (primarily willow and Nuttall oaks) accounted for about 43 percent of the basal area and dominated the upper canopy. Quadratic mean diameter of red oaks before thinning was 16.7 inches. Most of the stand's large trees were red oaks. Sweetgum comprised about 48 percent of the basal area and occurred in both the upper and middle canopies. Quadratic mean diameter of sweetgum was 15.1 inches. Other species, mainly sugarberry and American elm, comprised the remaining 9 percent of basal area. Those species were found almost exclusively in the lower canopy.

### Stand Development Following Thinning

Thinning reduced stand density to 33 trees and 59 square feet of basal area per acre, increased quadratic mean diameter to 17.9 inches, and reduced stocking to 47 percent. It removed 66 percent of the trees and 53 percent of the basal area. Average d.b.h. of trees removed was 13.5 inches. Across the study site as a whole, thinning removed about 3,500 board feet per acre (Doyle scale) of sawtimber and about 11 cords per acre of pulpwood. Following thinning, residual sawtimber volume contained in the butt logs only averaged 3,326 board feet per acre. Thinning produced stand density characteristics significantly different from the unthinned control.

The thinning operation reduced stand density to a level approaching the minimum residual stocking level necessary to maintain satisfactory stand-level growth, as recommended for other hardwood forest types (Hilt 1979, Lamson and Smith 1988). Thinning was unusually heavy because we emphasized the removal of all red oaks infected with hispidus canker. However, even with the additional removals of diseased red oaks, thinning improved species composition of the residual stand. It increased the red oak component of the stand from 43 percent to 56 percent of the basal area, and it reduced the sweetgum component from 48 percent to 41 percent of the basal area.

There has been little stand-level growth in either the thinned plots or in the unthinned control during the 6 years following thinning (table 1). In fact, basal area growth averaged about 1 square foot per acre per year under both treatments. Mortality has been negligible, averaging 1.5 percent or less per year for both treatments. Cumulative sawtimber volume growth (in butt logs only) in the unthinned control averaged about 750 board feet per acre over the 6-year period but only about 400 board feet per acre in the thinned plots. However, this difference in cumulative sawtimber volume growth was not statistically significant.

Quadratic mean diameter in the thinned stand increased 1.9 inches during the 6 years since thinning, from 17.9 to 19.8 inches (table 1). By contrast, quadratic mean diameter of the unthinned control increased only 1.0 inch, from 15.4 to 16.4 inches. However, quadratic mean diameter 6 years after thinning was not significantly different between the two stands.

### Diameter Growth

Thinning significantly increased cumulative diameter growth of individual trees, averaged across all species, during the first, third, and sixth years after thinning (fig. 1). A significant difference between the thinning treatment and the unthinned control was detected even after the first year; this difference between treatments widened over time. By the end of the sixth year, cumulative diameter growth of residual trees in the thinned plots was 2.5 times greater than the cumulative diameter growth of trees in the unthinned control—1.46 inches as compared to only 0.59 inches, respectively. These diameter growth averages represent trees of all species and all crown classes within each of the two treatments.

When we separated the data by species groups, we found that, by the end of year six, the red oaks (primarily willow and Nuttall oaks) and sweetgum had similar cumulative diameter growth responses to the operational thinning (fig. 2). Thinning more than doubled the diameter growth of both species groups, relative to the unthinned control. Residual red oaks in the thinned plots grew 1.55 inches in diameter; residual sweetgum in the thinned plots grew 1.36 inches. Both of these values were significantly greater than the corresponding values in the unthinned control. Cumulative diameter growth of red oaks and sweetgum in the unthinned control averaged 0.71 and 0.57 inches, respectively.

Of particular importance is the observation that thinning significantly increased diameter growth of codominant trees (by about 75 percent over the unthinned control), when averaged across all species (fig. 3). Further, diameter growth of dominant trees in the thinned plots was about 28 percent greater than diameter growth of dominant trees in the unthinned control plots; however, this growth difference was not statistically

**Table 1—Stand conditions 6 years after application of two thinning treatments**

Treatment	Trees <i>no./ac</i>	Cumulative mortality <i>%</i>	Basal area <i>ft<sup>2</sup>/ac</i>	Cumulative basal area growth <i>ft<sup>2</sup>/ac</i>	Sawtimber volume <i>bd ft/ac</i>	Quadratic mean diameter <i>inches</i>
Unthinned	92 a	8.0 a	135 a	6 a	6,724 a	16.4 a
Thinned	30 b	9.1 a	66 b	7 a	3,726 a	19.8 a

Means followed by the same letter are not significantly different at the 0.05 level of probability.

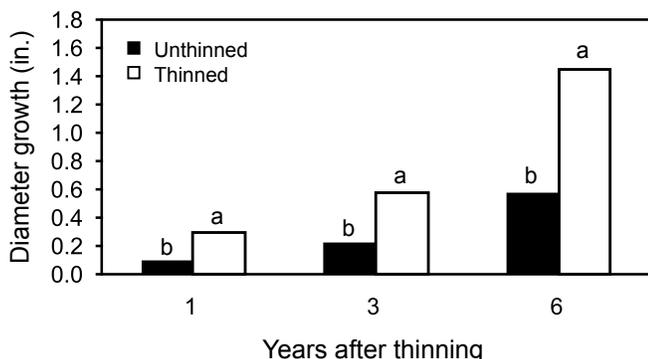


Figure 1—Cumulative diameter growth of residual trees 1, 3, and 6 years after application of two thinning treatments.

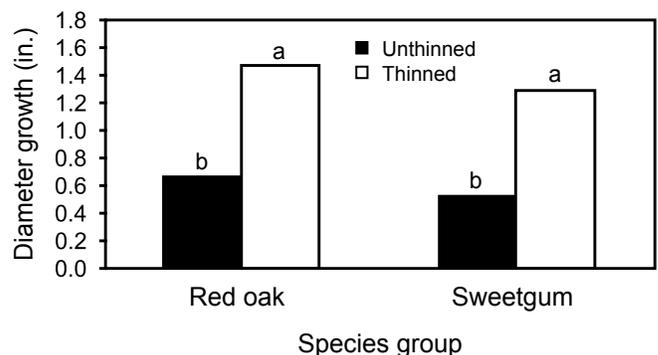


Figure 2—Cumulative diameter growth of residual trees, by species group, 6 years after application of two thinning treatments.

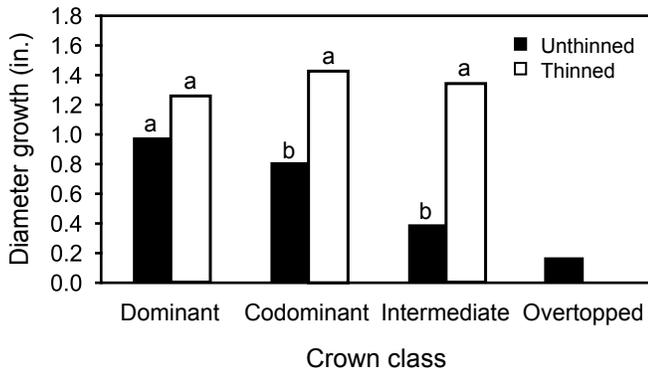


Figure 3—Cumulative diameter growth of residual trees, by crown class, 6 years after application of two thinning treatments.

significant. Thinning also more than tripled the diameter growth of trees in the intermediate crown class. This rapid increase in diameter growth of trees in the intermediate crown class is important because many of these smaller trees exhibited good potential to eventually develop into valuable sawtimber trees. We could make no comparisons for trees in the overtopped crown class because thinning removed all overtopped trees.

It is clear that thinning successfully increased cumulative diameter growth of residual trees during the first 6 years after treatment. Excellent diameter growth responses were observed for both red oak and sweetgum in the dominant and codominant crown classes. Those trees, but especially the red oaks, are classified as crop trees and, as such, are the most desirable trees in the stand for high-quality sawtimber production. From a timber production perspective, thinning greatly enhanced diameter growth of the stand's most valuable trees.

### Epicormic Branching

Thinning operations in hardwoods, while creating positive impacts on diameter growth, also may have negative effects on bole quality, particularly in the form of epicormic branches. The possible production of epicormic branches along the merchantable boles of residual trees can be a serious problem when thinning hardwood stands. Epicormic branches cause defects in the underlying wood and can reduce both log grade and lumber value. However, well-designed thinning prescriptions and proper marking rules can help reduce the production of new epicormic branches in most hardwood stands.

We recorded no significant effects of thinning on either the number of new epicormic branches or the total number of epicormic branches found on the butt logs of residual trees at the end of the first, third, or sixth years after thinning, when averaged across all trees and all species (fig. 4). There was little change in the total number of epicormic branches at the end of the first year. However, by the end of the third year, we found a fairly large increase in the total number of epicormic branches on the butt logs of residual trees in thinned plots, from an average of 4.1 branches at the end of the first year to an average of 6.4 branches at the end of the third year. The total number of epicormic branches on the butt logs of trees in both the thinned and the unthinned plots remained relatively stable from year three through year six.

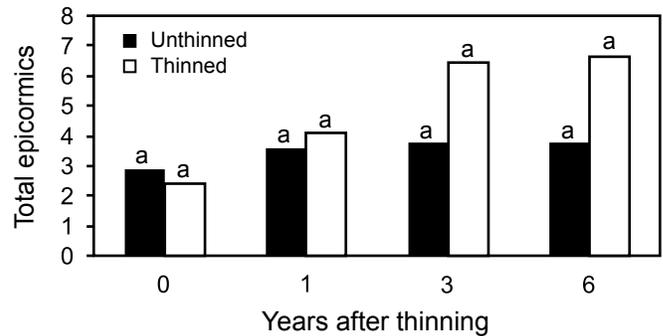


Figure 4—Total number of epicormic branches found on the butt logs of residual trees initially and 1, 3, and 6 years after application of two thinning treatments.

Even though residual trees in the thinned plots averaged more total epicormic branches on the butt log than trees in the unthinned control, those differences were not statistically different in any given year. Consequently, when epicormic branch data were averaged across all trees and all species, the thinning operation did not negatively affect bole quality. We did observe, however, that production of new epicormic branches on the butt log varied widely among individual trees. Most high-vigor trees, characterized by large, well-shaped crowns with dense foliage, produced either no new branches or only a few. Conversely, most of the low-vigor trees, characterized by small crowns with sparse foliage, generally produced many new epicormic branches.

To diagnose the source of this broad variation in epicormic branch production by individual trees following thinning, we partitioned the data by species groups. Previous research indicates that hardwood species, in general, vary widely in their susceptibility to the production of epicormic branches (Meadows 1995). In our study, thinning had no effect on the production of epicormic branches in red oak but caused a very large, significant increase in the total number of epicormic branches on the butt logs of residual sweetgum trees 6 years after thinning (fig. 5). In fact, residual red oaks in the thinned plots averaged only 3.4 epicormic branches on the butt log, whereas residual sweetgum trees averaged 10.9 branches.

Because both red oak and sweetgum are generally considered to be highly susceptible to the production of epicormic branches (Meadows 1995), further diagnosis was required to

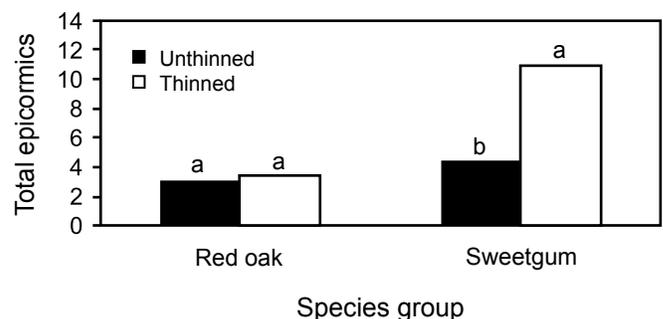


Figure 5—Total number of epicormic branches found on the butt logs of residual trees, by species group, 6 years after application of two thinning treatments.

explain the large difference between the species groups in the total number of epicormic branches found on the butt logs of residual trees 6 years after thinning. We observed that most residual red oaks in the thinned stand were high-vigor, dominant or codominant trees that are generally less likely to produce epicormic branches than are less healthy trees.

On the other hand, many of the residual sweetgum trees in the thinned stand were low to medium vigor, intermediate or weak codominant trees that are generally more likely to produce epicormic branches than are healthy trees. Consequently, we found very few new epicormic branches on the butt logs of residual red oaks and many new epicormic branches on the butt logs of residual sweetgum trees, even though Meadows (1995) categorized both species groups as highly susceptible to the production of epicormic branches following some type of disturbance, such as thinning. These observations strongly support the hypothesis proposed by Meadows (1995) that healthy, vigorous trees, even of highly susceptible species, are much less likely to produce epicormic branches than are trees in poor health.

When evaluating the effects of thinning on the production of epicormic branches, the most important consideration remains the total number of epicormic branches found on the butt logs of the crop trees, particularly sawtimber-sized red oaks and, to a lesser extent, sawtimber-sized sweetgum trees. Such trees are favored during the thinning operation and are most likely to produce high-quality, high-value sawtimber. In our study, thinning had no effect on the total number of epicormic branches found on the butt logs of sawtimber-sized red oaks 6 years after thinning (fig. 6). In fact, sawtimber-sized red oaks in both the unthinned control and in the thinned plots averaged fewer than three epicormic branches on the butt log, generally not enough to have a negative impact on bole quality.

Conversely, thinning greatly increased the total number of epicormic branches found on the butt logs of sawtimber-sized sweetgum trees. These trees averaged 10.5 epicormic branches on the butt log. Based on a very general rule of thumb that five epicormic branches are sufficient to cause a reduction in log grade (Meadows and Burkhardt 2001), it is likely that the bole quality of many sawtimber-sized sweetgum trees in our study was adversely affected by the excessive

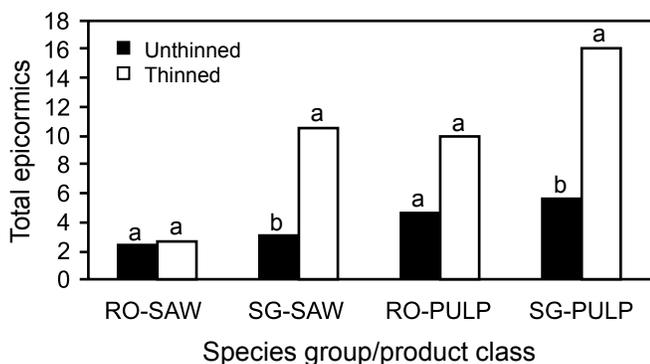


Figure 6—Total number of epicormic branches found on the butt logs of residual trees, by species group and product class, 6 years after application of two thinning treatments (RO-SAW = red oak sawtimber, SG-SAW = sweetgum sawtimber, RO-PULP = red oak pulpwood, SG-PULP = sweetgum pulpwood).

production of epicormic branches on the butt log following thinning. Production of epicormic branches on the boles of pulpwood-sized trees of both species groups was uniformly high 6 years after thinning. Most of the pulpwood-sized trees in the residual stand were relatively low-vigor, lower-crown-class trees that produced many new epicormic branches following thinning.

### Log Grade Distribution

Although it is clear that thinning had no effect on the production of epicormic branches in red oak sawtimber and greatly increased the number of epicormic branches on sweetgum sawtimber, it is not clear whether these results affect log grade and, therefore, stand value. In most hardwood species, there is a huge difference in value between grade 1 logs (the most valuable) and grade 3 logs (the least valuable). Any factor that reduces log grade in individual trees has a potentially large effect on stand value.

The log grade distributions for all sawtimber trees, regardless of species, in the unthinned control plots and in the thinned plots at both year zero and at year six are depicted in figure 7. These distributions are presented as the proportion of total sawtimber volume (butt log only) in each of the three log grades.

There was little change in log grade distribution from year zero to year six in the unthinned control plots, when trees of all species were combined (fig. 7). The proportion of total

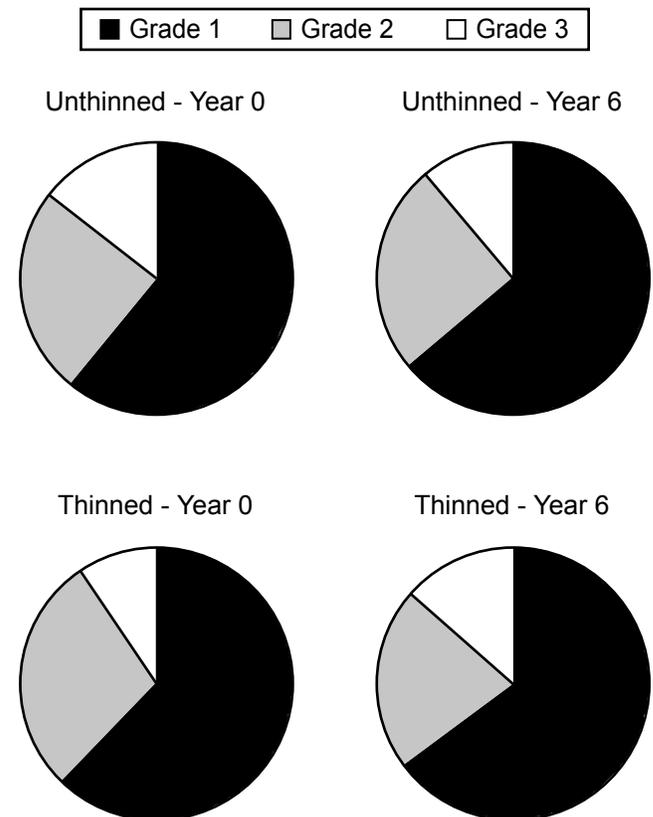


Figure 7—Log grade distributions for all sawtimber trees, regardless of species, at both year zero and at year six for both the unthinned control plots and the thinned plots.

volume in high-value grade 1 logs increased slightly (from 61 percent to 64 percent), and the proportion of total volume in low-value grade 3 logs decreased slightly (from 15 percent to 11 percent). This trend, observed in the unthinned control plots, is typical for undisturbed, midrotation hardwood stands. Generally, in these types of stands, there is a gradual upward movement of log grades over time, as trees get large enough to meet minimum size requirements for the higher grades. The end result of this process is a gradual upward shift in the proportion of total volume found in the higher grades.

The negative impact of the increased production of epicormic branches on sweetgum sawtimber trees is reflected in the log grade distributions in the thinned plots (fig. 7). At first glance, the log grade distributions for the thinned plots appear to be similar to the log grade distributions for the unthinned control plots. There was a slight increase in the proportion of total volume in grade 1 logs (from 62 percent to 65 percent), as was found in the unthinned control plots. However, in contrast to the trend observed in the unthinned control plots, there was a slight increase in the proportion of total volume in low-value grade 3 logs (from 10 percent to 13 percent) in the thinned plots. This increase in the proportion of total volume in grade 3 logs in the thinned plots is the manifestation of the negative impact on bole quality associated with the increased production of epicormic branches on sweetgum sawtimber trees. Many of the grade 2 sweetgum butt logs were downgraded to grade 3 logs because of the abundance of epicormic branches. A few grade 1 sweetgum logs were degraded to grade 3, but the most common situation was a one-grade reduction from grade 2 to grade 3. Although sweetgum is not as valuable as red oak, these reductions in log grade of sweetgum sawtimber trees will likely have at least a slight negative impact on stand value.

When analysis of the change in log grade distributions from year zero to year six was limited to only red oak sawtimber in the unthinned control plots (fig. 8), we observed a very similar trend to the one observed in the unthinned control plots, for all species combined (fig. 7). The proportion of red oak volume in high-value grade 1 logs increased slightly (from 67 percent to 71 percent), and the proportion of red oak volume in low-value grade 3 logs decreased slightly (from 12 percent to 9 percent). As in the analysis combining trees of all species, the trend observed for red oak sawtimber in the unthinned control plots is typical for undisturbed, midrotation hardwood stands: a gradual, upward change in log grades over time.

However, because thinning had no effect on the production of epicormic branches in red oak sawtimber, we did not observe the same patterns of change in log grade distributions of red oak sawtimber in the thinned plots (fig. 8) as was observed in the thinned plots when trees of all species were combined (fig. 7). The proportion of red oak volume in grade 1 logs in the thinned plots increased considerably (from 58 percent to 70 percent) and, in contrast to the trend observed in the thinned plots when trees of all species were combined, the proportion of red oak volume in grade 3 logs decreased slightly (from 9 percent to 7 percent).

A closer examination of the log grade distributions for red oak sawtimber in figure 8 reveals that the increased proportion of volume in grade 1 logs came from the grade 2 class. About one-third of the red oak volume classified as grade 2 in year

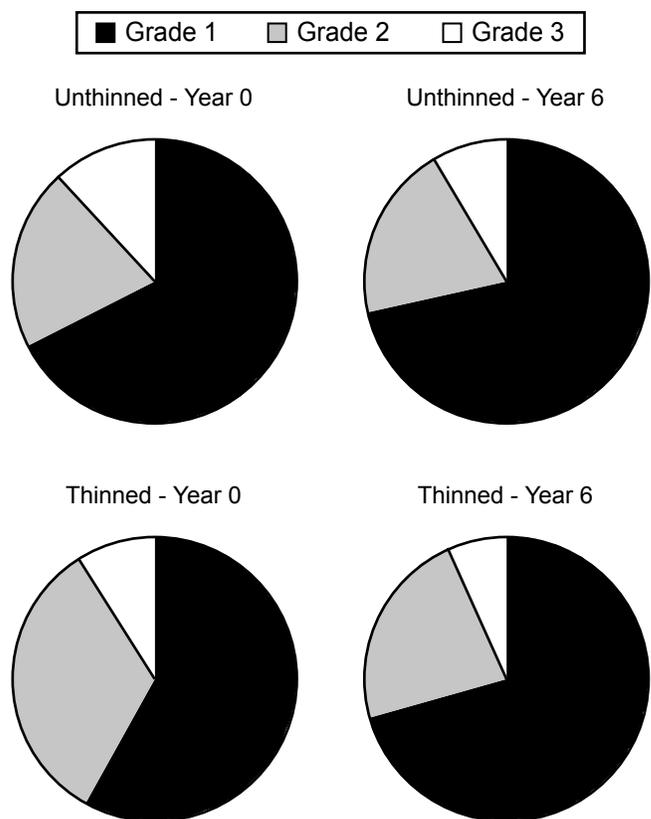


Figure 8—Log grade distributions for red oak sawtimber trees at both year zero and at year six for both the unthinned control plots and the thinned plots.

zero moved up to the grade 1 class by year six. In other words, instead of a gradual upward movement of log grades over time, which is typical in undisturbed stands, our thinning operation produced a fairly rapid acceleration of that process within red oak sawtimber, the most valuable component of the stand. This acceleration occurred because thinning greatly increased the diameter growth rate of individual red oak sawtimber trees without any negative impacts on bole quality. The increased diameter growth rate allowed trees to reach minimum size requirements for the higher log grades more quickly. The absence of negative impacts on bole quality allowed trees to move into the higher log grades and, thus, to fulfill their maximum potential in a shorter period of time. From a timber production perspective, the thinning operation conducted in this study was a notable success.

#### ACKNOWLEDGMENTS

We express appreciation to Delta National Forest for providing the study site and for its cooperation in all phases of study installation and measurement. We specifically thank Larry Moore and Ralph Pearce of Delta National Forest for their continuing assistance in this study. We also thank Luben Dimov and Dan Wilson for providing helpful suggestions on earlier drafts of this manuscript.

## LITERATURE CITED

- Broadfoot, W.M. 1976. Hardwood suitability for and properties of important Midsouth soils. Res. Pap. SO-127. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 84 p.
- Goelz, J.C.G. 1995. A stocking guide for southern bottomland hardwoods. Southern Journal of Applied Forestry. 19(3): 103-104.
- Hilt, D.E. 1979. Diameter growth of upland oaks after thinning. Res. Pap. NE-437. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.
- Lamson, N.I.; Smith, H.C. 1988. Thinning cherry-maple stands in West Virginia: 5-year results. Res. Pap. NE-615. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.
- Marquis, D.; Smith, C.; Lamson, N. [and others]. 1990. Standard plot layout and data collection procedures for the Stand Establishment and Stand Culture Working Groups, Northeastern Forest Experiment Station. Warren, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 55 p.
- McCracken, F.I. 1978. Canker-rots in southern hardwoods. Forest Insect & Disease Leaflet 33. Washington, DC: U.S. Department of Agriculture, Forest Service. 4 p.
- McCracken, F.I.; Toole, E.R. 1974. Felling infected oaks in natural stands reduces dissemination of *Polyporus hispidus* spores. Phytopathology. 64(2): 265-266.
- Meadows, J.S. 1995. Epicormic branches and lumber grade of bottomland oak. In: Lowery, G.; Meyer, D., eds. Advances in hardwood utilization: following profitability from the woods through rough dimension. Proceedings of the 23<sup>rd</sup> annual hardwood symposium. Memphis, TN: National Hardwood Lumber Association: 19-25.
- Meadows, J.S. 1996. Thinning guidelines for southern bottomland hardwood forests. In: Flynn, K.M., ed. Proceedings of the southern forested wetlands ecology and management conference. Clemson, SC: Clemson University, Consortium for Research on Southern Forested Wetlands: 98-101.
- Meadows, J.S.; Burkhardt, E.C. 2001. Epicormic branches affect lumber grade and value in willow oak. Southern Journal of Applied Forestry. 25(3): 136-141.
- Meadows, J.S.; Goelz, J.C.G. 2001. Fifth-year response to thinning in a water oak plantation in north Louisiana. Southern Journal of Applied Forestry. 25(1): 31-39.
- Meadows, J.S.; Leininger, T.D.; Nebeker, T.E. 2002. Thinning to improve growth and control the canker decay fungus *Inonotus hispidus* in a red oak-sweetgum stand in the Mississippi Delta. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 183-188.
- Rast, E.D.; Sonderman, D.L.; Gammon, G.L. 1973. A guide to hardwood log grading (revised). Gen. Tech. Rep. NE-1. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 31 p.
- Sonderman, D.L.; Rast, E.D. 1988. Effect of thinning on mixed-oak stem quality. Res. Pap. NE-618. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

# COMPARISON OF WINDTHROW DAMAGE AMONG THINNED AND UNTHINNED HARDWOODS AND ADJACENT PINE STANDS FOLLOWING A LATE WINTER TORNADO ON THE CUMBERLAND PLATEAU NEAR SEWANEE, TN

Karen Kuers and Samuel C. Grinstead<sup>1</sup>

**Abstract**—In March, 2004, prior to spring leaf-out, an F0 tornado snapped or uprooted 672 trees across 25 ha of the western margin of the Cumberland Plateau near Sewanee, TN. A ridgeline separated the impacted area into two parts: westward-facing slopes of mature hardwoods and eastward-facing slopes with thinned and unthinned hardwoods, pine stands, and clearcuts. Greatest damage (29 to 30 percent of damaged stems and basal area) occurred in the pine stands. Among hardwood stands, damage was greater in the mature hardwoods west of the ridgeline than in either thinned or unthinned hardwoods east of the ridge. Damage was intensified on the windward shoulders of ridges and along the margins of clearcuts. Canopy trees were impacted more than lower crown positions, with scarlet oak damaged more severely and white oak less severely than other oak species. Overall, 84 percent of damaged trees were uprooted rather than broken, upturning approximately 0.5 percent of the ground surface.

## INTRODUCTION

Prior to leaf-out in March 2004, an F0 tornado (Troutman 2004) snapped stems and uprooted trees across 25 ha of the western edge of the Cumberland Plateau near Sewanee, TN. Wind is a common disturbance factor on the Plateau, but tornadoes are quite rare, even on these western edges that are the first to receive the force of the westerlies-driven thunderstorm activity striking the Plateau.

The area impacted by the storm consisted of a variety of stand types and provided an opportunity to compare wind damage in adjacent stands representing different species, stand densities, and recent management activities. Approximately half of the area consisted of mature, upland hardwoods; the remainder consisted of recently thinned hardwoods, areas clearcut in response to southern pine beetle damage, hardwood buffer strips, and small remnant stands of eastern white pine (*Pinus strobes* L.) and loblolly pine (*Pinus taeda* L.).

The objectives of this study were to (1) compare wind damage in thinned and unthinned upland hardwoods and adjacent pine stands, (2) map wind damage with respect to Plateau topography and harvest edges, (3) identify species differences in response to the wind storm, and (4) quantify the degree of soil disturbance associated with the blowdown.

## STUDY SITE

The blowdown area is located on a narrow southward-projecting ridge of the Cumberland Plateau, 2.5 km SSW of Sewanee, TN (35°12'30"N and 85°55'W) (fig. 1). This 1,400-m-wide ridge, which ranges in elevation from 545 to 575 m, constitutes the western-most part of the Plateau at this latitude. Tennessee Highway 56, which follows the top of the ridge, separates the study area into two zones, one west and the other east of the highway. While most of the area is typical of Landtype 1 (undulating sandstone ridges), the area is drained both to the east and the west by several intermittent first-order stream drainages classified as Landtype 14 (streambottoms

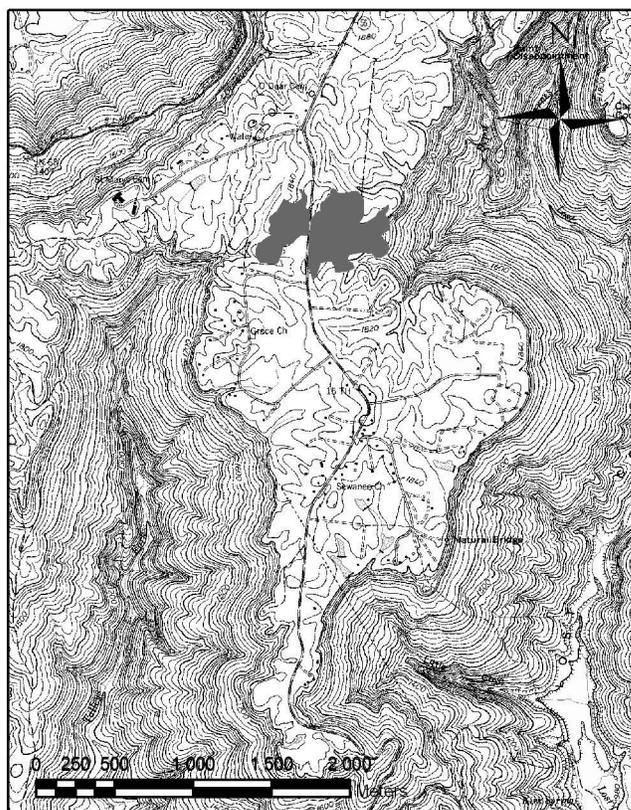


Figure 1—Location of the 25 ha March 2004 blowdown site (shaded area) within a portion of the Sewanee 7.5 minute topographic quadrangle. Note the site's location on a ridge of the western margin of the Cumberland Plateau, 2.5 km south of Sewanee, TN.

with good drainage) (Smalley 1982, Smalley and others 2001). The moderately deep to deep soils developed in loamy residuum from sandstone and some shale and are classified

<sup>1</sup> Associate Professor of Forestry and Research Intern, respectively, Department of Forestry and Geology, Sewanee: The University of the South, Sewanee, TN 37383.

as fine-loamy, siliceous (or mixed mineralogy), mesic, Typic Hapludults. Annual precipitation averages 155 cm and is evenly distributed, with lowest values typically recorded in September and October.

### Stand Descriptions

Based upon stand structure, species composition, and recent management, the stands impacted by the storm were classified into five categories: mature hardwoods, thinned hardwoods, hardwood buffers, pine stands, and clearcuts with reserves. The mature hardwoods area was located west of Highway 56, while the four more-recently managed stand types were located east of the highway.

**Mature hardwoods**—The mature hardwoods consisted of 7.8 ha of mixed upland hardwoods dominated by oaks. Stem disks collected from 5 of the downed canopy trees indicated at least 2 age classes, a dominant canopy age of 110 to 130 years and an intermediate crown class consisting of trees approximately 65 years old. The canopy height averaged 22 to 25 m, and the pre-storm basal area averaged 34 m<sup>2</sup> ha<sup>-1</sup>. Previous management included a selective harvest in 1970 and a white oak (*Quercus alba* L.) harvest in 1955.

**Thinned hardwoods**—The thinned hardwoods sites consisted of 6.4 ha of mostly mixed upland hardwoods with some loblolly and Virginia pine (*Pinus virginiana* P. Mill) that had been thinned in the 6 months just prior to the blowdown. The site had been marked to leave 100 high-quality hardwood crop trees/ha, with average diameters of 20 to 40 cm d.b.h. The residual basal area after thinning averaged 15 m<sup>2</sup> ha<sup>-1</sup> but was highly variable (5 to 27 m<sup>2</sup>).

**Hardwoods buffers**—The hardwood buffers totaled 4.4 ha and consisted of streamside management zones, visual buffers, and small areas of unthinned pine-hardwood mixtures. Selective removal of a few large trees occurred during the thinning of the adjacent hardwood stand. Pre-storm basal areas ranged from 20 to 34 m<sup>2</sup> ha<sup>-1</sup>.

**Pine stands**—The six pine stands consisted of 1.9 ha of pine left in small groups (0.2 to 0.5 ha) or in rows along fire lanes after the harvest of adjacent loblolly and Virginia pine. The groups were composed of planted loblolly pine (40 to 45 years old), and the fire lanes were bordered by planted eastern white pine.

**Clearcuts with reserves**—The clearcuts with reserves totaled 4.8 ha. They were created from pine stands harvested in 2002, 2 years before the storm, in response to an infestation from southern pine beetle (*Dendroctonus frontalis* Zimmermann). The cleared areas ranged in size from 0.3 to 3.1 ha with 3-20 residual canopy hardwoods/ha left after harvest.

### Storm Characteristics

The storm was classified as an F0 tornado by the Huntsville, AL, office of the National Weather Service, with maximum wind speeds of approximately 70 miles per hour (Troutman 2004). While there was no rainfall in the 24 hours immediately preceding the blowdown, 3.8 cm fell in the 48 hours preceding the tornado, and 20.6 cm (somewhat above average) fell during the preceding month. The storm approached the study area from the valley southwest of the Plateau. It proceeded northeasterly across the site, climbing in elevation as it traversed the western part of the study area (mature hardwood

forest) and descending in elevation as it crossed the eastern part of the site (recently managed stands).

### METHODS

The location of each damaged tree in the 25-ha blowdown area was mapped with a Garmin III+ GPS unit. The species, d.b.h., height, and azimuth of fall were recorded for each stem. The source of damage was classified as direct wind damage or indirect damage caused by an adjacent tree, and damage type was classified as uprooted or snapped for each stem. Length, width (now height), and thickness of each upturned rootball were measured and the area of disturbed soil in each rootball was calculated using the formula for one-half an ellipse:

$$\text{disturbed soil surface(m}^2\text{)} = 0.5 \times (0.5 \times \text{length} \times \text{width} \times \pi) \quad (1)$$

The volume of disturbed soil was then estimated by multiplying the disturbed soil area by the thickness of the rootball.

Pre-storm inventory data was available for the mature hardwood stand to the west of the highway and was used to calculate basal area loss by species. Marking guidelines were available for the thinned areas to the east of the highway and were used to estimate stand structure at the time of the storm. Post-storm basal areas were obtained with a series of randomly located prism points in each stand type. Pre-storm basal areas were estimated in the recently managed stands from prism points located in areas that lacked damaged trees. All reserve trees in the clear-cut areas were counted to determine percent loss during the storm.

The proximity of damaged trees to the margins of clear-cuts was evaluated for the managed areas on the east side of Highway 56. ArcView 3.2 software was used to construct successive 10-m zones around the clearcut areas to a maximum distance of 100 m. The number of hardwoods and pines within each 10-m strip was tabulated and plotted relative to distance from the clearcut to determine the extent to which damage density was controlled by proximity to the forest edge.

The azimuth of tree fall for each stem was analyzed using RockWorks™ software. Mean tree fall azimuth was calculated separately for the east and west sides of the ridge, with the highway serving as the boundary.

### RESULTS

A total of 672 stems and 64.8 m<sup>2</sup> of basal area were damaged across the 25.3-ha blowdown zone (table 1). Eighteen different species had uprooted or broken stems. The average diameter of the damaged stems (32 cm) did not differ among stand types but was almost 10 cm greater than the average pre-storm diameter for the mature hardwood stand (22.6 cm), indicating that proportionally more large than small diameter trees were felled by the storm. This relationship was true for most of the 11 species for which pre-storm diameters were available. However, hickory (*Carya* spp.), white oak, and red maple (*Acer rubrum* L.) showed an opposite relationship, with their storm-damaged stem diameter averages smaller than pre-storm diameter averages (fig. 2).

Among the hardwood-dominated stands, the western side of the ridgeline (Highway 56) received more damage than areas

**Table 1—Number of damaged stems, basal area loss, and average d.b.h. of damaged stems by stand type from the March, 2004 tornado on the Cumberland Plateau near Sewanee, TN**

Stand type	Total stem loss	Stem loss/ha	Damaged	Damaged	Avg. d.b.h. of damaged stems
			BA total	BA	
			$m^2$	$m^2 ha^{-1}$	
Mature hardwoods	245	31.5	24.1	3.1	31.5
Hardwood buffers	90	20.6	8.5	2.0	32.0
Thinned hardwoods	130	20.5	13.0	2.0	32.8
Pine stands	204	107.2	18.9	10.0	32.5
Clear-cuts	4	0.8	0.4	0.1	32.0
Overall	672	26.7	64.8	2.6	32.0

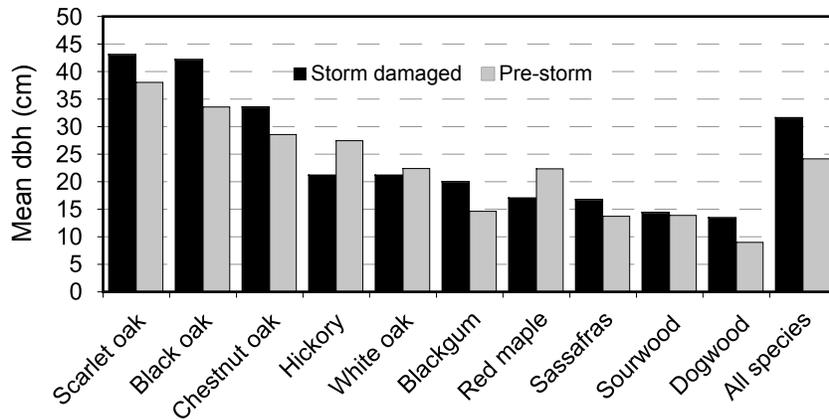


Figure 2—Comparison of pre-storm average diameters to damaged-stem diameters for the mature hardwood stand.

east of the ridgeline. The storm damaged  $3.1 m^2 ha^{-1}$  (9 percent) of the basal area in the mature hardwood forest west of the highway but only  $2.0 m^2 ha^{-1}$  in the thinned and unthinned hardwoods east of the highway. Very little damage occurred to the reserve trees in the clear-cut areas, with only 4 of approximately 86 stems damaged across the entire 1.9 ha of clearcuts.

By far the greatest basal area damage occurred in the pine stands, which sustained 3 to 5 times the basal area loss per unit area ( $10 m^2 ha^{-1}$ ) of the hardwood stands (table 1). While pine areas constituted only 8 percent of the total damaged areas, pines made up 29 to 30 percent of both damaged stems and basal area.

Over 75 percent of the damaged stems belonged to 6 of the 18 species: scarlet oak (*Quercus coccinea* Muenchh., 21.2 percent of all stems); eastern white pine (16.4 percent); loblolly pine (10.7 percent); chestnut oak (*Quercus montana* Willd., 10.6 percent); sourwood [*Oxydendrum arboreum* (L.) DC., 9.4 percent]; and black oak (*Quercus velutina* Lam., 7.9 percent). Four of those species (scarlet oak, eastern white pine, black oak, and chestnut oak) received 75 percent of the basal area damage. Overall, damage to oak species was quite

high. In the mature hardwoods, for example, 93 percent of the damaged basal area occurred among oak species, even though they only composed 66 percent of the pre-storm basal area. Among the oaks, damage was greatest to scarlet oak, intermediate to chestnut and black oak, and least to white oak (fig. 3). White oak, which represented 25.8 percent of the pre-storm basal area in the mature hardwoods, represented only 3.4 percent of the damaged basal area in the mature hardwoods and 3.7 percent of all damaged basal area.

With respect to damage type, the majority of the damaged stems were uprooted rather than broken (fig. 4). Only 15 percent of all damaged stems and 16 percent of all damaged basal area were due to stem breakage. The average diameter of the snapped stems was not significantly different from that of the uprooted trees (30.4 versus 32.4 cm). Among the oaks, the percentage loss of stems to breakage was highest for white oak (29 percent) and scarlet oak (27 percent), followed by black oak (23 percent) and chestnut oak (16 percent; fig. 4). The rankings by basal area were different, with white oak showing much lower percent loss than by stem counts. By basal area, damage due to breakage was highest in scarlet oak (29 percent) and black oak (21 percent), and lowest in chestnut oak (13 percent) and white oak (11 percent; fig. 5).

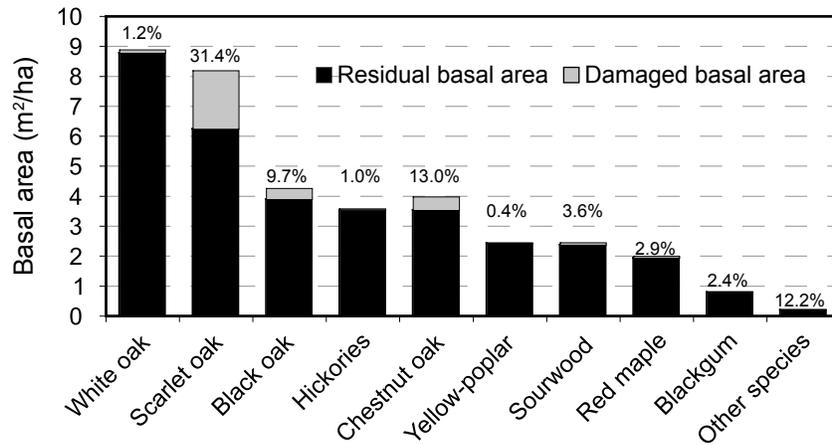


Figure 3—Percentage of pre-storm basal area damaged, by species, for the mature hardwood stand.

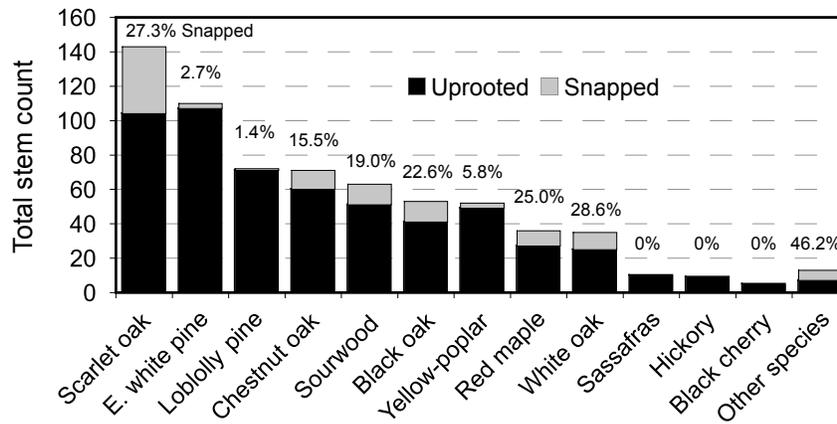


Figure 4—Number of stems uprooted or snapped, by species, across all stand types.

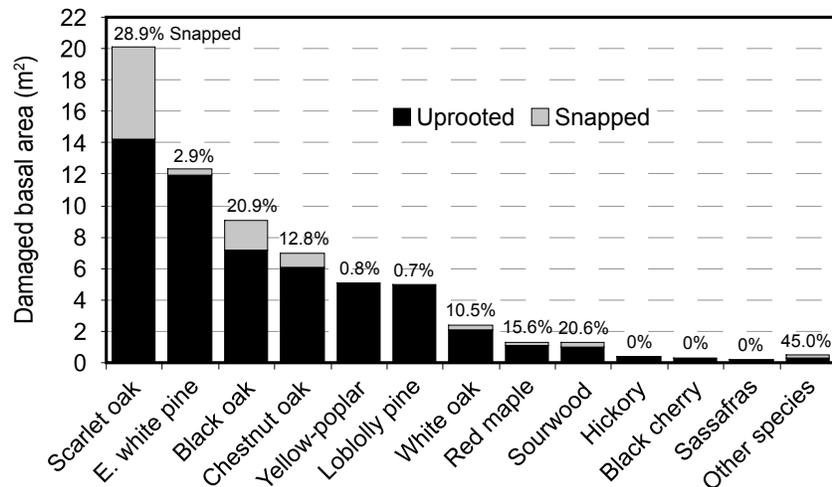


Figure 5—Basal area of stems uprooted or snapped, by species, across all stand types.

Direct wind effects accounted for 72 percent of stems damaged and 85 percent of the total basal area damage across the entire site (fig. 6). The diameter of trees directly damaged by the wind was greater than that of the trees indirectly damaged by the wind (35.7 versus 22.9 cm). Among the oaks, direct

wind damage was highest for scarlet, black, and chestnut oak, representing 88 percent of all damage to those species. In contrast, only 66 percent of the damaged white oak basal area was due to direct wind damage.

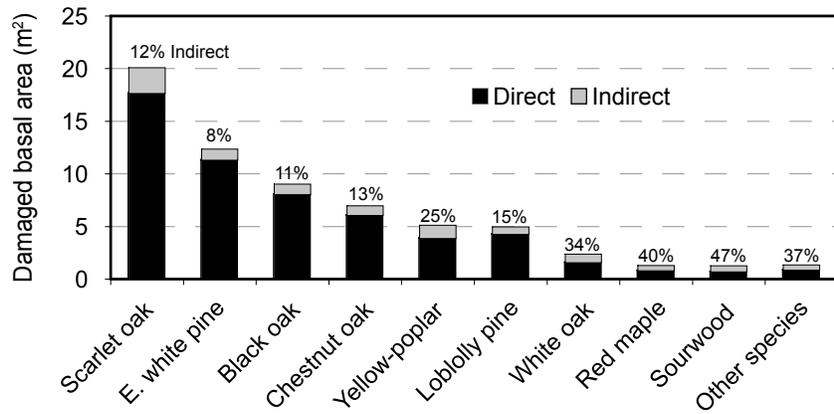


Figure 6—Relative contributions of direct and indirect wind effects on basal area damage, by species, across all sites.

A total of 594 separate mounds were created by uplifted root systems. The mean thickness of the soil layer uplifted with the roots was 71.3 cm, with a maximum of 198 cm. Rootball volume averaged 2.0 m<sup>3</sup>; average surface area disturbed by each upturned root system was 2.4 m<sup>2</sup>. Overall, 0.47 percent of the soil surface (47.2 m<sup>2</sup> ha<sup>-1</sup>) was disturbed across all sites. Because pine stands had the greatest stem damage, they also incurred the greatest area of soil disturbance (203 m<sup>2</sup> ha<sup>-1</sup>). However, even with the greater density of damaged stems, the disturbed soil represented only 2 percent of the ground surface in the pine areas.

The distinctly curved windfall pattern of the downed trees is consistent with tornadic rather than straight line winds (fig. 7). The pattern is even more consistent on the west of the highway than on the east. There is also a change in the average azimuth of tree fall from the west to the east side of the highway (fig. 8). The mean azimuth of tree fall west of the highway (N23°E) was 30° to the N/NW of the mean for the east side of the highway (N53°E). The mean azimuth of tree fall across the entire site was to the northeast (N45°E).

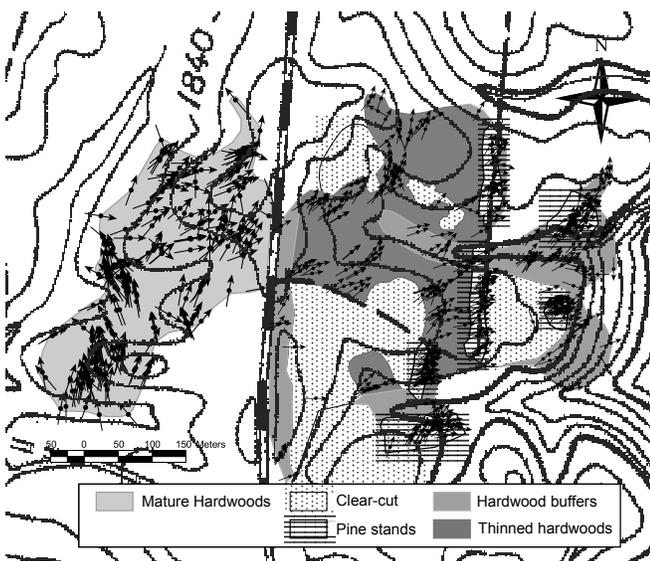


Figure 7—Tree fall azimuths and damage pattern across the March 2004 blowdown near Sewanee, TN.

On the west side of the highway, where the storm was moving toward the high point of the ridge, the highest tree fall densities occurred on the windward shoulders of the ridge (WSW). Less damage occurred within drainages on that side of the ridge. Once the storm passed the ridge, however, damage was highest within the pine stands and adjacent to the leeward forest edges of the clearcuts. All pine stands within the path of the storm were heavily damaged. While damage extended up to 100 m from the edges of the clearcuts, 50 percent of the damaged stems for both pines and hardwoods were within 30 m of a clear-cut edge (fig. 9), a distance less than 1.5 times the average canopy height (22 to 25 m). A greater number of trees fell within drainages on the leeward than the windward side of the ridge.

## DISCUSSION

Damage from catastrophic winds can be influenced by two main types of variables: biotic and abiotic. Biotic variables include factors such as tree size, species, stand condition, and tree health, while abiotic variables include storm intensity and site factors such as topography, soil characteristics, and past disturbance. Everham and Brokaw (1996) discuss the relative importance of each variable and note that it is often difficult to separate the relative influence of each factor, especially when only post-storm data is available.

While tree size has been positively correlated to wind damage in a wide variety of studies, there have also been studies that indicated no relationship or even a negative relationship (Everham and Brokaw 1996). In our study, the average diameter of the damaged trees was 10 cm greater than the pre-storm mean diameter. The larger average diameter of the damaged trees indicates that this storm impacted canopy trees to a greater degree than intermediate or overtopped stems.

Wind damage variations among species have been correlated with factors such as shade tolerance, wood density, and leaf persistence (Everham and Brokaw 1996). Evergreens have generally been found to be more susceptible to wind throw than deciduous hardwoods, especially during the winter leafless period. Foster and Boose (1992) constructed a susceptibility ranking for wind damage in forests of central Massachusetts (eastern white pine > conifer plantations > eastern white pine – hardwood mixtures > hardwoods), and the high degree of pine damage relative to that of hardwoods in the current study

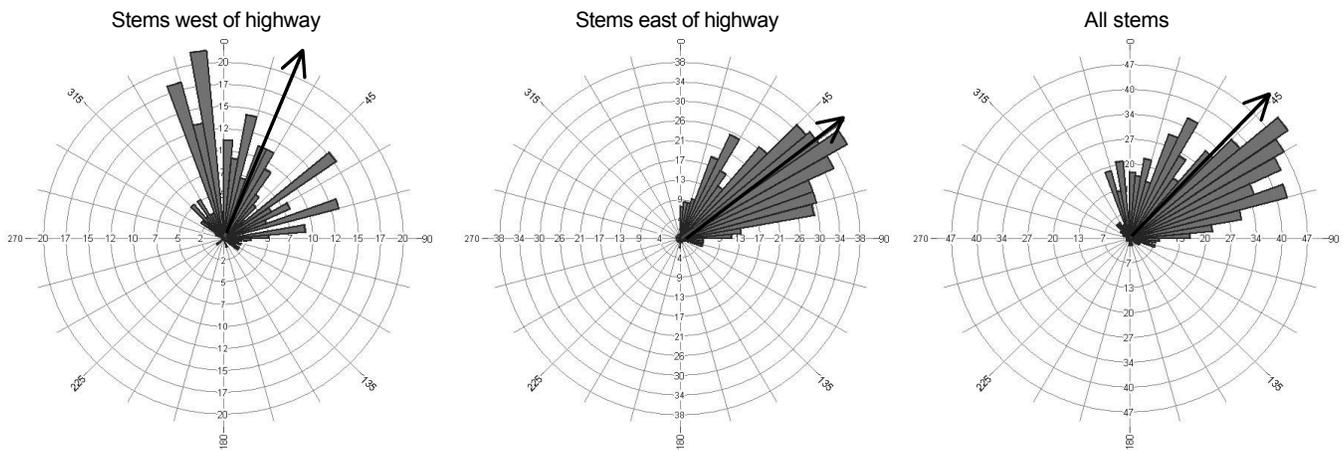


Figure 8—Tree fall azimuth for stems on different sides of TN Highway 56. The highway separated the blowdown into two distinct zones with respect to stand types and damage patterns.

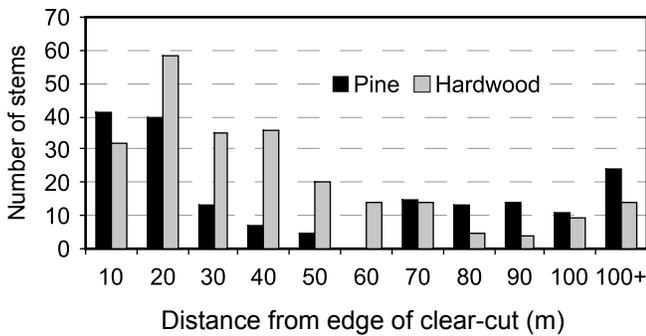


Figure 9—Stem damage by species type (pine or hardwood) at successive 10-m distances from the margins of the clearcuts.

(table 1) is similar to their results. Several characteristics of the pine stands in our study, including their small size, narrow shapes, location adjacent to clearcuts, and/or orientation perpendicular to the prevailing wind, may have contributed to their higher relative damage (pines made up 30 of the damaged stems yet only comprised 8 percent of the study area).

The difference in wind damage sustained among the oak species in this study may provide insight into the ecology of upland oaks on the Plateau and help explain the greater longevity of white oak compared to the other dominant oaks. Of the four major oak species, scarlet oak sustained the most damage and white oak the least, with chestnut oak and black oak intermediate. The storm damaged over 31 percent of the scarlet oak basal area, with a high percentage of that loss due to stem breakage. Previous studies have also found a high probability of stem breakage in scarlet oak (Cremeans and Kalisz 1988, Romme and Martin 1982). White oak, which had even more basal area than scarlet oak before the storm, only lost 1.2 percent of its basal area (fig. 3). While several factors might explain the low white oak damage in this study, including an inherent ability of white oak to withstand higher winds, it is possible that the smaller average size of the white oaks may explain the results. The average pre-storm diameter of white oak was 22 cm, below both the average pre-storm diameters of the other oaks (29 to 38 cm) and the 32-cm average diameter of stems damaged by the storm (fig. 2).

The hypothesis at the onset of this study was that thinned hardwood stands and hardwood buffer strips would show more damage than the unthinned, mature forest. It was thus surprising that the thinned hardwood areas actually sustained less damage/ha (2.0 m<sup>2</sup>) than the unthinned, mature forest (3.1 m<sup>2</sup>). Evidence from the literature is mixed, with some studies indicating increased damage in thinned areas and others showing increased damage in unthinned mature forests. Everham and Brokaw (1996) concluded that a key factor may be the timing of a thinning relative to a wind disturbance. They noted that more damage was generally associated with more recent thinnings. Following their reasoning, however, the damage in this study should have been higher in the thinned than unthinned stands because the thinning was completed less than 1 month before the storm. Several factors may have contributed to the reduced damage in the thinned areas of the current study: (1) because the trees were leafless, and the thinned areas were more open to wind movement, the trees provided less wind resistance; (2) the trees left after the thinning were mostly codominant stems that were already reasonably wind firm; and (3) the mature hardwood forest was located on the west side of the ridge where trees were more directly exposed to the force of the oncoming storm.

More direct wind damage than indirect damage in this storm and more uprooted than broken stems are consistent with the results in other studies (Clinton and Baker 2000, Coates 1997, DeWalle 1983). In their Southern Appalachian study, Clinton and Baker (2000) also found that indirectly damaged trees were much smaller in size than directly damaged trees (mean diameters: 16.6 versus 32.6 cm). While the difference between indirectly and directly damaged trees was slightly less in this study (22.6 versus 32 cm), it supports the conclusion that direct wind damage impacted mostly canopy trees while indirect wind damage occurred primarily to smaller stems that were either in the path of larger falling trees or attached to the rootballs of the uprooted stems.

Uplifted root systems disturbed, on average, 0.5 percent of the soil surface across the blowdown. In their study of pit and mound distribution on the Cumberland Plateau in Kentucky, Cremeans and Kalisz (1988) estimated that pits and mounds covered 0.4, 1.1, and 2.4 percent of the land surface on ridges, slopes, and coves, respectively. In our study of a single storm

event, soil disturbance ranged from 0.5 to 2.0 percent of the soil surface. The cumulative effects of the uprooting of trees from many storms can have a significant impact on the spatial variability of forest soils and in the mixing of surface and subsurface soils. While the mean thickness of the soil layer uplifted with the roots in this study was 71.3 cm, a number of uprooted trees upturned soil to a depth of 2 m.

Wind damage was not spatially uniform across the blowdown in our study. Foster and Boose (1992) found that the spatial pattern of wind damage in forested landscapes in central Massachusetts was controlled by vegetation height and site exposure, with site exposure most strongly influenced by slope angle and orientation with respect to wind direction. In this study, damage west of the highway, where the storm was moving toward the high point of the ridge, was highest on the windward (WSW) shoulders of the ridge and least in the drainages (fig. 7). Everham and Brokaw (1996) noted, however, that the relationship between topography and wind damage can be quite complex, with wind sometimes causing greater damage in valleys than on ridges.

Interpreting damage patterns on the east side of the highway is complicated by the presence of small pine stands, gaps created from past harvests, and variations in stem density from past management activities. In addition, the storm's path east of the highway was one of progressively decreasing elevation. Damage east of the highway was highest within pine stands and adjacent to the windward facing edges of the clearcuts. Damage adjacent to the clearcut was not unexpected, as a number of studies have shown that clearcuts and even natural canopy gaps can deflect or concentrate the path of the wind (Everham and Brokaw 1996). DeWalle (1983) also noted a high degree of damage adjacent to clear-cuts and identified different factors that contributed to the damage. He determined that damage was increased where either (1) pines were a component of the stand, or (2) the soil was poorly drained. Both of these components were typical of the damaged areas east of the highway in our study, where increased damage was typical of both pine areas and poorly drained soils of stream drainages. DeWalle's study also indicated that the windward-facing edge of a clearcut seemed to sustain the greatest damage, a pattern apparent in our study from the large number of downed trees along the northern and eastern edges of the clearcuts.

## CONCLUSIONS

Average diameter of damaged stems did not differ among stand types (32 cm across all sites). This diameter was almost 10 cm greater than the pre-storm average and indicated that damage was more prevalent in the larger trees that may have occupied dominant canopy positions.

By far the greatest basal area damage occurred in the pine stands, which covered only 8 percent of the total impacted area but sustained 29 to 30 percent of the damaged stems and basal area. Among the hardwood-dominated stands, basal area losses were higher west of the ridgeline, in the mature hardwood forest than east of the ridgeline in either the thinned hardwoods or the unthinned hardwood buffers. Very little damage occurred to the reserve trees in the clear-cut areas.

Over 75 percent of damaged basal area belonged to four species: scarlet oak, eastern white pine, chestnut oak, and

black oak. Oaks composed 93 percent of the damaged basal area in the mature hardwood stand and 60 percent across the entire study area. Among the oaks, damage was greatest to scarlet oak, intermediate to chestnut oak and black oak, and least to white oak.

Direct wind effects accounted for 72 percent of stems damaged and 85 percent of the total basal area damage across all sites. The majority of the damaged stems were uprooted rather than broken (84 to 85 percent), with scarlet oak exhibiting the highest susceptibility to breakage (29 percent of its basal area loss). Disturbed soil averaged 0.5 percent of the surface area (range: 0.4 to 2.0 percent), and while the mean thickness of the uplifted soil was 71.3 cm, some roots upturned soil layers nearly 2-m thick.

Wind damage patterns differed on the west and east sides of the highway, which was positioned along a topographic ridge. Greatest damage on the west side of the highway was associated with the windward slopes of this ridge. Damage east of the highway (on the east side of the ridge) was concentrated in remnant pine stands and along the leeward (eastern) margins of the clear-cut areas.

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## LITERATURE CITED

- Clinton, B.D.; Baker, C.R. 2000. Catastrophic windthrow in the southern Appalachians: characteristics of pits and mounds and initial vegetation responses. *Forest Ecology and Management*. 126: 51-60.
- Coates, K.D. 1997. Windthrow damage 2 years after partial cutting at the Date Creek silvicultural systems study in the Interior Cedar-Hemlock forests of northwestern British Columbia. *Canadian Journal of Forest Research*. 27: 1695-1701.
- Creameans, D.W.; Kalisz, P.J. 1988. Distribution and characteristics of windthrow microtopography on the Cumberland Plateau of Kentucky. *Soil Science Society of America Journal*. 52: 816-821.
- DeWalle, D.R. 1983. Wind damage around clearcuts in the ridge and valley province of Pennsylvania. *Journal of Forestry*. March: 158-159,172.
- Everham, E.M.; Brokaw, N.V.L. 1996. Forest damage and recovery from catastrophic wind. *The Botanical Review*. 62(2): 113-185.
- Foster, D.R.; Boose, E.R. 1992. Patterns of forest damage resulting from catastrophic wind in central New England, USA. *Journal of Ecology*. 80: 79-98.
- Romme, W.H.; Martin, W.H. 1982. Natural disturbance by tree falls in old-growth mixed mesophytic forest: Lilley Cornett Woods, Kentucky. In: Muller, R.N., ed., *Proceedings of the forth central hardwood forest conference*. Lexington, KY: University of Kentucky Press: 367-383.
- Smalley, G.W. 1982. Classification and evaluation of forest sites on the mid-Cumberland Plateau. Gen. Tech. Rep. SO-38. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 58 p.
- Smalley, G.W.; Myers, B.L.; Humphries, T.L., Jr. 2001. Landtypes of the University of the South. [http://www.sewanee.edu/Forestry\\_Geology/OFM\\_Page/smalley.htm](http://www.sewanee.edu/Forestry_Geology/OFM_Page/smalley.htm). [Date accessed: February 1, 2005].
- Troutman, T. 2004. National Weather Service, Huntsville, AL Weather Forecast Office. <http://www.srh.noaa.gov/hun/tornadodatabase/tornado.php?type=tornado&name=tornado337>. [Date accessed: February 1, 2005].

# CROP TREE RELEASE OPTIONS FOR YOUNG HARDWOOD STANDS IN NORTH CAROLINA

Jamie L. Schuler and Daniel J. Robison<sup>1</sup>

## Poster Summary

### INTRODUCTION

Harvesting southern hardwood forests using even-aged reproduction methods commonly regenerate new stands with 20,000 to 50,000 stems per acre. Overstocking and an overabundance of non-commercial tree species are considered major constraints to growing productive and valuable hardwoods. Crop tree release practices have been promoted as an efficient way of thinning young, overstocked stands since only select individuals are released. Efficiency is gained by releasing only those trees to be carried through to the end of the rotation, leaving areas with no desirable crop trees untreated.

### METHODS

Three mixed species, even-aged upland Piedmont hardwood stands on the North Carolina State Hill Demonstration Forest in Durham Co., NC, had completed 6, 8, and 11 growing seasons at the time of treatment. Site indices for the three sites were  $Sl_{50} 75 \pm 5$  feet for red oak. Release treatments specifically targeted yellow-poplar (*Liriodendron tulipifera* L.), red oak (*Quercus rubra* L., *Q. falcata* Michx., and *Q. coccinea* Muench.), and white oak (*Q. alba* L.) species. The release treatments imposed in the spring 1999 were as follows: (1) CON (control); (2) M (manual release)- the mechanical release of selected crop trees to a radius of 6 feet or 30 percent of crop tree height, whichever was greater; (3) 2M (repeated manual release)- same as in treatment M but also repeated after two growing seasons; (4) M+H (manual and herbicide release)- same as in treatment M, plus a 50 percent Garlon in water application to the cut stumps; and (5) M+H+F (manual and herbicide release plus fertilization)- same as in treatment M+H, plus the equivalent of 150 pounds N per acre and 50 pounds P per acre around each study tree.

Several recent studies performed by the Hardwood Research Cooperative (Newton and others 2002, Schuler 2005) have demonstrated substantial responses to fertilization on Piedmont and Upper Coastal Plain hardwood stands. In response to these new data, the initial treatments were modified in the Spring 2002 by adding 150 pounds N per acre to the M, 2M and M+C+F treatments.

### RESULTS AND DISCUSSION

After 6 years, significant treatment effects were noted at all three sites (fig. 1). In general, diameter growth of all three species responded positively to release. The treatments and

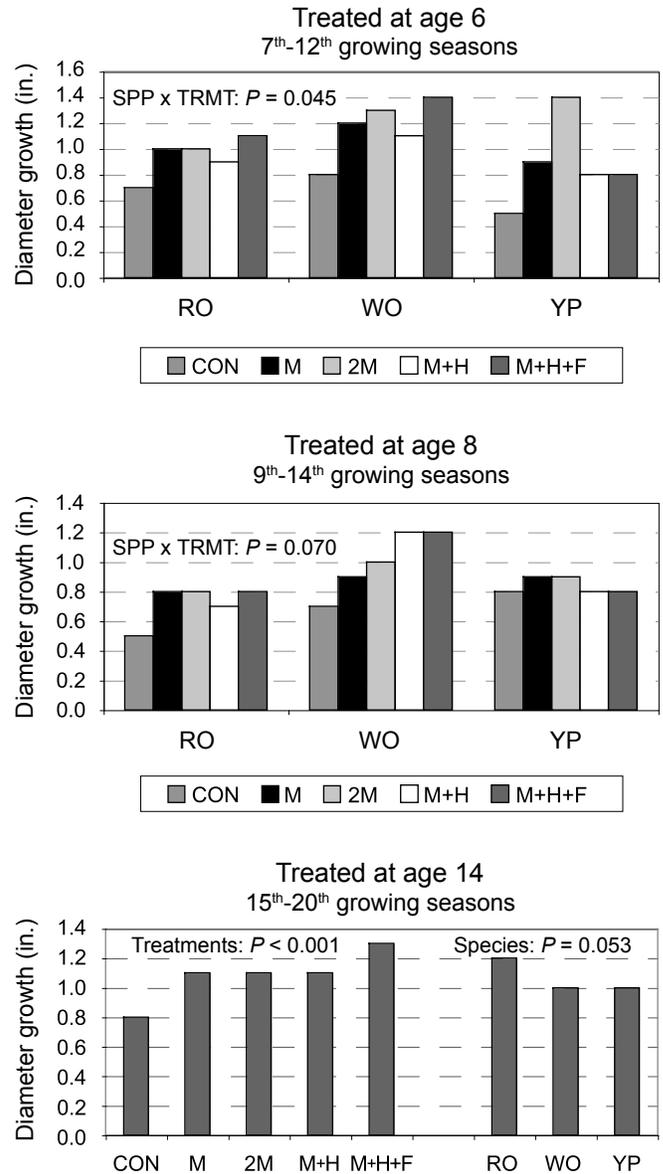


Figure 1—Six year diameter growth response of young upland hardwood stems to crop tree release treatments. Note: Main effects are reported when species x treatment interactions were not significant at  $P=0.10$ . Treatment descriptions are given in the text. RO = red oak, WO = white oak, YP = yellow-poplar.

<sup>1</sup> Assistant Director and Associate Professor/Director, respectively, Hardwood Research Cooperative, North Carolina State University, Raleigh, NC 27695-8008.

species interacted on two of the three sites (Ages 6 and 8). Yellow-poplar showed a greater growth response on the youngest site (Age 6) relative to the control. The 2M treatment provided the best diameter growth across the three sites for yellow-poplar. For the oak species, the M+H+F treatment produced the largest diameter response at each site. Both oak species were responsive at each age.

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#### **LITERATURE CITED**

- Newton, L.P.; Robison, D.J.; Hansen, G.; Allen, H.L., 2002. Fertilization and thinning in a 7 year-old hardwood stand in eastern North Carolina. In: Outcalt, K.W., ed. Proceedings of the 11<sup>th</sup> biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 193-195.
- Schuler, J.L. 2005. Stand dynamics and ecological constraints on growth in young naturally regenerated hardwood stands. Raleigh, NC: North Carolina State University. 149 p. Ph.D. dissertation.

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