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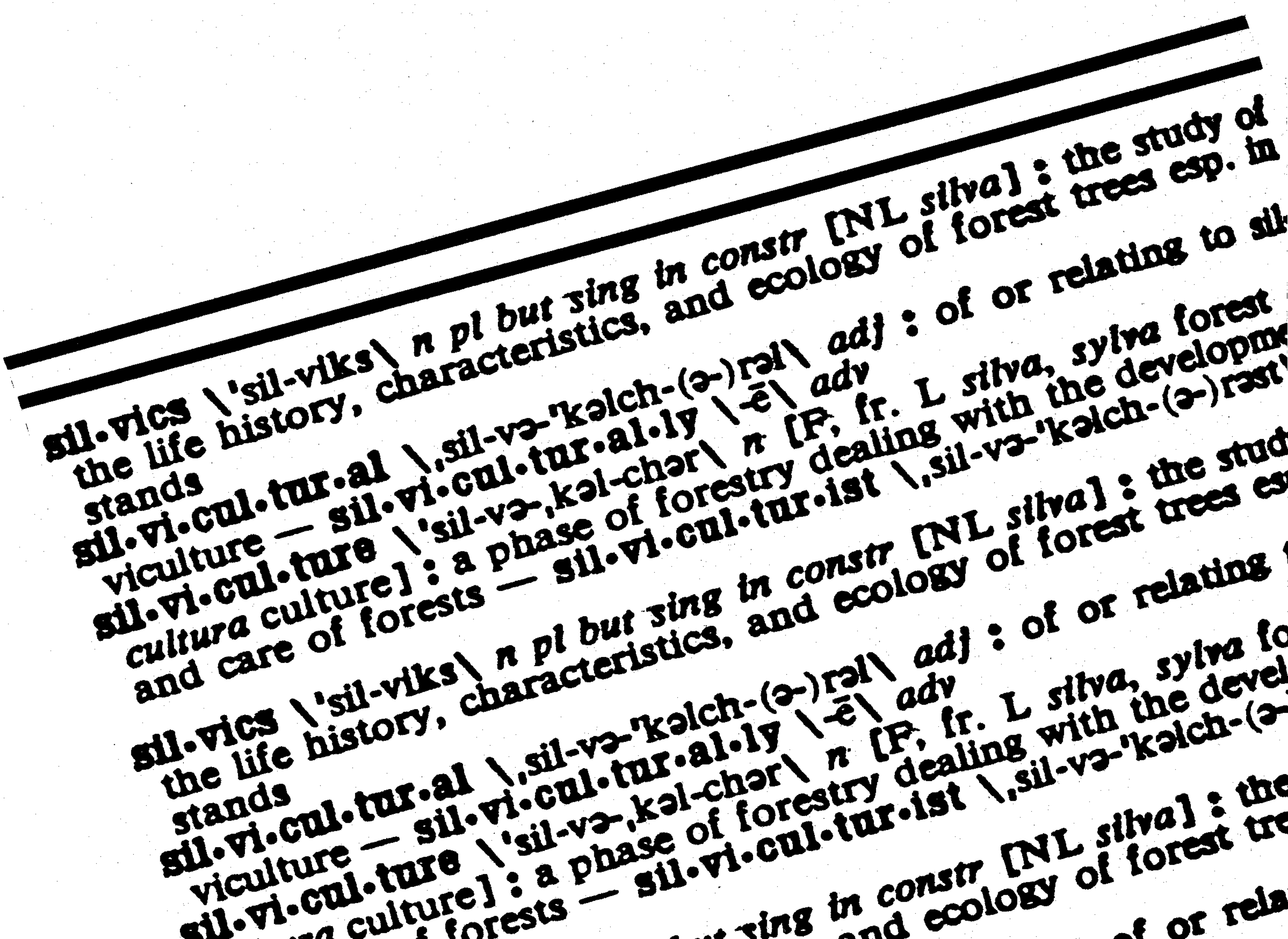
Shreveport, Louisiana
February 16-18, 1999



List of Abbreviations (GPO Style Manual 1984)

Metric unit letter symbols are set lowercase unless the unit name has derived from a proper name, in which case the first letter of the symbol is capitalized. The exceptions are the letter L for liter and M for million. The same form is used for singular and plural. A space is used between a figure and a unit symbol except in the case of the symbols for degree, minute, and second of plane angle.

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Length

km	kilometer
hm	hectometer
dam	dekameter
m	meter
dm	decimeter
cm	centimeter
mm	millimeter

Area

km^2	square kilometer
hm^2	square hectometer
dam^2	square dekameter
m^2	square meter
dm^2	square decimeter
cm^2	square centimeter
mm^2	square millimeter

Volume

km^3	cubic kilometer
hm^3	cubic hectometer
dam^3	cubic dekameter
m^3	cubic meter
dm^3	cubic decimeter
cm^3	cubic centimeter
mm^3	cubic millimeter

Weight

kg	kilogram
hg	hectogram’
dag	dekagram
g	gram
dg	decigram
cg	centigram
mg	milligram
μg	microgram

Land area

ha	hectare
a	are

Capacity of containers

kL	kiloliter
hL	hectoliter
daL	dekaliter
L	liter
dL	deciliter
CL	centiliter
mL	milliliter

The following forms are used when units of English weight and measure and units of time are abbreviated, the same form of abbreviation being used for both singular and plural:

Length

in.	inch
ft	foot
yd	yard
mi	mile (statute)

Area and volume

in^2	square inch
in^3	cubic inch
mi^2	square mile
ft^3	cubic foot

Time

yr	year
mo	month
d	day
h	hour
min	minute
s	second

Weight

gr	grain
dr	dram
oz	ounce
lb	pound
cwt	hundredweight
dwt	pennyweight
ton(s)	not abbreviated

Capacity

gill(s)	not abbreviated
Pt	pint
qt	quart
gal	gallon
pk	peck
bu	bushel
bbl	barrel

Abbreviations not in GPO:

ac	acre
d.b.h.	diameter at breast height
Mg	metric ton (old abbreviation was t)

Proceedings of the Tenth Biennial Southern Silvicultural Research Conference

Edited by
James D. Haywood

Shreveport, Louisiana
February 16-18, 1999

Hosted by
Stephen F. Austin State University, Arthur Temple College of Forestry
USDA Forest Service, Southern Research Station

Sponsored by
Stephen F. Austin State University, Arthur Temple College of Forestry
Historically Black Colleges and Universities Program
National Association of Consulting Foresters of America
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PREFACE

The Tenth Biennial Southern Silvicultural Research Conference was held February 16-18, 1999, at the Holiday Inn Financial Plaza in Shreveport, LA. This conference was the latest in a series of meetings designed to provide a forum for the exchange of research information among silviculturists and researchers in related areas, research coordination, review of research in progress, and new approaches or techniques of general interest. The conference consisted of four concurrent sessions over 2 days, two poster sessions, and three concurrent field tours on the third day. Presentations covered a wide array of topics related to silvics and silviculture. They emphasized research in pine, hardwood, and mixed-species forests in the areas of upland hardwood management, intensive management of bottom-land hardwoods, hardwood and bottom-land regeneration, site preparation for pine establishment, natural and artificial regeneration of pines, pine fertilization, biometrics, water and soil hydrology, insects and diseases, landscape management, and ecological relationships. Field trips included visits to (1) the Crossett Experimental Forest, USDA Forest Service; (2) the Hill Farm Research Station, LSU Agricultural Experiment Station; and (3) the Bayou Dorcheat Management Area, International Paper Company, managed cooperatively with the Arkansas Natural Heritage Commission. The conference was attended by over 350 people and had 141 oral and poster presentations. Daniel D. Angel, President, Stephen F. Austin State University; and Brian P. Oswald, Arthur Temple College of Forestry, made the welcoming remarks to the conference.

Sponsors for the conference included Stephen F. Austin State University, Arthur Temple College of Forestry; Historically Black Colleges and Universities; National Association of Consulting Foresters of America; National Association of Professional Forestry Schools and Colleges; National Hardwood Lumber Association; Society of American Foresters; Southern Group of State Foresters; Southern Industrial Forest Research Council; and the USDA Forest Service, Southern Research Station. Each sponsor provided one or more representatives to the steering committee. This committee worked numerous hours to review abstracts that were submitted by authors, establish the program for oral and poster presentations, and make all necessary arrangements for the conference. Steering committee members included:

Stephen F. Austin State University, Arthur Temple College of Forestry
- Brian Oswald (Local Arrangements Chair)

USDA Forest Service, Southern Research Station
- Robert Doudrick (Conference Chair), Asheville, NC
- James Haywood (Program Chair), Pineville, LA
- Tom Waldrop (Past Program Chair), Clemson, SC
- James Guldin, Hot Springs, AR
- Mike Shelton, Monticello, AR
- Ken Outcalt (Poster Session), Athens, GA
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- Doug Back, Chartered Foresters, Quincy, FL

National Hardwood Lumber Association
- Dan Meyer, Memphis, TN

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- Brian Lockhart (Conference Evaluations), University of Arkansas at Monticello
- Bob Wittwer, Oklahoma State University
- Wayne Clatter-buck, University of Tennessee
- Dave Smith, VPI & State University

Society of American Foresters
- Vick Ford (Continuing Education Credits Coordinator), Westvaco, Rubert, WV

Southern Industrial Forest Research Council
- Bert Cregg, Union Camp Corporation, Savannah, GA
- Dick Daniels, Westvaco, Summerville, SC

Partial funding for the many conference expenses was provided by the Southern Research Station and Louisiana Tech University. The Southern Research Station is especially grateful to Stephen F. Austin State University, Arthur Temple College of Forestry, for their diligence in handling the fiscal responsibilities of this meeting as well as funding their efforts. Special thanks to Tom Waldrop for his advice and guidance; Brian Oswald and Joyce Westmoreland for many hours of tedious work in making hotel and audio-visual arrangements and handling registration; the students from Stephen F. Austin State University who worked the audio-visual equipment, ran errands, and drove buses-Sandra Rideout, Shelley Gardner, Kelly Scott, Hayden Evans, Jacob Clavit, Bryan McElvany, Brett Williams, and Danny Johns; Kenneth Outcalt, Patricia Outcalt, and Mike Allen for organizing, setting up, and taking down the poster sessions; John Adams for organizing the field tours and Brian Lockhart, Terry Clason, Mike Shelton, and Jim Guldin for being tour hosts; Brian Lockhart for compiling the conference evaluations; Vick Ford for keeping tract of the SAF CFE Credits; Charlene Howell and Beulah Sketo for ordering supplies or working registration; and Phil Cannon for organizing the sports events.

Special recognition is given to the panel of moderators who led each session-David Van Lear, Dave Smith, Larry Walker, Sam Foster, Bert Cregg, Phil Cannon, David Lenhart, John Rennie, Graeme Lockaby, Tom Fox, John Hodges, Dean Gjerstad, Jimmie Yeiser, David Kulhavy, Jim Guldin, Nancy Herbert, and Wayne Clatterbuck.

Special thanks goes to Bertha McAlister who did the word processing needed to get the papers into the proper format.

James D. Haywood
Program Chair
Southern Research Station, Pineville, LA

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Moderators:

DAVID VAN LEAR
Clemson University

and

DAVE SMITH
Virginia Polytechnic Institute and State University

VEGETATIVE COMPOSITION OF RIPARIAN FOREST ONCE DOMINATED BY AMERICAN CHESTNUT[1]

David B. Vandermast and David H. Van Lear[2]

Abstract-American chestnut (Casfanea denfafa) has often been described as dominating mesic midslopes and xeric ridges in the southern Appalachians but its former importance in riparian forests of the region has not been documented. Numerous remnant stumps in riparian forests suggest it played an important role in these sites as well. Riparian forests in the southern Appalachians may contain abundant and diverse herbaceous vegetation but are often dominated by Great Rhododendron *(Rhododendron maximum).* Previous studies suggested, among other reasons, that the spread of rhododendron is correlated to the demise of chestnut earlier this century. This paper characterizes the importance of American chestnut in pre-blight riparian forests in the southern Appalachians and describes current composition and structure of the understory surrounding the remnant stumps. Density of rhododendron cohorts is related to logging disturbance, suggesting that chestnut salvage operations and other logging activities played a major role in the spread of rhododendron thickets in riparian forests.

INTRODUCTION

Prior to the chestnut blight **(*Cryphonectia parasitica*),** American chestnut (Casfanea ***dentata*** (Marsh.) Borkh.) was the most common overstory tree from the southern New England states to northern Georgia, Alabama and Mississippi (Russell 1987). In the southern Appalachians it reached its greatest size (Ayres and **Ashe** 1902, Sargent 1933) and stand density, occasionally approaching 100 percent of overstory composition of some stands (Agrawal and Stephenson 1995, Spurr 1956). It most commonly grew in association with other trees, rarely by itself (Zon 1904). On average, the tree probably represented roughly 40-45 percent of the canopy trees in southern Appalachian forests (Keever 1953, Reed 1905). It was considered the predominant tree of the Blue Ridge Mountains (Ashe 1919).

Habitat requirements of the tree have been listed as deep, loose, moist but well-drained, acid soils which are not necessarily rich in nutrients (Russell 1987, Society of American Foresters 1926, Zon 1904). Chestnut is thought to have been strongly calciphobic (Russell 1987). Nor was it found on poorly drained alluvial soils (Hawley and Hawes 1925). Although the tree was restricted to the Piedmont and mountains in the southern part of its range (Russell 1987), it reportedly grew throughout southern New England and was even reported overhanging salt water (Metcalf 1914).

Due to sensitivity to frost, glaze and ice (Croxton 1939, Parker and others 1993, Zon 1904) it was thought to avoid bottoms of ravines and valleys, and wet or cold soils (Zon 1904). It is most often listed as a dominant species on ridges (Abrams and Ruffner 1995) and mid-slope areas (Reed 1905, Whittaker 1956, Zon 1904). While chestnut has been recognized as a member of cove forests (Ayres and Ashe 1902, Lorimer 1980), and is known to contribute large woody debris to streams (Hedman and Van Lear 1995, Hedman and others 1996, Muller and Liu 1991), it has never been quantitatively identified in riparian forests.

Trees commonly associated with chestnut included oaks: chestnut **(*Quercus prinus*)**, northern red (Q. ***rubra***), white (Q. ***alba***), black *(Q. **velutina**)*, and scarlet (Q. *coccinea),* as well as yellow-poplar ***(Liriodendron tulipifera)***, hickories **(*Carya*** spp.), black gum **(*Nyssa sylvatica*)**, black birch **(*Betula lenta*)**, basswood (***Tilia*** ameficana), sugar maple ***(Acer** saccharum),* and beech **(*Fagus*** *grandifolia)* (Foster and **Ashe** 1908, Society of American Foresters 1926). Braun (1950) noted Rosebay rhododendron and mountain-laurel **(*Kalmia latifolia*)** shrub synusia were common in oak-chestnut forests. There is some evidence that downed chestnut debris is important in the regeneration of black birch, a mixed mesophytic species (Collins 1962, Good and Good 1972). Chestnut associated with far more trees and shrubs in the southern Appalachians than in the northern part of its range (Frothingham 1924).

Many researchers have studied the change in forest composition and structure since the demise of American chestnut (Agrawal and Stephenson 1995, Keever 1953, McCormick and Platt 1980, Retan 1918, Woods and Shanks 1959). These studies have all focused on replacement of chestnut by other canopy tree species with the findings split between evidence for succession to an oak-hickory forest and an oak association forest. Rarely have effects of chestnut demise on the shrub and herb synusia been studied (Keever 1953). Few studies have considered the ecological significance of the loss of chestnut (Shugart and West 1977).

Chestnut was an important species in any area in which it grew due to its prolific sprouting ability from the root crown (Paillet 1982, Zon 1904), growth rate (Ayres and Ashe 1905, Graves 1905), overall growth in height (Zon 1904), longevity (Zon 1904), durability (Scheffer and Cowling 1966, Spalding 1929), tolerance to shade when young (Paillet 1982, Zon 1907), ability to grow on poor soil (Zon 1904), and mast production (Zon 1904). A recent study indicates chestnut is more drought tolerant than oaks, maintaining greater tissue elasticity and leaf turgor at a low relative water content (Abrams and others 1990). Latham (1992) found chestnut had the greatest competitive ability over the broadest range of resource combinations when compared to co-occurring tree species. The demise of chestnut as a canopy tree has been implicated in the spread of rhododendron thickets in the southeast (Phillips and Murdy 1985). The role of this tree as an ecological dominant (Odum 1971) and the effects of

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February **16-18, 1999.**

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the eventual loss of decaying chestnut wood in riparian ecosystems are unknown.

OBJECTIVE

The objective of this paper is to document American chestnuts presence in riparian forests of the southern Appalachians and provide a preliminary analysis of the vegetative community developing following the chestnut blight.

METHODS

Sites

Field reconnaissance and USDA Forest Service data were used to locate southern Appalachian riparian forest sites containing identifiable American chestnut stumps. For purposes of this study, riparian forest was considered to be an area extending 30.5 meters up slope on either side of a perennial steam.

Four sites were located in the Blue Ridge Physiographic Province of the southern Appalachians. They were: Slatten Branch, Andrew Pickens Ranger District, Sumter National Forest, South Carolina; Thomas Creek on Rabun Bald, Tallulah Ranger District, Chattahoochee National Forest, Georgia; headwaters of the Tallulah River, Southern Nantahala Wilderness, Wayah Ranger District, Nantahala National Forest, North Carolina; Little Santeetlah Creek, Joyce Kilmer/Slickrock Wilderness, Cheoah Ranger District, Nantahala National Forest, North Carolina.

Two of the sites (Thomas Creek and Tallulah River) showed signs of chestnut salvage logging activity in the past. Old logging roads were present and while chestnut stumps were present, there was little chestnut coarse woody debris on the ground.

The other two sites (Slatten Branch and Little Santeetlah Creek) are considered remnant old-growth stands. Carlson (1995) lists Slatten Branch as a high quality old-growth stand and Lorimer (1980) cites the remoteness of the Little Santeetlah Creek area as a reason it was never cut. Both of these sites contain the classic indicators of an old-growth forest and they contain abundant downed chestnut debris which indicates a lack of salvage logging in the area.

American Chestnut Sampling

Once a site was located, each chestnut stump was numbered, measured for diameter at ground line, and where possible, diameter breast height (dbh). Microsite descriptions such as aspect, slope and stump distance from stream were recorded. For trees where no dbh measurement was possible, estimates were obtained by formulating a regression equation from trees that did have a measurable dbh. Diameters were then used to calculate relative basal areas as a measure of the importance of chestnut on each site. Differences in diameter and basal area among sites were analyzed using an Analysis of Variance (ANOVA) program (SAS 1987).

Vegetation Sampling

Fifty-eight plots were located on the four sites for the purpose of vegetation sampling. Ten plots were located on Slatten Branch, 19 on Thomas Creek, 18 on Tallulah River, and 11 on Little Santeetlah Creek.

Ten percent of chestnut stumps on each site were randomly selected for vegetation sampling. Trees, saplings, seedlings and shrubs were sampled using the Braun-Blanquet method on 0.04 ha plots. Trees were measured for dbh, which was used to calculate basal area for comparison between sites and to chestnut basal area. Herbaceous vegetation was intensively sampled in five 1-m^2 quadrats randomly selected from a 7x7 m^2 area around the stump. The number of aboveground stems was tallied. Data from sites with heavy rhododendron coverage was then compared to data from sites with little or no rhododendron.

Rhododendron Sampling

Rhododendron density and age data were obtained by counting the number of stems within each 0.04 ha plot. Differences in density for unlogged sites were compared to logged sites with ANOVA.

RESULTS AND DISCUSSION

American Chestnut

A linear total of 3.1 kilometers stream was surveyed on the four southern Appalachian riparian forest sites. Along this distance, 589 American chestnut stems were identified on 16.4 ha for an overall average of 35.9 chestnut trees/ha. Stems of chestnut tallied at each site show the species to have had a range of densities from 25 to 49 trees/ha. At this abundance level chestnut would have represented between 6.1 and 11.7 percent of the forest when compared to current tree densities (table 1). As a consequence of 60 years of decay, only large chestnut trees were found and recorded. It is likely that these data are conservative and under represent actual chestnut abundance in these forests. Additionally, current live stem densities are probably higher

Table l-Density and average diameter (d.b.h.) of American chestnuts and currently living trees on four Southern Appalachian rlparian forest sites

Site	Chestnut	Live	Chestnut d.b.h.	Live d.b.h.
	Stems/ha	*Stems/ha*	*cm*	*cm*
Slatten Branch	30.4	331.1	56.2b	26.2a
Thomas Creek	48.7	414.9	43.9c	26.9a
Tallulah River	39.1	440.1	53.6b	27.6a
Little Santeetlah	25.4	415.5	73.7a	28.6a

than in pre-blight times as the forests are still recovering from the loss of chestnut and, in two cases, logging.

A better representation of the importance of chestnut to pre-blight riparian forests is a comparison of the dbh and basal area values of chestnut to current forest diameter structure. Average chestnut dbh was 1.6 to 2.6 times larger than the average dbh of live trees on each site (table 1). Even taking into account that the current forest is denser, with relatively smaller dbh values than in pre-blight times, chestnut was probably still the largest tree in these riparian forests (Ayres and Ashe 1902, Zon 1904). Basal area analysis also shows chestnut to be the dominant tree in these forests. Table 2 shows chestnut basal area per stem to be 2.5 and 5.4 greater than the average basal area of live stems. Chestnut basal area ranged from 8.4 to 12.3 m^2/ha, suggesting that chestnut represented between 25 and 40 percent of the basal area in these stands if basal area of the previous riparian forests was similar to current conditions. This estimate is similar to that of Keever (1953).

Numerous chestnut stumps in the riparian forest have cat-faces, fire scars, and charcoal remains indicating fire was a factor.

Vegetation Analysis
Rhododendron was the predominant plant on each of the four sites occurring in over 80 percent of plots (table 3). Rhododendron thicket densities were significantly (p=0.01) greater on the two logged sites than on the two unlogged sites, although stem densities among sites were not significantly different. Stem densities on Thomas Creek and Tallulah River were 1378.8 and 1524.6/ha, respectively. In comparison, mean stem densities on Slatten Branch and Little Santeetlah Creek were 800.6 and 726.5/ha, respectively (table 3).

More importantly, the percent of plots where rhododendron Importance Value (IV) was greater than 50 (on a 0 to 100 scale) was 45.5 on Little Santeetlah Creek and 50 on Slatten Branch, the two old-growth sites. In comparison, the percent of plots with rhododendron IV>50 on cutover sites was 73.7

Table 2-Mean basal area (cm^2) of American chestnuts and live stems and per hectare (m^2) on four Southern Appalachian rlparian forest sites

	Basal area			
Site	Chestnut	Live	Chestnut	Live
	—•— Per stem ——		*- - - - Per hectare - - - - -*	
Slatten Branch	2918.6b	686.1a	8.88	22.70
Thomas Creek	1717.7c	693.2a	8.37	28.76
Tallulah River	2555.0b	748.7a	9.99	32.95
Little Santeetlah	4843.8a	902.4a	12.3	37.49

Analysis of the mean dbh and basal area of chestnut stems from old-growth forest shows them to be significantly larger than those from cutover forests. Little Santeetlah Creek chestnuts were significantly larger than the other three sites. Chestnuts from Slatten Branch and Tallulah River were significantly larger than those from Thomas Creek but not than each other (tables 1 and 2). Live stem dbh values were not significantly different between sites, although basal area values were (tables 1 and 2).

Although it no longer exists as an overstory tree, chestnut continues to contribute to ongoing ecological processes of these forests. It is one of the dominant components of coarse (CWD) woody debris on the forest floor in areas where there was no salvage logging. As CWD, chestnut provides wildlife habitat (McMinn and Crossley 1996) and affects soil formation (Harmon and others 1986, Kimmins 1987). Chestnut stumps and downed debris provide a litter-free substrate for the germination of rhododendron and birch. Chestnut logs sometimes dominate CWD loadings in southern Appalachian streams (Hedman and others 1996).

on Thomas Creek and 66.7 on Tallulah River, suggesting that herbaceous diversity and tree regeneration could be limited on cutover sites where rhododendron reestablishes itself or invades rapidly. Rhododendron seed is very small and it seems unlikely that it could germinate and survive on a forest floor layered with leaf litter. Supporting this view is the observation that on unlogged sites rhododendron does not seem to be expanding its range or increasing its density as rapidly.

The dominant live tree species in these riparian forests was eastern hemlock (*Tsuga canadensis).* Hemlock was also the most important regenerative element in rhododendron thickets. Its importance value on many rhododendron-influenced plots was 100 percent, meaning it was the only tree species in the sapling or seedling stage of development.

Herbaceous diversity was affected by rhododendron presence. Little of the vegetation found in open forest conditions exists in rhododendron thickets. The most

Table 3-Rhododendron stem densities on two cutover (Thomas Creek and Tailuiah River) and two uncut (Siatten Branch and Little Santeetiah) sites in Southern Appalachian riparian forests

Site	Mean	Mean	Plots with stems	Plots (IV >50)
	Stems/plot	*Stems/ha*	*Percent*	
Siatten Branch	**32.4a**	800.6	90.0	50.0
Thomas Creek	**55.8a**	1378.8	89.5	73.7
Talluiah River	**61.7a**	1524.6	88.9	66.7
Little Santeetlah	**29.4a**	726.5	81.8	45.5

abundant herbs in rhododendron thickets were galax (*Galax aphylla*) and false ginger (*Hexastylis arifolia*). One rare species, an orchid called Appalachian twaybiade (*Listera smallii*), was found only in dense rhododendron thickets and only on the Taliuiah River site. Although its fidelity to rhododendron thickets was high, its frequency was low. Vegetative diversity and tree regeneration in all classes and among species was significantly higher on sites without rhododendron.

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OAK REGENERATION FOLLOWING THREE CUTTING TREATMENTS ON MOUNTAIN SLOPES IN NORTHERN ALABAMA[1]

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Abstract-Early regeneration success of upland oaks (*Quercus* spp. L.) was compared for three regeneration cutting treatments in the Sandstone Mountain Region of northern Alabama. Two 4-acre replications each of block clearcutting, strip cutting, and deferment cutting were established on north-facing slopes. The three harvesting treatments were applied in midsummer. Regeneration subplots were reinventoried in both the first and second autumns following harvest. Major oaks present were chestnut oak (*Q. prinus* L.), white oak (*Q. alba* L.), and northern red oak (*Q. rubra* L.). Milacre plot stocking of oak reproduction after the second season was related to advance reproduction stocking, topographic position, cutting treatment, harvesting damage, and cover of logging slash. Both small advance reproduction (less than 1 ft tall) and post-harvest germination contributed substantially to the post-harvest stocking of oaks.

INTRODUCTION

Oak-hickory forests cover 35 percent (7.7 million acres) of Alabama's timberland and is the principal forest type in the mountain regions in the northern part of the state (McWilliams 1992). As a group, oaks are highly desirable for landowners of this region, both as timber and for wildlife food production. However, dependable regeneration of oaks is often a problem (Smith 1993).

The objective of this study was to identify important factors that influence early regeneration success of oaks in mountain-slope mixed hardwood stands in northern Alabama. More specifically, we compared regeneration results from block clearcutting, narrow strip clearcutting, and "deferment cutting" (a form of irregular sheltetwood).

METHODS

Study Site

The study site is located on a forest industry tract in Lawrence County, AL, at 35 degrees 25 minutes north latitude. It is in the Sandstone Mountain Forest Habitat Region (Hodgkins and others, 1979). The treatments and measurement plots were placed in an upland mixed hardwood stand located on north-facing ridge shoulders and slopes of a large ridge complex oriented roughly east-to-west. Elevation within treatment areas range from about 650 to 800 ft above mean sea level. Soils are primarily residual from sandstone on the ridge shoulders and some mixture of residuum and colluvium from sandstone or a sandstone-shale mixture on the slopes. Common soil series include Apison, Albertville, Bankhead, Gorgas, Sipsey, and Townley. Slope steepness ranges from less than 5 percent on the shoulders to more than 60 percent on some middle and lower slopes. Narrow benches and short rocky drop offs (less than 10 ft drop) occur on some slopes.

Study Design

Six rectangular treatment blocks of 4 acres (400 by 440 ft) each were established along north slopes of the ridge complex, with the long axis of each block oriented roughly perpendicular to elevation contours (i.e., down slope, south to north). Two replications of each of three harvesting treatments were randomly assigned to the six blocks.

The block clearcutting treatment (CC) consisted of cutting all trees in each block larger than 1.5 inches d.b.h. For the strip clearcutting treatment (SC), all stems larger than 1.5 inches d.b.h. were felled in alternate strips approximately 120 ft wide (uncut strips the same width were left between each cut strip), oriented roughly along contours. For deferment cutting (DC), trees totaling approximately 26 ft^2 per acre of basal area were marked and not cut in the two blocks. Criteria used in marking the reserved trees were that they were evenly distributed and where possible, good quality codominant oaks. For distribution, where oaks were not present, a small number of other species were marked and left. Commercial harvesting was conducted during July and early August. Trees were felled using chain saws and merchantable logs were skidded to loading decks on the main ridge using grapple skidders. Most of the limbing and topping was done at the felling site. Non-merchantable trees greater than 1.5 inches d.b.h. were felled and left.

Pre-Harvest Measurements

Before harvest, a system of reproduction plots was established consisting of three equally spaced belt transects in each block, each 6.6 ft wide, extending from upper to lower edge of the block. Each belt transect was divided into 6.6 ft square segments (1 milacre), and alternate segments (odd-numbered) were established as reproduction measurement plots. Plot corners were marked with pin flags which were later replaced with ½-inch conduit after harvesting was completed. During late spring before harvesting, all trees within each reproduction plot were counted by species and by size classes divided as follows: less than 6 inches tall, 6 inches to 11.9 inches tall, 1 ft to 3 ft tall, taller than 3 ft to 1.5 inches d.b.h., and more than 1.5 inches d.b.h. The d.b.h. was recorded for trees of the largest class. All oaks in each milacre measurement plot were tagged with plastic poultry bands, color-coded so that each individual tree was identifiable. Additionally, all trees of all species in the southwestern quarter of each milacre plot were similarly tagged for identification. The height of each tagged tree taller than 12 inches was recorded.

To characterize the preharvest mid- and overstory trees (those larger than 1.5 inches d.b.h.) of each block, three

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33-ft wide strips, one centered on each reproduction plot transect, were inventoried. Each tree's location was mapped to a grid of quarter-milacre cells, with species, crown classification, and d.b.h. recorded. The heights of trees in every sixth cell were measured.

Slope angle and azimuth were measured for each reproduction plot. Initially all the plots were classified into one of seven microsite classes. These were later consolidated into four major topographic classes, namely lower slope, midslope, upper slope, and ridge shoulder.

Post-Harvest Measurements

After harvesting was completed, soil and site impacts of harvesting were rated for each measurement plot. This included a rating of the degree of litter cover and surface soil movement, amount of bare soil exposed, the amount and depth of rutting from skidder traffic, and the percentage of the plot affected. Logging slash density, percent coverage, and depth were also assessed for each plot.

In autumn after harvest, the reproduction plots were relocated and marked with conduit stakes. Reproduction counts for plots were repeated as for the preharvest inventory. The apparent fate of all tagged stems was determined, and heights remeasured, including that of stump sprouts. All new oak seedlings, and sprouts and new stems of all species in the southwestern plot quarter-milacre were measured, tagged, and recorded. Multiple sprouts from a single stump were treated as one tree, with the tallest stem height recorded. This remeasurement and tagging was repeated during the second autumn, approximately 15 months after harvest.

Data Analyses

In all reproduction data analyses reported here, only the reproduction plots that were located in the cut areas of the SC treatment were used. All plots in the CC and DC treatments were included, for a total of 488 plots. Preharvest mid- and overstory information was derived from the full 25 percent sample of the treatment blocks.

Simple descriptive statistics were computed using PROC's MEANS and FREQ of the Statistical Analysis System (SAS Institute Inc. 1990a). To utilize individual reproduction plot data, presence within each plot of one or more established oaks (those taller than 6 inches) at the 15-month measurement time was the criterion used to assess early regeneration success, with a plot being either "stocked" or "non-stocked".

PROC LOGISTIC of the Statistical Analysis System (SAS) for Windows, release 6.12, was used for performing logistic regression analyses (SAS Institute Inc. 1990b, 1997). Overall model fit was assessed by the chi-square probability from the log-likelihood ratio test (Hosmer and Lemeshow 1989, Menard 1995), by the proportion of variation explained as interpreted by an adjusted R^2 (Nagelkerke 1991), and by the Hosmer and Lemeshow (1989) goodness-of-fit test (SAS Institute 1995).

For stepwise logistic regression analyses, all potential measured explanatory variables available for individual plots were tested in the initial model. These included various variable forms of oak advance reproduction (AR), slope steepness (percent), aspect (cosine transformation of Beers and others 1964), topographic position, treatment type, logging disturbance, and logging slash.

Oak AR (all oak species included) was tested as an explanatory variable in quantitative and binary forms, with various size categories examined. Number of oak AR per plot was tested in three forms: for all sizes combined, for only those taller than 6 inches, and for only those taller than 1 ft. Three binary forms of simple stocking (presence) using the same three size classes were tested. Topographic position and treatment type effects were tested in both "dummy" and ordinal forms. For the ordinal form, topographic position was coded as lower slope = 1, midslope = 2, upper slope = 3, and ridge shoulder = 4. Treatment type was coded as CC = 1, SC = 2, and DC = 3. Logging disturbance and slash were tested both as their separate components (exposed bare soil, amount and depth of rutting; density and depth of slash) and as an ordinal variable reflecting increasing degree of logging disturbance or expected slash impact on shading (where 1 = lowest, 3 = highest).

All of the various forms of each variable were examined in multiple runs of forward stepwise selection. In all cases, the results and apparent interpretations were similar whether the quantitative, dummy, or ordinal form of variables were used. Since the binary (for advance reproduction) and ordinal forms are easier to report and describe, they will be reported in the results.

RESULTS AND DISCUSSION

Pre-Harvest Tree Composition

Results of the tree inventory for all six treatment blocks combined are shown in table 1. Overall, canopy-sized trees (5 inches and larger d.b.h.) averaged 138 stems per acre and 118.3 ft^2 in basal area. Oaks (*Quercus* spp. L.) comprised the largest group, with 39 percent of basal area and 30 percent of stems. Most abundant among these were chestnut (Q. *prinus* L.), white (Q. *alba* L.), and northern red oaks (Q. *rubra* L.). Abundance of the oaks was very high on ridge shoulders and noticeably declined on lower slopes. Hickories, including red (*Carya ova/is* (Wangenh.) Sarg.), shagbark (C. ovata (Miller) K. Koch), and mockernut (C. *tomentosa* (Poiret) Nutt.), comprised 25 percent of basal area and 26 percent of stems. Although rare in Alabama, sugar maple (*Acer saccharum* Marsh.) was present in low numbers (8 per acre) in the overstory, and exclusively on lower slopes (table 1). Most of the oaks appeared to be approximately 65-70 years old, with scattered older trees. Site indexes (age 50) for upland oaks (Olson 1959) ranged from about 65 to more than 100 ft. Ridges and upper slope site indexes were mostly 70-80 ft and mid- and lower slopes 85-l 00 ft.

Composition of the subcanopy/understory stratum (trees 1.5 to 4.9 inches d.b.h.), which averaged 176 stems per acre, was markedly different (table 1). Sugar maple and American beech (*Fagus grandifolia* Ehrh.) were most abundant (21 and 18 percent of stems, respectively), though this abundance was most evident (even dominant) on lower slopes. Oaks, on the other hand, were scarce in the subcanopy/understory, averaging only 5 per acre. Most of these were chestnut oaks on ridge shoulders. Black tupelo (*Nyssa sylvatica* Marshall) and eastern hophornbeam (*Ostrya virginiana* (Miller) K. Koch) were also common in this stratum, both averaging 30 stems per acre (table 1).

Table I-Preharvest basal areas and stem densities of the canopy (>4.9 inches d.b.h.) and densities of the subcanopy (154.9 inches d.b.h.), harvested areas only

Species	Canopy Basal area	Canopy Density	Subcanopy density
	Ft²/ac	*Stems/ac*	*Stems/ac*
Chestnut oak	22.0	20	4
White oak	12.7	13	1
Northern red oak	8.5	6	0
Black oak	1.8	1	0
Southern red oak	1.3	0	0
Scarlet oak	.3	0	0
All oaks combined	46.6	41	5
Hickories[a]	29.0	36	7
Yellow-poplar	9.7	7	1
American beech	8.5	10	32
Sweetgum	6.8	10	4
Black tupelo	4.4	9	30
Sugar maple	4.3	8	37
Red maple	2.2	4	7
Cucumber-tree	1.9	4	3
Ashes*	1.8	4	5
American hornbeam	.6	2	30
Elms[c]	.4	1	3
Other canopy species	1.6	1	1
Other subcanopy species	.5	2	9
Total	118.3	138	176

[a] Red (C. ova/is), shagbark (C. ovafa), and mockernut (C. ***tomentosa***).
[b] Mostly green ***(F. pennsylvanica)***, some white ***(F. americana)***.
[c] Winged ***(U. alata)*** and American ***(U.*** *americana).*

Advance Reproduction and Potential Sprouts

Since all of the hardwood species here have the potential to sprout from cut stumps, all trees were considered as potential reproduction on the site after harvesting. So, all size classes that were present within the miiacre plots were included in table 2, reflecting the full "advance reproduction" (AR) potential present before harvest (Johnson 1993).

All commercial species together averaged 14,982 stems per acre in broadly-defined advance reproduction (table 2). An additional 967 per acre of non-commercial species (eastern hophornbeam, flowering dogwood (*Cornus florida* L.), eastern redbud (*Cercis* canadensis L.), American hornbeam (*Carpinus coroliniana* Walter), and **sourwood** *(Oxydendrum **arboreum*** (L.) DC.)) were present. All oaks together averaged 2,523 AR per acre, but only 222 per acre of these were in the highly desirable large seedling and sapling sizes (1 ft tall to 4.9 inches d.b.h.). Of the oaks, white oak had the highest overall numbers of AR (994 per acre), but 87 percent of these were less than 6 inches tall, and just 18 per acre were present in the large seedling/sapling sizes (table 2). Most of the white oaks were in one block. Northern red oak was highest in numbers among oaks in the large seedling/sapling sizes (117 per acre), but had less than half that of chestnut oak over all sizes (414 compared to 844 per acre).

For ail sizes combined, sugar maple had the highest numbers of AR of any species, averaging 7,447 per acre overall (table 2). it was also more heavily represented in the large seedling/sapling sizes than any other species, averaging 1,264 per acre. Red maple (***Acer rubrum*** L.) was present in moderate numbers overall (1,273 per acre) and in the large seedling/sapling sizes (414 per acre). Although not high in small seedling numbers, American beech and black tupelo had fair numbers in the large seedling/sapling sizes (229 and 312 per acre, respectively; table 2).

Factors Affecting Oak Stocking at 15 Months

Presence of any oak (taller than 6 inches) in a plot at 15 months after harvest (miiacre stocking) was the response variable in the logistic regression analysis. The final model was highly significant and the Hosmer and Lemeshow goodness-of-fit test was non-significant (thus the hypothesis of good fit cannot be rejected). The adjusted R^2 indicated that the model accounted for about 40 percent of variation.

Table 2-Advance reproduction and cut trees in reproduction plots in the harvested areas (from 488 plots), by size class

Species	Height			D.b.h.			All sizes combined
	<6"	6" - 1'	1' - 3'	• 1.5	1.6 -4.9	>4.9	
	Number per acre						
White oak	869	94	18	0	0	12	994
Chestnut oak	611	156	41	16	4	16	844
Northern red oak	117	178	109	4	4	4	416
Other oaks	170	72	20	4	0	2	268
All oaks	1,766	500	189	25	8	35	2,523
Sugar maple	5,260	910	752	477	35	12	7,447
Hickories	977	55	150	27	4	39	1,551
Red maple	568	285	289	119	6	6	1,273
Other commercial	129	125	129	53	6	16	459
Black tupelo	53	72	133	148	31	16	453
American beech	47	78	61	135	33	6	361
Ash	39	64	13	37	4	2	258
Yellow-poplar	0	0	2	0	2	4	8
Total							
Commercial	9,135	2,598	1,926	1,053	131	137	14,982
Non-commercial	156	164	348	260	37	2	967

Advance reproduction-Five explanatory variables, milacre stocking of advance reproduction more than 6 inches tall (AR stocking), cutting treatment, topographic position, degree of logging disturbance, and logging slash cover were significant at a chi-square probability of less than 0.03. The most influential factor was the presence of oak AR taller than 6 inches. Its parameter estimate and odds ratio were high relative to the other factors (even when scale differences are considered). In other models tested using stocking or numbers of all AR sizes or of just those taller than 1 ft, the model test statistics and the AR variable parameters were significant, but model R^2's and variable influence parameters were smaller than when the size division was at 6 inches.

With a relatively large and highly significant parameter estimate and a high odds ratio, AR stocking was the most influential factor tested. At 15 months after harvest, 38 percent of all plots in the cut areas were stocked with oaks taller than 6 inches (table **3),** which is only 1 percent lower than overall preharvest reproduction stocking. Based on this close match, one might infer that post-harvest reproduction stocking was affected primarily by AR stocking. However, a detailed examination of individual plot stocking showed that 33 percent of the plots stocked with AR taller than 6 inches did not remain stocked at 15 months after harvest. Similarly, 19 percent of plots that were not stocked preharvest were stocked with at least one oak (taller than 6 inches) at 15 months after harvest. So, both mortality of AR and post-harvest germination influenced the **15-months** stocking levels.

Treatment-Cutting treatment type was also identified as a highly significant factor by the logistic regression analysis. The positive slope parameter and the nature of the coding appeared to indicate an increased probability of oak stocking in the DC treatment, which was assigned the highest coded value. This influence is clearer when percent stocking was compared for pre- and post-harvest among the three treatments (table 3). By chance, the preharvest stocking among the CC reproduction plots was much lower (approximately one-half) than for the other two treatments. However, 11 percent of the CC and 15 percent of the SC preharvest stocked plots were no longer stocked at the post-harvest assessment, compared to a gain in stocking of 8 percent for the DC treatment. These numbers imply that higher mortality occurred in the CC and SC treatments and higher post-harvest establishment occurred in the DC treatment. The higher mortality was likely a result of damage from logging, further discussed below. Earlier analysis found that the clearcut, strip cut, and deferment cut areas had 25, 13, and 9 percent exposed bare soil, respectively (Dubois and others 1997). In addition to lower mortality due to less logging disturbance, there was enough post-harvest establishment from germination in the DC treatment to exceed oak stocking losses that were incurred through mortality.

Topographic position-Slope position was also a significant factor in the logistic regression model. The AR levels were strongly correlated with topographic position, increasing from lower slope to ridge (table 3).

No consistent pattern was evident among slope positions however, when preharvest to post-harvest changes were examined (table 3). Fewer oaks were present in both the overstory and understory strata of lower and **midslope** areas before harvest. This was likely due somewhat to the high

Table 3-For oaks, change in stocking of milacre plots from preharvest (AR) to 15 months after harvest, compared for factors having a significant effect on oak regeneration success

Factor	# plots	Preharvest	At 15 months	Change'	Change, as % of AR[b]
		Stocking			
		Percent (number)		*Percent*	
AR stocking					
Overall	488	39(191)	38(185)	-1	-3
Cutting treatment					
Clearcut	200	27(54)	24(48)	-3	-11
Strip	88	52(46)	44(39)	-a	-15
Deferment	200	46(91)	49(98)	+4	+a
Topographic position					
Lower slope	177	29(52)	29(51)	-1	-2
Midslope	190	33(62)	36(68)	+3	+10
Upper slope	103	61(63)	50(52)	-11	-17
Ridge shoulder	18	78(14)	78(14)	0	0
Logging disturbance					
Light	267	37(98)	44(118)	+7	+20
Medium	145	41(60)	37(53)	-5	-12
Severe	76	43(33)	18(14)	-25	58
Logging slash					
Light slash	303	43(129)	43(131)	+1	+2
Medium slash	a9	36(32)	33(29)	-3	-9
Heavy slash	96	31(30)	26(25)	-5	-17

[a] As proportion of total plots in the class.
[b] As proportion of plots that were stocked at preharvest.

abundance of shade-tolerant tree species in the understories of lower and midslopes and their comparative scarcity on ridges. In sizes from 3 ft tall to 4.9 inches d.b.h., preharvest sugar maple and beech stems averaged 1,042 and 946 stems per acre on lower and midslopes, respectively, but 111 per acre on ridge shoulders. This negative relationship of oak reproduction success with more mesic and higher quality sites is consistent with that reported for oaks in other regions (Kays and others 1985, Sander and others 1984), with competition from mesic species usually cited as the major reason.

It is apparent that slope position has and will continue to correlate strongly with oak stocking on these north-facing slopes. At the 15-month measurement, the effect was primarily through influence on AR, but in the future developing stand the negative effect of intense competition from mesic species on the middle and lower slope positions may become evident. This will come from established rootstocks of tolerant species such as sugar maple and beech, and from recent seedlings of yellow-poplar. At 15 months, more than 2,400 stems per acre of sugar maple and more than 3,200 per acre of yellow-poplar taller than 1 ft were present in the lower slope plots. These will likely overtop and shade out a substantial proportion of existing oak reproduction.

Logging effects-The regression model indicated that increasing levels of logging disturbance, as evidenced by bare soil and rutting, had a significant negative impact on oak regeneration success. This is reinforced by the changes in numbers of stocked plots from pre- to post-harvest (table 3). Where logging disturbance was light or absent, there was a 20 percent increase in number of post-harvest stocked plots over those stocked preharvest, contrasting with a 58 percent decrease where logging disturbance was severe. The apparent mechanism for this negative effect was direct damage or destruction of stems and root systems. First-season oak seedling survival for this study was earlier reported to be negatively related to percent exposure of bare mineral soil (Dubois and others 1997).

The other significant factor found was residual logging slash level. The effect on regeneration stocking was negative with increasing density and depth. As used, the rating placed more emphasis on density than depth. Based on changes in stocking, pre- to post-harvest, most of the effect occurred between the light and medium slash levels, with a slight increase in stocked plots for the light slash level, but a reduction of 9 and 17 percent for the medium and heavy slash levels, respectively (table 3). Presumably, the negative effect was due to shading of seedlings by increasingly denser and deeper slash.

Effects of Advance Reproduction Size and Post-Harvest Establishment

In order to determine the effects of post-harvest establishment and also size of AR on oak milacre stocking, data from all three measurement times for the tagged oaks (taller than 6 inches) present in each plot at the 15-month inventory were examined. The "origin" of stocking for a plot was classified as being from either AR of one of the five AR size classes, or else from post-harvest germination (PHG)of seed from one of the two possible seed crops. If any of the oaks had been present before harvest, the plot stocking was considered to have originated from AR, and the plot stocking origin was further classified by the size of the oak AR at preharvest. If oaks from various sizes of AR had survived, the plot was classed by the largest AR size. If the only oaks present at 15 months in a plot had been first tagged after harvest, stocking was classed as originating from post-harvest germination of seed. By examining the time when seedlings were first tagged, it was possible to determine whether stocking from PHG had originated from acorns present before the harvest or from acorns of the first fall after harvest. If seedlings originating from both seed crops were present, plot stocking origin was classed as being from the earlier time.

Of the 185 stocked plots overall (38 percent milacre stocking), 40 percent (74) owed their stocking to AR seedlings less than 1 ft tall, and 32 percent (60) were stocked due to PHG. Only 6 percent (12) originated from preharvest trees taller than 3 ft, with stump sprouts comprising most of this (4 percent). Two-thirds of the PHG stocking (22 percent of the stocked plots) came from the acorn crop following harvest (second season). The acorn crop for most oaks on the site appeared to be heavy that fall.

The 38 percent milacre stocking for oaks at 15 months compared very closely to preharvest AR milacre and overstory basal area stocking levels, both at 39 percent, and was higher than the 30 percent of preharvest overstory stem density. At this early time, it is impossible to predict the number of these plots that were stocked at 15 months that will contribute to the overstory stratum 30-40 years later, when many surviving oaks will be producing acorns and available for timber utilization. For 91 percent of the stocked plots, the tallest oak was still less than 3 ft tall. Stump sprouts produced the tallest reproduction, with all plots stocked from sprouts having trees taller than 3 ft. However, this comprised only 4 percent of the stocked plots.

The finding that advance reproduction was important in determining oak reproduction was no surprise, for this is generally accepted as the key for upland oaks (Johnson 1993). However, analyses from upland stands have usually concluded that only large, well-established advance reproduction is dependable in contributing to the future stand (Loftis 1990, Sander 1972). For seedling heights, studies from the Missouri Ozarks for assessing adequacy of oak advance reproduction have used 1 ft (Sander and others 1984) or even 4.5 ft (Sander and others 1976) as minimums for adequacy. Using 1 ft as the minimum height, only 10 percent of the oak advance reproduction measured in these plots (table 2) would have qualified.

Additionally, although oaks originating from seeds after harvest have been reported important in some bottomland stands(Golden 1995, Loewenstein and Golden 1993) this source has generally been considered unreliable in upland stands (Loftis 1990). Although the stocking from seedlings that germinated after harvest was substantial on this site, their ability to survive and contribute to the future overstory is uncertain. PHG contributed strongly to early stocking, but the ability of these late-starting seedlings to survive as competing vegetation develops is questionable. Only 5 percent of the plots stocked by PHG had oaks more than 3 ft tall.

CONCLUSIONS

The presence of at least one oak taller than 6 inches prior to harvest was the factor most strongly related to post-harvest stocking. Topographic position was related to oak reproduction stocking, but this appeared to be due to the strong effect of topographic position on stocking of advance reproduction. Cutting treatment affected reproduction stocking also, with the DC treatment resulting in a post-harvest increase in stocking and the CC and SC treatments leading to declines. This was possibly due to higher logging-induced mortality in the CC and SC, and higher post-harvest germination in the DC treatment. Logging disturbance and residual logging slash both reduced post-harvest reproduction stocking of oaks, presumably through causing direct mortality of AR. Both small AR (less than 1 ft tall) and post-harvest germination contributed substantially to the 15-month milacre stocking, although the contribution of these to the future overstory is uncertain.

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OAK ADVANCED REGENERATION FOLLOWING SEASONAL PRESCRIBED FIRES IN MIXED HARDWOOD SHELTERWOOD STANDS[1]

Roderick D. Cooper, David H. Van Lear, and Patrick H. Brose[2]

Abstract-Regeneration of oaks (Quercus) on productive upland sites is a long-standing silvicultural problem due to aggressive competition from faster growing indeterminant species. We hypothesized that a single prescribed fire 3-5 years after an initial sheltenvood cut would increase the competitive position of oak regeneration. Three productive oak-dominated shelterwood stands in the Virginia Piedmont were divided into control, spring-,summer-, and winter-burn treatments. Density and stocking of competitive oaks were greater in burned areas than in the unburned control, especially where medium to high intensity burns occurred during the spring and summer. Oak regeneration was evenly distributed over the burned areas while yellow-poplar *(Liriodendron tulipifera* L.), oak's primary competitor on these sites, occurred in small clumps. Results of this study indicate that areas receiving a single prescribed burn of medium to high intensity during the growing season will develop into oak-dominated stands. Other combinations of fire intensity and season-of-burn will produce mixed hardwood stands with varying proportions of oak.

INTRODUCTION

Regeneration of oaks on productive upland sites is a long standing problem in the hardwood forest of eastern North America (Beck and Hooper 1986; Pallardy and others 1988; Hix and Lorimer 1991). Harvest of mixed hardwood stands on higher quality mesic sites often results in a shift of species composition favoring non-oak indeterminate hardwoods (Beck and Hooper 1986, Loftis 1983, McGee 1979). Some of the contributing factors to oak regeneration failure are acorn supply, seedling density, insects, disease and animal depredation (Loftis and McGee 1992). The primary cause of oak regeneration failure is thought to be the slow growth of oak reproduction relative to aggressive intolerant species (Beck and Hooper 1986; Johnson and others 1989; Loftis and McGee 1992). In the early years of development, oak regeneration allocates more photosynthate to root development while intolerant species such as yellow-poplar *(Liriodendron tulipifera* L.) allocate more to shoot development (Kolb and others 1990). These differing growth strategies result in oaks being suppressed in the shaded understory while intolerant species move to dominance of the overstory.

If oaks are to be regenerated as the dominant component of a future stand, managers must develop silvicultural prescription to favor oaks. Loftis (1983) found that sheltetwood harvests alone would not produce oak-dominated stands. Carvell and Tryon (1961) found that burned areas possess greater reservoirs of oak regeneration. Hannah (1987) suggested prescribed fires as a follow-up treatment for shelterwood harvests.

Johnson and others (1989) proposed that the key to oak regeneration might be competition control rather than long regeneration periods. Sander (1988) stated that multiple understoty burns at 2-3 year intervals might be required for effective control of hardwood competition. The frequency of fire is thought to be as important as fire intensity for reduction of fire-susceptible species (De Selm and others 1973).

Recent research indicates that prescribed fire a few years after a shelterwood harvest can enhance the competitive position of oak regeneration (Keyser and others 1996, Brose and Van Lear 1998). Brose and Van Lear (1998) found that oak (Quercus) and hickory (Carya) regeneration vigorously resprout with improved stem form after such burns while yellow-poplar (Liriodendron tulipifera) and other competitors succumbed more easily. This current study is a follow up to Brose and Van Lear's (1998) original study of oak advanced regeneration using a shelterwood cut followed several years later by seasonal prescribed fires. In this study we examined the competitive status of advanced oak regeneration in 1997, three years after the 1995 treatments of seasonal prescribed fires of varying intensities described in Brose and Van Lear (1998). We attempted to define those conditions of fire intensity and timing of burn that would result in adequate free-to-grow oak regeneration in an oak dominated shelterwood stand.

STUDY SITE

This study was conducted in the Piedmont of central Virginia and located in the Horsepen Wildlife Management Area. This land is owned and managed by the Virginia Department of Game and Inland Fisheries. Topography consists of broad gently-rolling hills between 150 and 180 m elevation. Mean annual precipitation is 110 cm, distributed evenly throughout the year. The average growing season is 190 days. Mean annual temperature for the area is 14°C with a January mean of 4°C and a July mean of 24%.

The study area consists of three mature oak dominated hardwood sands with a white oak site index 75 (base age 50). The stands are similar in site characteristics and species composition. Overstory trees in the preharvest stand numbered approximately 200/ha, with approximately 75 percent being upland oaks [white oak (Quercus *alba* L.), northern red oak (Q. *rubra* L.), Black oak (Q. *Velutina* Lam.), scarlet oak (Q. *coccinea* Muenchh.), and chestnut oak (Q. *prinus* L.)]. The remaining 25 percent were yellow-poplar, pignut hickory (*Carya glabra* (Mollier) Sweet), and mockernut hickory (C. *tomentosa* (Poiret) Nuttall). Common

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midstory hardwoods included red maple (*Acer rubrum* L.), blackgum *(Nyssa sylvatica* Marshall), American beech (*Fagus grandifolia* Ehrhart), American hornbeam *(Carpinus caroliniana* Walter), and sour-wood *(Oxydendrum arboreum* L.). There were approximately 2500 stems/ha with most species represented although beech, dogwood, hornbeam, and red maple were most abundant (Brose and Van Lear 1998).

These stands had grown in an undisturbed condition for over 30 years until two of the stands were shelterwood cut in 1990 and the third in 1992 removing 50 percent of each stands overstory. Fifty to 75 dominant oaks and hickory were retained with residual basal areas averaging 13 m^2/ha. Each stand was previously divided into four 2-5 ha treatment areas and subjected to winter, spring, and summer burns in 1995. One treatment area in each stand was left unburned as a control.

STUDY DESIGN AND MEASUREMENTS

This study was conducted in a randomized complete block design using the same treatments as Brose and Van Lear (1998) to examine the density, stocking and spatial pattern of oak and yellow-poplar. The design replicates the four treatments: 1) winter burn, 2) spring burn, 3) summer burn, and 4) unburned control in each of the three shelterwood stands. Thirty plots (2.6 m diameter) were systematically located in each treatment area with a plot density of 6-15 plots/ha. We set size and stem form sampling requirements for oak and yellow-poplar because we were interested in the oaks that would have optimal growth and competitiveness.

An acceptable oak had a straight stem and was >1.37 m tall in the control and winter burn treatments, >1.O m tall in the spring burn treatment, and >0.7 m tall in the summer burn treatment. Sanders and other (1976) showed that oak regeneration must be >1.37 m tall to be competitive after release. Our height specifications vary as a result of differences in the amount of growing time due to seasons of burning. An acceptable yellow-poplar was at least half the required oak height for the treatment (0.7, 0.5, and 0.35 m tall in winter and control, spring, and summer treatments, respectively). These height requirements were allocated because of yellow-poplar's ability to outgrow oak on these sites (Beck and Hooper 1986, Johnson and other 1989).

Densities (stems/ha) were obtained by counting all acceptable oak and yellow-poplar stems in each plot. Stocking of oak and yellow-poplar was measured by determining the proportion of plots containing an acceptable representative. The T-square sampling method was used to determine the spatial pattern of oaks and yellow-poplar in the treatment area (Ludwig and Reynolds 1988). An index was calculated separately for oak and yellow-poplar using distance measurements (+- 0.1 m) from plot center to nearest species and then to next nearest species to determine if regeneration was clustered, random, or uniformly distributed.

Competition of the present advance oak regeneration was measured in the different treatment areas. We examined these inter-species spatial relations using a modified Heygi competition index (Clinton and others 1997). The largest most competitive oak was visually selected and its height recorded. Heights of all competitors and their distance from selected oak were measured within a 3-m radius of the target oak. These measurements were used to calculate a competition value.

A competitor was defined as a yellow-poplar seedling at least half the height of the oak located within a 1.5-m radius of the oak and any yellow-poplar stump sprout within a 4.5-m radius. A competitor will also be any of the following species that are of equal or greater height and within a 3-m radius of the oak: hickory, cherry (*Prunus serotina* Ehrhart), sweetgum *(Liquidambar styraciflua* L.), yellow-poplar, loblolly pine (*Pinus taeda* L.), ash *(Fraxinus* L.), locust *(Robinia* L.), and red maple stump sprouts with a 2 inch or greater ground-line diameter. Species that only occupy midstory upon maturity such as blackgum, flowering dogwood, and hornbeam, were not considered major competitors because oak will eventually surpass them .(Nix 1989, Waldrop 1997).

A 3-m radius was used because it corresponded to Heygi's index and provides at least 50 percent of the growing space needed at maturity for the target oak. Target oaks with no competitors were considered free-to-grow (Nix 1989).

Due to varying fire intensities within treatments (Brose and Van Lear 1998), plots in the burned treatment areas were assigned to one of four levels of fire intensity. Fire intensities were based on fuel consumption during the prescribed burns. Brose (1997) documented fire behavior, fire intensity, and changes in fuel loading within each treatment area as follows. Low-intensity fires (flame lengths ≤0.3 m) partially consumed litter and small woody debris (<0.6 cm diameter), and top-killed <75 percent of the advanced regeneration. Low-medium-intensity fire (flame lengths between 0.3 and 0.75 m) completely consumed litter and small fuels and top-killed 75-100 percent of the regeneration. Medium-high-intensity tire (flame length 0.75-l .2 m) top-killed all regeneration, visibly reduced loading of 2.5-7.5 cm diameter fuels, caused approximately 50 percent mortality of midstory trees, and scorched bark on occasional overstory trees. High-intensity fire (flame lengths >1.2 m) visibly reduced woody debris >7.5 cm diameter, killed most midstory trees, charred bark on most overstory trees, and caused occasional mortality of an overstory tree. A 3x4 factorial design, with three fire seasons and four fire intensity levels, was used to examine the effects of different fire-intensity levels.

STATISTICAL ANALYSIS

Analysis of variance with Student-Newman-Kuel mean separation test was used to compare season-of-burn treatments for differences in density and clustering of oak and yellow-poplar regeneration (SAS Institute 1993). Competitive condition of oak was tested with analysis of covariance and least-squares mean separation with regeneration age as the covariate (SAS Institute 1993). Analysis of variance with least-squares mean separation was used to test for differences among these variables as fire intensity interacted with season-of burn (SAS Institute 1993). Chi-square analysis was used to compare differences in stocking among treatments and among fire intensities within season-of-burn (SAS Institute 1993). In all tests, $\alpha=0.05$ and data were rank-transformed as needed to correct unequal variances and non-normality of residual values.

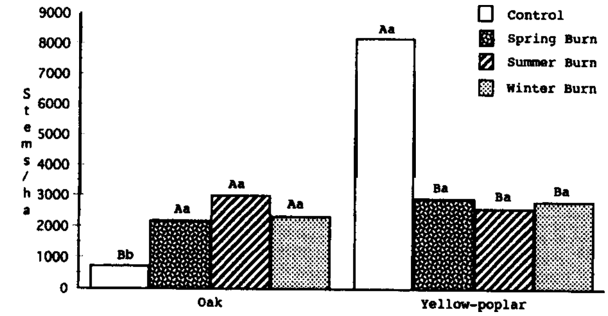

Figure l-Density of oak and yellow-poplar advanced regeneration after seasonal prescribed fires in shelterwood stands in the Virginia Piedmont. Bars with different uppercase letters are different for that species (alpha=0.05). Bars with different lowercase letters are different for that treatment (alpha=0.05).

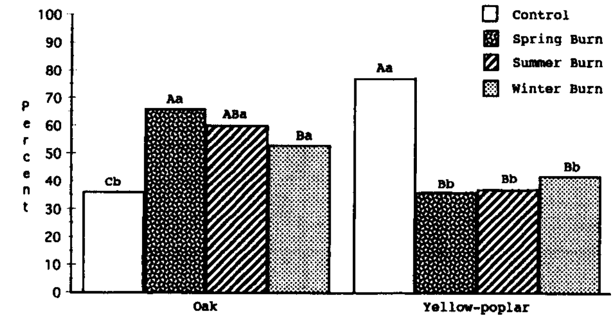

Figure P-Stocking of oak and yellow-poplar advance regeneration after seasonal prescribed fires in shelterwood stands in the Virginia Piedmont. Bars with different uppercase letters are different for that species (alpha=0.05). Bars with different lowercase letters are different for that treatment (alpha=0.05).

RESULTS

Density

Oak density was significantly greater in the bum treatments with three times as many oak stems (fig. 1). The burned treatments had half as many yellow-poplar as the unburned control. In the burned areas yellow-poplar and oak had equivalent densities while in the unburned control yellow-poplar out-numbered oak 8:1.

Oaks were most abundant in high intensity spring and low-to-medium intensity summer burns (Table 1). Yellow-poplar had significantly higher densities in the low intensity areas of all seasons of burn, especially in the winter burn. Oak and yellow-poplar density were equivalent in the medium intensity areas while oak was significantly greater in high intensity tires.

Stocking

Oak stocking was significantly higher than yellow-poplar in the burn treatments while yellow-poplar stocking was significantly higher in the unburned control (77 percent) (fig. 2). The spring burn treatment had the highest oak stocking (66 percent).

Highest stocking of oak was in the low-medium summer burn areas (79 percent), while the high intensity summer burn (42 percent) had the lowest stocking (Table 2). Oak varied little between other season-of-bum and fire intensities (47-67 percent). Yellow poplar had highest stocking in low intensity burn areas (72-92 percent) and decreased as fire intensity increased. Yellow-poplar equaled or exceeded oak stocking in low intensity fire while oak stocking was greater in high intensity fires.

Table l-Density (mean stems/ha ±1 se) of oak and yellow-poplar regeneration after four different levels of fire intensity in the Virginia Piedmont

	Fire intensity levels			
Species	Low	Low medium	Medium high	High
Spring burn				
Oak	1694±600C[a]b[b]	1709±571B[a]b[b]	2385±571AB[a]b[b]	4160±511A[a]a[b]
Yellow-poplar	5567±1887AB[a]a[b]	2776±682B[a]a[b]	3685±1047A[a]a[b]	1134±699C[a]b[b]
Summer burn				
Oak	2724±813BC[a]b[b]	4945±1077A[a]a[b]	2043±701AB[a]b[b]	2389±499B[a]b[b]
Yellow-poplar	4051 ±1037B[a]a[b]	3631 ±1158AB[a]	1134±921B[a]ab[b]	573±131C[a]b[b]
Winter bum				
Oak	2006±737C[a]b[b]	1955±436B[a]b[b]	1961 ±538AB[a]b[b]	3111 ±402B[a]a[b]
Yellow-poplar	9077±2418A[a]a[b]	2823±714AB[a]b[b]	1470±647B[a]bc[b]	865±694C[a]c[b]

[a] Means with different uppercase letters are different within that column (a = 0.05).
[b] Means with different lowercase letters are different within that row (a = 0.05).

Table 2-Stocking percent (mean ±1 se) of oak and yellow-poplar regeneration after four different levels of fire intensity in the Virginia Piedmont

Species	Fire intensity levels			
	Low	Low medium	Medium high	High
Spring burn				
Oak	64±25AB[a]ab[b]	63±13AB[a]ab[b]	53±9Bb	48±15Aa
Yellow-poplar	83±27AB[a]a[b]	58±16AB[a]ab[b]	44±10B[a]ab[b]	21±15CD[a]b[b]
Summer burn				
Oak	54±8B[a]b[b]	79±11A[a]a[b]	56±18B[a]b[b]	42±20BC[a]b[b]
Yellow-poplar	72±12B[a]a[b]	45±12B[a]a[b]	13±D[a]b[b]	10±10D[a]b[b]
Winter burn				
Oak	50±8B[a]b[b]	47±11B[a]b[b]	67±5A[a]a[b]	52±14B[a]b[b]
Yellow-poplar	92±8A[a]a[b]	56±6B[a]b[b]	49±5C[a]c[b]	14±14D[a]c[b]

[a] Means with different uppercase letters are different within that column (a = 0.05).
[b] Means with different lowercase letters are different within that row (a = 0.05)

Intra-Species Spatial Pattern
The spatial arrangement of oak and yellow poplar regeneration differed from each other in all the treatments. The oaks scored between 0.27-0.39 on **a** O-l spatial index indicating that oak regeneration was uniformly distributed over all treatments. Yellow-poplar scored between 0.64-0.73 indicating that yellow-poplar regeneration was clustered. The spatial patterns within species were not affected by treatments or fire intensities.

Intra-species Competitive Relationship
Oaks in the burn treatments had significantly lower competition (Hegyi **index≈0.24)** than oak in the unburned control **(index≈0.35)** (Table 3). The number of competitors was highest in unburned control and lowest in the spring and summer burn treatments. Distance to nearest non-oak competitors was also significantly closer in the unburned treatment than in the burned treatments. There was no difference in competition between seasons of burn. As fire intensity increased within the burned treatments density of competitors decreased.

There were significantly more free-to-grow oak in the spring and summer burn treatments (425 and 363 stems/ha, respectively) than in the winter burn and unburned control (62 and 141 stems/ha, respectively) (fig. 3). The high intensity spring burn areas (632 stems/ha) had the most free-to-grow oaks. The medium intensity summer burn areas (551 and 453 stems/ha) had the next largest quantity of free-to-grow oak followed by the medium intensity spring fires (321 and 373 stems/ha). Free-to-grow oaks were nearly absent in the low intensity spring and winter burn areas with

Table 3-Competitive status (mean ±1 se) of oaks 3 years after seasonal prescribed fires In shelterwood stands in the Virginia Piedmont

Treatment	Oak height	Number of competitors	Competitor height	Distance to nearest competitor	Heygi competition index
	m	*Stems/plot*	*m*	*m*	
Control	2.4±1A[a]b[b]	7.6±0.8A[a]	2.9±0.1A[a]a[b]	0.8±0.1B[a]	0.35A[a]
Spring burn	1.6±1C[a]b[b]	5.3±0.3C[a]	2.0±0.1C[a]a[b]	1.3±0.1A[a]	.25B[a]
Summer burn	1.1±1D[a]b[b]	4.7±0.3C[a]	1.5±1.0D[a]a[b]	1.3±0.1A[a]	.23B[a]
Winter burn	1.9±1B[a]b[b]	6.0±0.1B[a]	2.5±0.1B[a]a[b]	1.2±0.1A[a]	.25B[a]

[a] Means followed by different uppercase letters are different within that column (a = 0.05).
[b] Height means followed by different lowercase letters are different from each other within that *row (a* = 0.05).

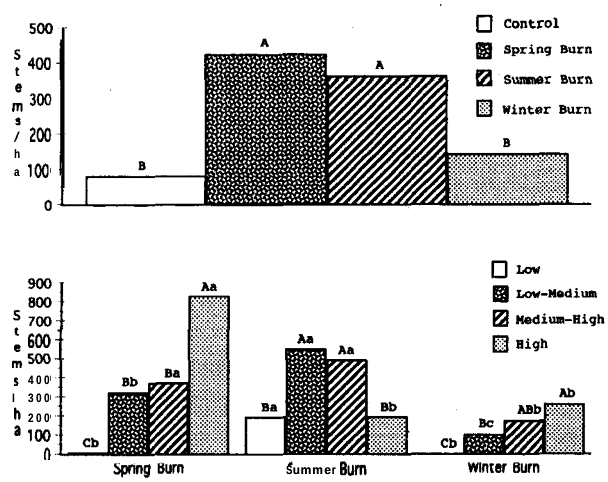

Figure 3-Density of free-to-grow oaks among treatments and among fire intensity levels within season-of-burn in shelterwood stands in the Virginia Piedmont. Bars with different uppercase letters are different for that species (alpha=0.05). Bars with different lowercase letters are different for that treatment (alpha=0.05).

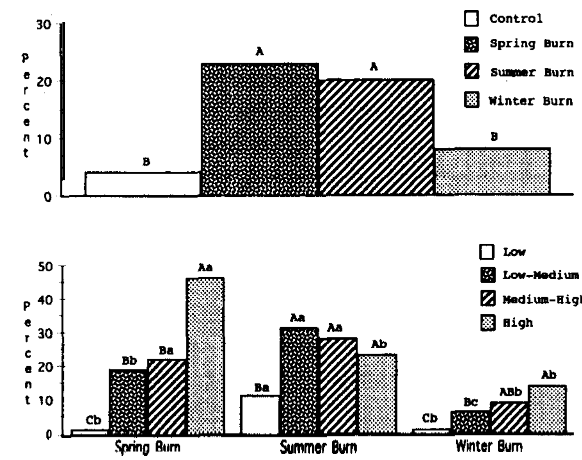

Figure 4—Stocking of free-to-grow oaks among treatments and among fire-intensity levels within season-of-burn in shelterwood stands in the Virginia Piedmont. Bars with different uppercase letters are different for that species (alpha=0.05). Bars with different lowercase letters are different for that treatment (alpha=0.05).

less than 5 stems/ha. There were 101 and 173 stems/ha in the medium intensity winter burn areas and 259 stems/ha in the high intensity winter areas.

Stocking of free-to-grow oak were higher in the spring and summer burn (24 and 20 percent, respectively) than in the winter burn and control (8 and 4 percent, respectively) (fig. 4). The high intensity spring burn areas had the highest stocking (46 percent) while the low intensity area in the spring and winter burn had the lowest stocking (1 percent). The two medium and high intensity burn areas in the summer burn had equivalent stocking.

DISCUSSION

Disturbance of the stand and increased lighting of the forest floor after shelterwood harvest results in tremendous numbers of yellow-poplar. Preburn densities of yellow-poplar in our study area reached 10,000 stems/ha while oak was around 2,000 stems/ha in all treatments (Brose and Van Lear 1998) Yellow-poplar seed banks can remain viable in the forest floor up to seven years (Beck 1981) and profusely germinate upon disturbance.

Prescribed fire drastically reduced the density and stocking of yellow-poplar in all burn treatments while increasing that of oak. Burning reduced competition in the stand and resulted in smaller clusters of yellow-poplar.

Acorns are usually buried by animals and have hypogeal germination (cotyledons remain in seed) which places the root collar and its dormant buds below the surface. Yellow-poplar seeds have epigeal germination, generally placing the root collar and its accompanying dormant buds above the soil surface (Beck 1981). This difference in germination strategy makes yellow-poplar more susceptible to lethal temperatures at or above ground level. Oaks also allocate more carbon to development of a large tap root in their early years while yellow-poplar allocates carbon to stem growth. This difference in growth strategy gives oak a more favorable root/shoot ratio for vigorous resprouting after being top killed by fire.

Fire intensity, season of burn, and varying growth strategies, affect the composition of regeneration. Medium to high intensity growing season burns resulted in lower densities and stocking of yellow-poplar with abundant free-to-grow oaks and reasonable stocking.

CONCLUSION

Oaks were adequately stocked in burned areas. However, free-to-grow oaks were only adequately stocked in medium-high to high intensity burned areas in the spring burn. The number of yellow-poplar saplings were greatly reduced by burning and were in smaller clusters while oaks were uniformly distributed over the stands. Competition of oak is also lower in burned areas and decreases as fire intensity increases. We recommend a medium-high to high intensity burn a few years after the initial shelterwood cut to regenerate oak on productive upland sites. If the fire intensity is not maintained at a consistent medium-high to high intensity level then a second burn will likely be required. Otherwise, a mixed hardwood stand with varying proportions of oak will develop.

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GROWTH OF OAK REPRODUCTION INCREASED BY SHELTERWOOD TREATMENTS IN NORTHERN ARKANSAS'

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Abstract-Nine-year survival and growth of oak *(Quercus alba* L., *Q. rubra* L., and *Q. velutina* Lam.) reproduction was evaluated in upland oak stands representing a range in site quality, residual overstory stocking, and understory treatments. Analysis of variance was used to test for differences in establishment, survival, and growth of oaks and other species groups as affected by site quality, overstory stocking, and intensity of understory treatment. Establishment of new oak reproduction was not significantly affected by study treatments. However, survival and growth of new and original oak reproduction and change in oak stocking values were significantly affected by the intensity of understory treatment.

INTRODUCTION

Mixed oak types occupy most of the upland commercial forest in northern Arkansas, and oaks are the dominant timber species. However, oak reproduction may not adequately replace present stands, especially on the more productive sites (Graney 1989, Graney and Rogerson 1985). Although declines in oak dominance may result in greater species diversity, the oaks are prized for their timber and wildlife values.

Commercially desirable fast-growing species such as yellow-poplar *(Liriodendron tulipfera* L.) do not occur in western Arkansas, and valuable species such as black walnut *(Juglans nigra* L.), black cherry *(Prunus serotina* Ehrh.), and white ash *(Fraxinus americana* L.) occur infrequently and primarily on the more productive sites. Because most associated species in these upland stands are either slower growing or of lower economic value than the oaks, it is important to ensure that oaks will be a major component of new stands after harvest.

The oak component of future hardwood stands depends on sprouts from cut overstory stems and large oak advance reproduction present at time of harvest (Loftis 1990a, Sander and Clark 1971, Sander and others 1984). Newly established oak seedlings grow too slowly to compete successfully after harvest (Sander and Clark 1971). In contrast, large oak advance reproduction grows rapidly after harvest and has a high probability of becoming dominant in the new stand (Loftis 1990a, Sander and others 1984).

Upland hardwood stands in the Boston Mountains of northern Arkansas may have more than 1,000 stems per acre of oak advance reproduction, but most are <1 ft tall and larger reproduction is often absent. Many of these stands are mature and fully stocked and have well-developed understories of shade-tolerant noncommercial species. Given the size and status of existing reproduction, new stands that develop after harvest will almost certainly contain a low proportion of oak. Researchers are trying to stimulate the growth of small advance reproduction using shelter-wood treatments with light to medium overstory cutting plus partial to complete understory control (Graney 1989, Loftis 1990b, Sander 1987, Sander and Graney 1993).

Variants of the shelterwood method for regenerating oaks have shown promise in the Missouri Ozarks (Schlesinger and others 1993), and the Southern Appalachians (Loftis 1990b). In these studies, development of oak reproduction on medium and good quality sites has been enhanced.

Graney and Murphy (1995) described the 9-year height development of individual white oak *(Quercus alba* L.), northern red oak (*Q. rubra* L.), black oak (Q. *velutina* Lam), white ash, and black cherry stems as influenced by study treatments and initial stem size. This paper reports the 9-year effects of the various overstory and understory shelterwood treatments on mortality and density of original reproduction of oaks and other species groups and the growth and mortality of *new* oak reproduction established after treatment. The effects of the shelterwood treatments on changes in oak regeneration stocking values over the 9-year period are also evaluated.

PROCEDURES

Study Region

The Boston Mountains are the highest and most southern of the Ozark Plateaus physiographic province. They form a band 30 to 40 mi wide and 200 mi long from north-central Arkansas westward into eastern Oklahoma. Elevations range from about 900 ft in the valley bottoms to 2,500 ft at the highest point. The plateau is sharply dissected, with most ridges flat to gently rolling and generally <0.5 mi wide. Mountainsides consist of alternating steep simple slopes and gently sloping benches.

Soils on mountaintops and slopes usually have shallow to medium depth and are represented by medium-textured members of the Hartsells, Linker, and Enders series (Typic *Hapludults*). They are derived from sandstone or shale residuum, and their productivity is medium to low. In contrast, soils on mountain benches are deep, well-drained members of the Nella and Leesburg series (Typic *Paleudults*). They developed from sandstone and shale colluvium, and their productivity is medium to high. Rocks in the area are alternating horizontal beds of Pennsylvanian shales and sandstones. Annual precipitation averages 46 to 48 in., and March, April, and May are the wettest months. Extended summer dry periods are common, and autumn is usually dry. The frost-free period is normally 180 to 200 days long.

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Study Description
Six mature upland hardwood stands were selected for study at three locations in the Ozark National Forest. Three stands are on upper north- or east-facing slopes with site indices of 57 to 63 ft (mean=60 ft) for northern red oak, base age 50 years. The other three stands are on north- or east-facing mountain benches with northern red oak site indices of 72 to 80 ft (mean=75 ft). Mean age for upper slope stands was 74 years (range=72-84 years), while stands on mountain benches averaged 78 (range=70-84) years. Six plots (approximately 1 acre in size) were established in each stand. Overstory (stems ≥1.6 in. d.b.h.) densities were reduced to either (1) 40 or (2) 60 percent relative stocking density (Gingrich 1967). Understory (stems <1.6 in. d.b.h.) treatments were: (1) kill all competing stems (intensive), (2) kill all competing stems >5.0 ft tall (partial), or (3) no understory treatment. The six overstory-understory treatment combinations were randomly assigned to each plot.

Pretreatment overstory stocking for all plots averaged 106 percent and basal area averaged 118 ft^2 per acre (table 1). The overstory was cut from below. After all subcanopy stems ≥ 1.6 in. d.b.h. were removed, the overstory canopy was cut to the prescribed stocking goal. Stumps of all less-desirable (slow growing or noncommercial) overstory stems were sprayed with 2,4-D plus picloram to reduce sprouting. Overstories on all plots were predominantly oak. Northern red, black, and white oaks accounted for 80 percent of the overstory stocking before treatment and more than 90 percent after treatment. Ash and cherry represented less than 1 percent of the stocking on all plots.

Understory control treatments were imposed by cutting target stems near ground level and spraying stumps with the 2,4-D plus picloram herbicide immediately after cutting.

Understory treatments were completed in May 1980, and overstories were cut May through July 1980. Understories on upper slope sites (site index 60) were dense mixtures of tolerant brushy or less-desirable species such as red maple (*Acer rubrum* L.), serviceberry (*Amelanchier arborea* Michx. F. Fern), redbud (*Cercis canadensis* L.), and blackgum (*Nyssa sylvatica* Marsh.). Dogwood (*Cornus florida* L.), hophornbeam (*Ostrya virginiana* (Mill.) K. Koch.),pawpaw (*Asimina triloba* L.), and sugar maple (*Acer saccharum* Marsh.) were common on bench sites (site index 75).

Reproduction was measured on a series of sixteen 1/735-acre subplots systematically distributed across the interior 0.25 acre of each plot. On each subplot, all reproduction <1 .5 in. d.b.h. was tallied by species and I-ft height classes. In addition, all oak stems were identified and mapped for remeasurement. For these stems, height and basal diameter (1 in. above groundline) were measured to the nearest 0.1 ft and 0.1 in., respectively. Reproduction was measured before treatment and 1, 3, 5, and 9 years after treatment.

Data Analysis
The study was laid out as a randomized block split-plot design. There were three locations or blocks, with the upper slope of each block corresponding to site index of 60 and the lower slope to site index of 75. Within each site index (whole plot) area, six subplots were established and randomly assigned one of the six experimental treatment combinations. The treatment combinations involved the residual stocking density (40 and 60 percent) and understory control (intensive, partial, and no control). Analysis of variance was used to compare expressions of reproduction response and stand conditions among treatments. Differences among treatment means were isolated by using the Ryan-Einot-Gabriel-Welsch Multiple Range Test ($\alpha=0.05$) (SAS Institute 1989).

Table 1—Overstory values per acre for original stand after treatment and 9 years after treatment

	Original stand		After treatment		Year 9	
Stocking treatment	Basal area mean range	Stocking mean range[a]	Basal area mean range	Stocking mean range[a]	Basal area mean range	Stocking mean range[a]
	Ft^2	*Percent*	*Ft^2*	*Percent*	*Ft^2*	*Percent*
Site Index = 60 feet						
40 percent	118 (110-127)	108 (110-115)	51 (45-54)	41 (40–42)	63 (57-69)	50 (45-53)
60 percent	119 (107-126)	108 (98-115)	72 (69-76)	59 (57-61)	84 (77-88)	67 (63-70)
Site index = 75 feet						
40 percent	114 (110-124)	103 (100-108)	51 (45-54)	40 (38–42)	59 (53-67)	47 (42-51)
60 percent	118 (112-130)	106 (102-120)	73 (69-81)	58 (57-60)	82 (75-93)	64 (60-70)

[a] Based on stocking equation from Gingrich (1967).

RESULTS AND DISCUSSION

Advance Reproduction Before Treatment

The pretreatment height distribution of advance reproduction on study plots was typical of well stocked mature upland oak stands in the Boston Mountains (table 2). Total oak, ash, and cherry reproduction and advance reproduction >1 ft tall are greatest on less productive upland sites. Large advance reproduction (>5 ft) is often sparse or absent. Most of the oak reproduction is <1 ft tall and few stems are >2 ft tall. Ash and cherry reproduction is highly variable throughout the Boston Mountains but is usually most abundant on medium to good sites. Although ash and cherry are minor components of the overstory in these upland stands, they represent the majority of the desirable species reproduction >2 ft tall.

The other species group (table 2) is dominated by tolerant, brushy, and noncommercial species; hickories (*Carya* spp.); and other less common species that would be considered acceptable stocking on selected sites.

Table 2—Mean height distribution per acre of reproduction by species group before treatment

Species	Height class (feet)					
	<1	2	3	4	5	>5
	Number of stems					
Site index = 60						
Oaks”	1,959	106	15	13	5	0
Ash & cherry	930	222	143	72	41	5
Other species	4,341	2,910	1,346	1,187	905	1,569
Site index = 75						
Oaks[a]	1,243	61	18	8	5	0
Ash & cherry	452	179	74	38	31	5
Other species	4,813	2,387	1,523	1,153	1,160	1,408

‘White, black, and northern red oaks.

Reproduction After Treatment

Nine years after shelterwood cutting, reproduction size and abundance indicated little or no response to site quality or the overstory density treatments. Number of small (<1 .1 ft) oak and other species stems were greater in stands cut to 60 percent overstory stocking but number of stems in the larger height classes were not affected by the 40- or 60-percent overstory stocking densities (table 3). Graney (1989) reporting 5-year response to the overstory density treatments found that numbers of ash, cherry, and other species stems in the 1 .1 - 5.0 and >5.0 ft height classes were significantly greater in stands cut to 40 percent stocking. However, this initial response did not persist through the 9-year period. The effect of overstory density on reproduction development may have been modified by overstory mortality that resulted from the severe drought in the 1980 growing season. While most overstory mortality occurred in 1980, some stems that survived in poor condition died over the next 2 to 4 years. As a result of this mortality, stocking in the 40 percent treatment increased from 40 percent in 1980 to 50 percent in 1988 while the 60 percent stands increased from 59 percent to 66 percent over the same period.

Control of competing understory stems produced the greatest response in oak reproduction height development of all the study treatments. Stands receiving the intensive and partial understory treatments produced significantly more oak stems in the medium and large reproduction height classes than stands receiving no understory control (table 3). Numbers of ash and cherry stems in the small, medium, and large height classes did not differ significantly among the three understory treatments. After 9 years, effects of understory control on numbers of other species were only apparent in the large height class. Stands receiving the most intensive understory treatment had significantly fewer stems >5 ft tall than those receiving intermediate and no control treatments (table 3).

The primary objective in applying the shelterwood method in mature upland oak stands is to develop a sufficient amount of oak advance reproduction large enough to successfully compete after overstory removal. This objective may be accomplished through establishment and growth of new seedlings, enhanced development of small pre-established stems, or both. In this study, the overstory/understory density control treatments increased the average size of oak, ash, and cherry reproduction. The numbers of oak stems >1 ft tall also increased from about 100 per acre before treatment to more than 1,000 per acre in stands with partial or intensive treatment. The number of ash and cherry stems >1 ft tall increased by 400 to 600 per acre after

Table 3-Reproduction 9 years after treatment as affected by residual stocking and understory treatment

Species and height class	Pretreat-ment	Residual stocking (percent) 40	60	P>F	Understory treatment 1[a]	2	3	P>F	Mean square error
Feet	*Number of stems*								
Oaks[b]									
<1.1	1,601	1,030	1,750*[c]	0.03	1,440	1,496	1,323	0.77	8.95E5
1.1-5.0	115	590	919	.23	1,054*	897*	313	.05	6.33E5
>5.0	0	95	92	.93	139*	123*	19	.01	9.32E3
Ash and cherry									
<1.1	691	368	140	.34	155	124	483	.40	4.90E5
1.1-5.0	400	726	484	.21	684	501	629	.71	3.08E5
>5.0	5	432	256	.09	360	335	337	.97	8.67E4
Other species									
<1.1	4,577	1,350	1,855*	.05	1,513	1,592	1,703	.81	5.13E5
1.1-5.0	6,286	5,285	5,911	.28	5,571	5,762	5,461	.91	2.90E6
>5.0	1,488	4,389	3,621	.11	2,879	4,528'	4,609*	.05	1.91 E6

[a] 1 = All stems treated; 2 = stems >5 ft treated: 3 = no treatment.
[b] White, black, and northern red oaks.
'Stocking or understory means in rows followed by * are significantly different at a = 0.05.

treatment. Most of the increase in oak reproduction >1 ft tall resulted from smaller pretreatment stems and new reproduction growing into the 2- and 3-ft height classes (table 4). Height development of surviving pretreatment oak and ash reproduction was significantly affected by initial stem height and intensity of understory control. Greatest height growth was produced by large (4 to 5 ft) stems on plots with the intensive control treatment. However, small oak and ash stems (<1 ft) also responded to understory control and grew into the 2- or 3-ft height classes over the 9-year period (Graney and Murphy 1995).

Black cherry produced the greatest height growth response to the overstory and understory treatments. Cherry reproduction >5 ft tall developed from pretreatment seedlings and seedling sprouts >1 ft tall. Stems in the 2- to 5-ft classes developed from stems <1 ft tall before treatment and from new seedlings established after treatment (table 3). While no study treatments were statistically significant in terms of total numbers of stems by height class groups (table 3), height growth response of individual pretreatment cherry stems was strongly influenced by overstory and understory treatments as well as site quality. Nine-year height growth ranged from about 3 ft for the smallest stems in stands on the most productive sites thinned to 60 percent overstory stocking with no understory control to >12 ft for large stems on average sites thinned to 40 percent stocking with intensive competition control (Graney and Murphy 1995).

Redevelopment of the competing understory varied considerably with the intensity of the overstory and understory treatments. On plots cut to 60 percent stocking with the intensive understory treatment, redevelopment of competing understory was very slow. Stems of desirable species in all size classes were essentially free to grow for the first 5 years after treatment. Although numbers of competing stems increased considerably over the 9-year measurement period only the smallest desirable stems were overtopped after 9 years. However, on plots cut to 40 percent stocking, the intensive control treatment was effective only for about 5 years. By the end of the fifth year, most of the small oak stems were overtopped and by the ninth year only ash and cherry stems initially >3 ft tall were free to grow.

The partial (>5 ft) understory control increased growth of oak reproduction, but its effect probably will not continue much beyond the ninth year. Understory development was most pronounced on plots cut to 40 percent stocking where all small oak stems and most large stems were overtopped by competing stems:

Overstory cutting (stems ≥ 1.6 inches) resulted in height growth response of ash and cherry reproduction but only the largest oak stems increased in height. After 9 years, all oak and most of the ash and cherry reproduction were overtopped by competing stems.

Table 4-Mean height distribution per acre of original and new oak reproduction 9 years after understory treatment

Understory treatment[a]	<1	2	3	4	5	>5
	Height class (feet)					
	Number of stems					
Original oaks						
Pretreatment	1,601	84	16	10	5	0
1[b]	414	361	90	67	39	88
2	414	295	103	54	47	61
3	341	161	42	27	4	0
New oaks[c]						
1	1,026	389	93	12	4	51[d]
2	1,082	369	17	8	4	62
3	892	72	7	0	0	19

[a] 1 = All stems treated; 2 = stems >5 ft treated; 3 = no treatment.
[b] White, black, and northern red oaks present before treatment.
[c] White, black, and northern red oaks established after treatment.
[d] New oaks stems >5 feet are stump sprouts.

New **oak** reproduction-Establishment of new oak reproduction after the shelterwood treatments was erratic and varied greatly among stands and plots within stands. Although some new oak seedlings were inventoried during each measurement, most of the new oak seedlings were associated with the good local acorn crops of 1980, 1986, and 1987. Nine-year oak seedling establishment ranged from 500 to 7,000 per acre and averaged 1,640 per acre on medium sites (site index 10) and 2,170 in site index 75 stands. Northern red and black oak made up 50 percent of the new oak stems in site index 60 stands and 95 percent in site index 75 stands. The amount of new oak reproduction was not related to site quality, overstory density, or understory control.

Mortality of oak reproduction-Mortality of pretreatment oak reproduction occurred throughout the 9-year period but the greatest losses were associated with the drought of 1980 when 30 percent of the original oak stems died the first year after treatment. Over the 9-year period, mortality of original oak stems was not significantly influenced by site quality or overstory stocking but was strongly affected by understory density control. Loss of original oak stems was 50 percent in stands receiving the intensive treatment, 69 percent in those receiving the partial treatment, and 71 percent in stands with no understory control (table 5). Mortality was primarily concentrated in the stems in the <1-ft height class and only about five percent of the original oak stems >1 ft tall were lost.

Mortality of new oak stems established between 1980 and 1984 was also affected significantly by understory treatments. Losses of new oak stems in stands receiving the intensive and partial control treatments were about the same averaging 20 and 32 percent, respectively. Mortality of new oak stems in stands receiving no understory treatment averaged more than 50 percent (table 5). Mortality in terms of number of stems was greatest for the red oaks, but losses in terms of percent of total stems were about the same for red oaks and white oak for each understory treatment.

Oak regeneration stocking values-Although the shelterwood treatments applied in this study resulted in an increase in the numbers of oak stems >1 ft tall over those in the pretreatment stands, abundance of advance reproduction alone is not a good indicator of whether oaks will be a major component of a new stand after harvest. Reproduction size and distribution should also be considered in evaluating oak regeneration potential. Site quality should also be considered because height growth of competing species will be greater on the more productive sites.

Sander and others (1984) developed a procedure to evaluate the regeneration potential for oak advance reproduction on upland sites in the Missouri Ozarks. The method evaluates the probability of individual oak reproduction stems becoming dominants or codominants at new stand age 20 years. An oak stocking value of 30 for reproduction in the present stand will develop to C-level stocking in the new stand at age 20 years.

Subsequent research indicated that the 1984 prediction system produced very conservative estimates of oak stocking values for upland stands in the Missouri Ozarks. Consequently, a comprehensive regeneration simulator was developed for more reliable regeneration prediction in the Ozark Highlands Region (Dey and others 1996). Although the new system is recommended for regeneration prediction in the Missouri Ozarks, the more conservative method

Table 5—Mortality of original and new oak reproduction as affected by understory treatment

Understory treatment	Original oak reproduction[a] Mortality	Error mean square	P>F	New oak reproduction[b] Mortality	Error mean square	P>F
Number of stems						
1[c]	1,014			249		
2	1,365	1.49E6	0.88	387	1.58E5	0.27
3	1,278			521		
Percent of total						
1[c]	50			20		
2	69*[d]	3.26E2	.01	32	4.03E2	.01
3	71*			53*		

[a] Original oak reproduction present before treatment.
[b] New oak reproduction established afler treatment.
[c] 1 = All stems treated; 2 = stems >5 ft treated; 3 = no treatment.
[d] Mortality values in columns followed by * are significantly different (a = 0.05).

Table 6-Calculated oak stocking values for oak reproduction present before treatment and 5 and 9 years after treatment as affected by understory treatment

Year	Oak stocking value[a]/understory treatment[b] 1	2	3	Error mean square	P>F
	-Mean stocking values (x10)-				
1979	12.72	16.36	11.36	9.01 El	0.1149
1984	39.70*[c]	57.42**	19.15	3.62E2	.0004
1988	72.31*	97.26*	26.18	1.18E3	.0002

[a] Stocking value is the contribution of oak reproduction to future stand stocking at stand age 20 years (Sander and others 1984).
[b] 1 = All stems treated; 2 = stems >5 ft treated; 3 = no treatment.
[c] Understory means in rows followed by * or ** are significantly different at a = 0.05 and 0.01, respectively.

Sander and others 1984) was used to predict oak stocking values for the Boston Mountain stands in this study. The 1996 Missouri Ozark system was developed for a physiographic region having a different array of major competing understory species and a lower density of competing stems than are common to upland stands on medium and good quality sites in the Boston Mountains.

Calculated oak stocking values for pretreatment stands demonstrate that oak advance reproduction in present undisturbed upland oak stands on medium and good sites is currently inadequate to ensure a significant oak component in the new stands after harvest (table 6). While the mean oak stocking value for all plots averaged 1.4, stocking values averaged 2.1 (range = 0.5 to 3.2) on medium sites and a mean of 0.6 (range = 0.1 to 2.2) on good sites. After treatment, stocking values increased on all plots but stocking values 5 and 9 years after treatment were significantly greater in stands receiving the partial and intensive understory control treatments (table 6). Stands receiving partial treatment produced the greatest initial response, but after 9 years, the stocking values of stands receiving the partial and intensive treatments did not differ significantly. Overstory stocking did not affect oak stocking values. Plots cut to 40 percent overstory density produced average stocking values of 5.6 while stands cut to 60 percent averaged 7.5. Site quality did not significantly affect oak stocking values but the difference between medium and good sites should be silviculturally significant. Plots in site index 60 stands receiving the intensive and partial treatments produced oak stocking values of 11 .O and 14.6, respectively.

Plots on the good oak sites (site index 75) had oak stocking values of 3.5 and 4.9 for intensive and partial treatments, respectively. Based on calculated stocking values for advance reproduction in stands on medium sites with the intensive and partial treatments would require approximately 140 and 115 stump sprouts per acre, respectively, to attain the 30 percent stocking goal. Stands on site index 75 with complete and partial treatments would require about 195 and 185 sprouts per acre, respectively, to reach the 30 percent stocking value (Sander and others 1984). Predicted stump sprouting for residual stands in this study would average only about 20 per acre.

Ash and cherry reproduction will supplement the deficiency in oak stocking and will result in adequate stocking in stands on medium sites. However, on good sites, predicted stocking values for oak, ash, and cherry reproduction would still be less than one-half the recommended target. On both medium and good upland sites, the overstory treatments with partial or intensive understory control significantly increased the numbers of oak, ash, and cherry stems between 1 and 5 ft in height over the 9-year period. Graney and Murphy (1995) found that oak, ash, and cherry reproduction in the I- to 5-ft classes produced the greatest response to the understory treatments. Thus, the first treatment developed a pool of advance reproduction that is now in the height range to produce a significant height growth response to a second understory treatment. A second understory treatment is especially required on the good sites.

MANAGEMENT IMPLICATIONS

On medium and good upland sites in the Boston Mountains, oak advance reproduction is plentiful, but most oak stems are too small to successfully compete with less-desirable species after harvest. Consequently, the overall regeneration potential of the oaks is inadequate. Overstory thinning plus removal of midcanopy stems >1 .6 in. d.b.h. increases growth of oak advance reproduction >3 ft tall, but few stems of this size are present in these mature upland stands. To enhance development of existing small stems and ensure survival and growth of new oak stems established after treatment, intensive understory treatment will be required. Removal of all or most of the competing understory will be necessary if oaks initially 1 to 2 ft tall are to survive and attain adequate size before final overstory removal. In fact, two understory treatments may be required to insure adequate numbers of large stems in these upland stands on medium sites and will certainly be required on good upland sites. Understory treatments can be done chemically or mechanically or by using fire. Treatment by fire may be desirable because it would mimic disturbance dynamics of the past.

Small ash and cherry reproduction is also stimulated by intensive understory control, and one treatment would appear sufficient. Large advance ash and cherry reproduction require only overstory and midcanopy density reduction to compete successfully with other reproduction.

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AN ASSESSMENT OF RESIDUAL STAND CONDITIONS FOLLOWING SHELTERWOOD-WITH-RESERVES CUTS IN APPALACHIAN HARDWOODS[1]

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Abstract-In recent years foresters managing hardwoods in the Southern Appalachians have been investigating a variety of regeneration methods that lead to the development of a two-aged stand. The reserved trees that make up the older age class usually meet a variety of objectives such as timber, wildlife food and cover, and aesthetic values. A series of 20 operational cuts in Appalachian hardwood stands was evaluated 2 to 5 years post-logging. Residual stand characteristics such as species composition, density, volume, grade, and damage were investigated to determine the early fate of the reserve trees. Residual stand density across the 20 stands averaged 39 ft^2/ac, the number of residual trees per acre averaged 47, and the residual stand volume averaged 3,210 bd. ft./ac (Int. ¼"). Most of the residual stands were classified as low-risk (69 percent), and only 8 percent of the trees per ac were either standing dead or blown down 2 to 5 years following the harvest.

INTRODUCTION

For many years, foresters have recommended the use of clearcutting as a method of regeneration for Central Appalachian hardwoods. Clearcutting, followed by site preparation to remove residual small or noncommercial stems, results in a high light environment favorable for the regeneration of many commercial species such as yellow-poplar (*Liriodendron tulipifera*), northern red oak (*Quercus rubra*), and black cherry (*Prunus serotina*). However, public dissatisfaction with the aesthetics of clearcutting, coupled with the desire to manage forests for multiple objectives or on an ecosystem basis, have led to the investigation of alternative practices (Bartuska 1994, Heissenbuttel 1996).

In recent years, a method of cutting that leaves a light, residual overstory of 15 to 20 codominant trees occupying 10 to 20 ft^2 of basal area per ac has emerged. This method has been called deferment cutting (Smith and others 1989), and leads to the development of a two-aged stand (Beck 1986). The cut is heavy enough to stimulate seed germination and sprouting so that regeneration resembles, in both species composition and numbers, that which would be expected following clearcutting (Miller and Schuler 1995, Miller and others 1998). The residual overstory trees mitigate the visual impact of the logging, provide a continuing source of seed, provide food and cover for wildlife, and continue to grow into larger and more valuable trees for future harvest. The regeneration eventually develops into a second age class, hence the term "two-aged stand." The residual overstory may remain in place for as long as the entire next rotation, typically 80 years, or may be gradually removed along with regular thinnings when the younger age class develops to a merchantable size, typically 40 years. This practice, by current definition, is known as shelterwood-with-reserves.

A recent inventory of commercial timber harvests in West Virginia has shown that, while partial cuts are common, planned shelterwood seed or removal cuts are not (Fajvan and others 1998). In a random survey of 99 harvests, only about 20 percent were associated with a planned silvicultural application. Nevertheless, shelterwood-with-reserves is being used by the U.S. Forest Service Monongahela National Forest, and to a lesser extent on forest industry and private nonindustrial lands. This study was established to investigate the residual stand characteristics and regeneration following 20 such operational cuts on the Monongahela National Forest in West Virginia. This paper will report only the stand-level characteristics, individual tree quality characteristics and regeneration having been reported elsewhere (Johnson and others 1998).

METHODS

Study Area

During 1996, 20 tracts were identified on the Monongahela National Forest in West Virginia (table 1). The stands had all received a shelterwood cut two to five growing seasons prior to measurement. Previous studies have shown that butt log epicormic branches and logging wounds appear within two years after cutting, and change little over the next eight years (Smith and others 1994, Miller 1996); thus, it was felt that an evaluation after two growing seasons would be sufficient to evaluate residual quality. The study tracts were located on four ranger districts, and were part of the ongoing timber sale program on the forest. Tracts ranged from 8 to 33 ac in size and occurred in two physiographic provinces and three forest cover types (table 1). Residual stands were generally left to meet aesthetic, timber, and wildlife objectives. Site preparation, which entailed cutting all stems greater than 1 in dbh, but less than 5 in dbh, was completed during or soon after logging in each stand.

Residual Stand Measurements

Both stand level and individual tree measurements were made in each stand. In each stand, BAF 10 prism points were systematically established, at a density of one per ac up to a maximum of 25 per stand. All trees 5.0 in dbh and larger were tallied. From the point sampling data, number of trees per ac, basal area per ac, and International ¼" bd. ft.

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Table l-General description for 20 shelterwood cuts on the Monongahela National Forest

Stand	Ranger District	Area	Physiographic Province	Forest cover type	Site index[a]	Year of harvest	Management objectives[b]
		Acres					
1	Greenbrier	15	Allegheny Mts.	Beech-cherry-maple	78	1993	TWA
2	Greenbrier	13	Allegheny Mts.	Beech-cherry-maple	89	1994	TWA
3	Greenbrier	15	Allegheny Mts.	Beech-cherry-maple	80	1992	TWA
4	Greenbrier	10	Allegheny Mts.	Beech-cherry-maple	70	1993	TWA
5	Greenbrier	10	Allegheny Mts.	Beech-cherry-maple	89	1993	TWA
6	Greenbrier	13	Allegheny Mts.	Beech-cherry-maple	81	1992	TWA
7	Greenbrier	22	Allegheny Mts.	Beech-cherry-maple	69	1993	TWA
8	Greenbrier	13	Allegheny Mts.	Beech-cherry-maple	74	1992	TWA
9	Greenbrier	25	Allegheny Mts.	Mixed Appal. hdwds.	72	1995	TWA
10	Potomac	24	Allegheny Mts.	Mixed Appal. hdwds.	85	1993	TA
11	Potomac	14	Ridge & Valley	Mixed oaks	60	1993	T
12	Potomac	14	Ridge & Valley	Mixed oaks	65	1992	T
13	Potomac	13	Ridge & Valley	Mixed oaks	60	1992	T
14	Potomac	8	Allegheny Mts.	Beech-cherry-maple	58	1992	WA
15	Potomac	33	Ridge & Valley	Mixed oaks	54	1994	TA
16	Potomac	13	Allegheny Mts.	Beech-cherry-maple	58	1992	W
17	Potomac	9	Allegheny Mts.	Beech-cherry-maple	58	1992	W
18	Cheat	10	Allegheny Mts.	Mixed Appal. hdwds.	65	1994	T
19	Cheat	10	Allegheny Mts.	Mixed Appal. hdwds.	75	1994	W
20	Marlinton	24	Allegheny Mts.	Mixed Appal. hdwds.	58	1994	WA

[a] Site index is average ht. in ft of dominant and codominant trees at 50 yrs of age.

[b] Management objectives are timber (T), wildlife (W), and aesthetics (A).

volume per ac were computed by species, risk class, and potential use. Risk classes used were: 1 = low risk of death or blowdown within 10 years; 2 = moderate risk; 3 = high risk of death or blowdown within 10 years; 4 = standing dead with death occurring after the cut; and 5 = blown down after the cut. Trees with low forks, severe lean, weak crowns, and/or advanced decay were generally classed as high risk. Potential use classes were timber or wildlife/aesthetic. Wildlife/aesthetic trees were residual trees of non-commercial species or commercial species that were of such poor quality before logging as to render them non-merchantable. Timber trees were of a commercially desirable species and contained merchantable volume for pulpwood or sawtimber.

RESULTS

Four of the ranger districts on the Monongahela National Forest have adopted the shelterwood-with-reserves method as a standard practice. The oldest of the cuts surveyed was completed in 1992, while the most recent were completed in 1995 (table 1). Harvest tracts ranged from 8 to 33 ac in size, and occurred in three primary forest cover types — beech-cherry-maple, mixed Appalachian hardwoods, and mixed oaks. The beech-cherry-maple cover type occurs at the higher elevations in the Allegheny Mountains, and consists of American beech (*Fagus grandifolia*), black cherry, sugar maple (*Acer saccharum*), sweet birch (*Betula lenta*), yellow birch (*B. alleghaniensis*), and red maple (*A. rubrum*). Lesser amounts of white ash (*Fraxinus americana)* and eastern hemlock (*Tsuga canadensis)* occur. Site index averaged 73 feet at base age 50 years. The mixed Appalachian hardwoods also occur west of the Allegheny Front, but at lower elevations. Typical species include yellow-poplar, northern red oak, sugar maple, white ash, and American basswood (*Tilia americana),* and site index averages 71 feet. The mixed oaks occur on the drier sites in the Ridge and Valley Physiographic Province east of the Allegheny Mountains. Site index for the mixed oak stands surveyed in this study averaged 60 ft. at 50 years (table 1). Typical species include white oak (Q. *alba*), chestnut oak (Q. *prinus*), black oak (Q. *velutina*), scarlet oak (Q. *coccinea),* and various hickories (*Carya* spp.). Management objectives for the harvested tracts varied somewhat by ranger district (table 1). For example, on the Greenbrier Ranger District, the multiple objectives of timber production, wildlife habitat, and aesthetic concerns controlled the selection of reserve trees. Timber production alone was an objective for three stands on the Potomac Ranger District, and one stand on the Cheat Ranger District (table 1). The decision to adopt the shelterwood-with-reserves method and create two-aged stands was mainly driven by wildlife and aesthetic concerns, but was made easier because the method had been researched from a timber management perspective (Miller and others 1997).

There are usually several objectives to be met by the shelterwood-with-reserves method. The cut must be heavy enough to allow for adequate regeneration of desirable species, the residual stand must be dense enough to insure that visual quality is maintained, and the residual trees should remain healthy to maintain visual quality and satisfy future timber and wildlife needs. It is important, therefore, that the cut lead to adequate regeneration of a new age class, and the residual stand remain intact with minimal mortality, blowdown, or grade loss. General characteristics for the 20 stands measured in this study are presented in Tables 2 and 3. Residual basal area ranged from 6 to 75 ff per ac, and averaged 39 ft^2 per ac. Current guidelines call for two-aged residual basal areas to range from 10 to 40 ft^2 of basal area per ac. Half the stands in this study fell within that range, with most of the rest above. The residual trees per ac numbered, on average, 47, with a range of 8 to 74. This total includes both pulpwood and sawtimber-sized

Table P-Residual stand characteristics for 20 shelterwood cuts on the Monongahela National Forest

Stand	Basal area	Number of trees	Volume/acre
	Ft^2 per acre	*Trees per acre*	*Int. ¼" bf*
1	58	63	5,920
2	75	74	6,020
3	40	43	3,540
4	47	48	3,640
5	29	46	1,330
6	39	32	3,600
7	31	40	2,190
8	70	66	6,250
9	58	67	5,220
10	32	38	2,520
11	46	58	3,790
12	51	72	3,730
13	23	26	2,090
14	12	21	570
15	42	47	3,400
16	14	22	750
17	6	8	520
18	44	81	3,250
19	35	34	3,770
20	31	59	1,880
Means	39	47	3,210

Table 3-Residual basal area, number of trees, and volume by risk classes following two-aged cutting of 20 tracts on the Monongahela National Forest

Risk class[a]	Basal area			Number of trees			Volume per acre		
	Mean	Standard error	Range	Mean	Standard error	Range	Mean	Standard error	Range
	------ *Ft^2 per acre* -------			----- *Trees per acre* -----			-------- *Int. ¼" bf* --------		
1	26.9	3.0	4.0-48.8	30.4	3.2	5.1-53.2	2,490	336	1,280-3,150
2	5.9	.7	.0-12.0	8.4	1.0	.0-19.4	380	59	130- 550
3	3.4	.8	.o-14.0	4.5	.9	.o-14.0	160	37	50- 170
4	1.5	.4	.O- 6.0	1.8	.5	.O- 6.1	80	24	o- 130
5	1.4	.4	.O- 6.0	2.1	.7	.0-11.7	100	32	0- 160
Total	39.1	—[b]	—	47.2	—	—	3,210	—	—

[a] Risk classes: 1 = low; 2 = moderate; 3 = high; 4 = standing dead with death occurring after cut; 5 = blown down after cut.
[b] No value.

trees. Volumes ranged from 520 to 6250 bd. ft. per ac, with an average of 3210. Across all stands the dominant risk class was low. For example, 69 percent of the basal area and 64 percent of the trees were classified as low-risk. Loss due to standing mortality and blowdown was also low. On average, only 7 percent of the basal area and 8 percent of the trees per ac fell into these classes. If high-risk trees eventually die, mortality may rise to 16 percent (table 3).

As trees were sampled, any that had commercial value due to size, species, and quality, were classified as timber trees. Culls, trees with cavities, and noncommercial trees with hard or soft mast potential are examples of trees that were classified as wildlife trees. The distribution of trees by use class is presented in Table 4. A relatively small proportion of the residual trees did not have commercial value. For example, the basal areas and volumes shown for wildlife trees in Table 4 represent only 9 to 20 percent of the residual basal area, and 9 to 11 percent of the residual board foot volume. It is also important to point out that many trees, such as all the oaks, can meet both objectives.

The species distribution of reserve trees is shown in Table 5. In the beech-cherry-maple type, American beech comprised the majority of the residual basal area. This species, while having low commercial value, has a high wildlife value due to hard mast production. Additionally, many of the larger, old beech trees also have cavities. Interestingly, 18 percent of the residual basal area in this type is comprised of black cherry, the highest-value species. In the mixed Appalachian hardwood type, northern red oak and sugar maple dominated the residual stand, while in the mixed oak type northern red oak and chestnut oak comprised the majority of the residual basal area (table 5). The mast-producing oaks, important to wildlife, comprised 41 percent of the residual basal area in the mixed Appalachian hardwood stands and 45 percent in the mixed oak stands in the Ridge and Valley.

Table 4-Distribution of basal area, number of trees, and volumes by use classes for 20 residual stands following two-aged cutting on the Monongahela National Forest

Ranger District	n	Basal area		Number of trees		Volume	
		Timber	Wildlife	Timber	Wildlife	Timber	Wildlife
		- - - Ft^2 per acre - - -		- - Trees per acre - -		- - Bd. ft. per acre - -	
Greenbrier	9	39.7	9.7	43.2	9.9	3,770	420
Potomac	8	24.2	4.0	31.9	4.6	1,930	250
Cheat	2	35.9	3.7	54.1	3.3	3,190	320
Marlinton	1	27.8	3.7	52.1	9.4	1,710	180

Table 5—Dominant species composition, expressed as a percentage of basal area, in 20 residual stands following two-aged cutting on the Monongahela National Forest

Species	Physiography and forest cover type		
	Allegheny Mountains beech-cherry-maple (n= 11)	Allegheny Mts. mixed Appalachian hardwoods (n = 5)	Ridge & Valley mixed oaks (n = 4)
	- - - - - - - - - - Percent	- - - - - - - - - -	
American beech	36	5	0
Black cherry	18	3	0
N. red oak	1	26	19
Sugar maple	21	20	8
Red maple	12	7	9
Yellow-poplar	1	2	6
American basswood	0	8	0
White oak	0	8	8
Chestnut oak	0	7	18
Other species[a]	11	15	31

[a] Other species include red spruce (*Picea rubens*), eastern hemlock, white ash, sweet birch, yellow birch, misc. hickories, serviceberry (*Amelanchier arborea*), scarlet oak, black oak, black walnut (*Juglans nigra*), blackgum (*Nyssa sylvatica*), black locust (*Robinia pseudoacacia*), slippery elm (*Ulmus rubra*), and pitch pine (*Pinus rigida*).

DISCUSSION

The purpose of this study was to evaluate reserve shelterwood stands from a timber perspective. This is still a relatively new practice, and future applications will depend upon knowledge and experience developed by the current practitioners. Nine of the 20 stands, or 45 percent, were left with a residual overstory above the original goal, indicating that foresters are reluctant to mark the stands heavily. In some stands, clumps of trees were left for wildlife purposes. In these areas the potential for regenerating shade-intolerant species is relatively low. Maintaining a large residual overstory is likely to be detrimental in the long run, and certainly the 40 ft^2/ac basal area should be considered an upper limit. For example, if 40 trees, each 14" in dbh, were left per acre as a residual, the stand would be at the upper limit of 40 ft^2/ac basal area. Assuming no mortality and an average growth rate of two inches per decade, after 40 years each tree will have a dbh of 22 in, or a basal area of 2.64 ft^2. This represents a stand basal area of 106 ft^2/ac, a fully stocked condition with no room for a younger age class struggling to reach the main canopy. In a case like this, it is obvious that some intermediate treatments in the residual stand will be necessary to create more growing space for the new age class of trees.

Although the intent of this study was not to evaluate the wildlife or aesthetic values of the stands, subjective observations indicate that these goals will be met as well. Large proportions of the residual stands are comprised of soft and hard mast-producing species like black cherry, American beech, northern red oak, white oak, and chestnut oak. A recent evaluation of several IO- to 15-year-old two-aged stands in West Virginia has shown that the practice results in a diversity of woody species and vertical structures. Songbird density counts were higher in the two-aged stands than in adjacent even-aged stands over a two-year observation period (Miller and others 1995). Further evaluation of the wildlife implications of two-aged cuts is progressing.

Two-aged cuts appear to mitigate the visual impact of timber harvesting, at least after several years. Figure 1 shows a background, middleground, and foreground sequence of a two-aged cut on the Potomac Ranger District, taken during late spring. The area is not highly visible from a distance, and has the appearance of a heavily thinned area up close. Figure 2 shows an interior view of a two-aged stand four years following the cut. Site preparation, which removes stems from 1 to 5 in dbh, increases the visual penetration.

A

B

C

Figure I-(A) A two-aged cut on the Potomac Ranger District viewed from background; (B) A two-aged cut on the Potomac Ranger District viewed from middleground; (C) A two-aged cut on the Potomac Ranger District viewed from foreground.

Figure 2-Interior view of a two-aged stand 4 years following the cut.

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RESPONSE OF VASCULAR PLANT COMMUNITIES TO HARVEST IN SOUTHERN APPALACHIAN MIXED-OAK FORESTS: TWO-YEAR RESULTS'

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Abstract-A long-term study has been established to monitor the effects of seven silvicultural prescriptions on vascular flora community attributes. Treatments include a control, understory vegetation control, group selection, two levels of shelterwoods, leave-tree, and clearcut. Second growing season, post-treatment results are compared to pre-harvest values for residual basal area, residual mean diameter, and species richness. Species richness is a count of species per defined unit of area. Species richness is reported for tree, shrub, and herb strata, as well as at an overall treatment level. Following treatment, mean residual basal area and diameters are within or near cutting specification ranges for all treatments. Tree stratum species richness declines with increasing canopy disturbance. Shrub stratum species richness appears unaffected by treatment. Similarly, richness of woody species in the herb stratum does not change in response to treatment. An increase in richness of non-woody species in the herb stratum is detectable at a large sampling scale, but not at finer scales.

INTRODUCTION

The management of forested lands for wood products and the maintenance of biological diversity are often not perceived as compatible. The ongoing discussion between forest managers and a public that is increasingly critical of commercial forestry practices-most notably timber harvesting-warrants greater consideration for understanding ecosystem condition in future management regimes. Already land management agencies, the forest industry, and professional forestry organizations have taken steps toward achieving this end. The National Forest Management Act of 1976 mandates the preservation of diversity on all federally managed lands. A task force assembled by the Society of American Foresters (1991) extended its recommendations for maintaining, and where appropriate, enhancing diversity, to all professional foresters working on both public and private lands. The framework, however, for developing a national strategy to achieve these goals did not exist in the early 1990's, and as yet is only in the development stages (Salwasser 1990). Fundamental to that framework, but noticeably lacking, is experimental data demonstrating how natural patterns of diversity and species composition are affected by forest management practices (Roberts and Gilliam 1995).

In May of 1993, the Virginia Polytechnic Institute and State University, College of Forestry and Wildlife Resources, in cooperation with the Jefferson National Forest, the Southern Research Station, and the Westvaco Corporation initiated a long-term study entitled, "The Impacts of Silviculture on Biodiversity in the Southern Appalachians". The objective of this undertaking is to quantify changes in floral and salamander community attributes over time in response to seven silvicultural treatments. The short-term response of salamanders has been reported elsewhere (Harpole and Haas 1999); this report addresses only changes in the vascular plant community. Specifically, we examined short-term changes in woody and herbaceous plant species richness in response to different levels of canopy removal associated with seven silvicultural treatments.

STUDY AREA

Each of the three 14-ha study sites is located within the Ridge and Valley physiographic province of southwest Virginia. Site selection criteria were stand age, site quality, elevation, aspect, forest type, and recent disturbance history. Sites were to represent south-facing, moderately productive, mixed-oak stands at elevations of 600-l 200 m. Sites were to be composed of a contiguous, harvestable stand whose dominant trees were age 60-120. Only sites that appeared to be free of silvicultural disturbance for the previous 15 years were selected. Sites were established on the Jefferson National Forest; the Blacksburg 1 (BB1) and Blacksburg 2 (BB2) sites are located in the Blacksburg Ranger District, while the New Castle (NC) site is located in the New Castle Ranger District.

METHODS

Study Design

A randomized complete block (RCB) experiment with sub-sampling was established with three replicate sites. Each 14-ha study site is divided into seven 2-ha treatment plots to which the seven silvicultural prescriptions were applied. Treatment application was completed in March 1995 for BB1 and June 1996 for both BB2 and NC. Treatments include a control, understory vegetation control, group selection harvest, two levels of shelterwood harvests, a leave-tree harvest, and a clearcut. Understory vegetation control was achieved via streamline basal applications of Garlon 4 and Stalker to undesirable midstory stems. The objective of the chemical control was to favor advance regeneration of preferred species, particularly oaks (*Quercus* spp.). The group selection treatment consisted of up to three harvest groups whose diameters were not to exceed twice the height of the adjacent canopy. The stand was thinned between groups. The two shelterwood harvests differed in the basal area and size distribution of residual stems. The high-leave shelterwood retained 12-14 m^2/ha of dominant canopy basal area. The low-leave shelterwood retained 4-7 m^2/ha of pole timber basal area. The residual stands in each shelterwood treatment may be harvested as deemed necessary following

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future stand evaluation. The leave-tree harvest was not to exceed 4-6 m^2/ha in sawtimber trees intended to remain throughout the rotation. All stems to 5 cm diameter at breast height (dbh) were removed in the clearcut treatments.

Vegetation was sampled using a nested plot design. Species composition lists of all vascular flora were compiled by conducting a 100 percent walk through inventory of each 2-ha treatment plot. Nested within each treatment plot are three randomly located 24x24 m tree plots. The species, dbh, canopy position, and spatial location were recorded for each tree within a tree plot. The tree stratum was defined as all stems >5 m. Tree plots were further divided into sixteen 6x6 m shrub plots. Three randomly selected shrub plots were used to record crown diameter and number of rootstocks by species within the shrub stratum. Shrubs were defined as those stems I-5 m in height. The herbaceous stratum was sampled in 1x1 m herb plots systematically nested along the perimeter of tree plots. Of the eight herb plots per tree plot, six were randomly selected and sampled. Attributes measured in herb plots were number of individuals and percent cover by species. The herb stratum includes all woody and non-woody stems <1 m in height. Herb plot sampling and treatment plot walk through inventories were performed in mid-May to early June and again in early August in order to account for differences in early and late season species assemblages. Shrub and tree plots were sampled only once in June. Pre-treatment sampling was conducted on all sites the growing season immediately prior to treatment application. BB1, therefore, was first sampled in 1993 while BB2 and NC were sampled in 1995. Post-treatment sampling was conducted the second full growing season following treatment application: BB1 in 1996, BB2 and NC in 1998. Pre- vs. post-harvest comparisons allowed for an initial assessment of treatment effects on plant community attributes.

Data Analysis

Species richness is calculated as the number of species per unit of area. Richness values are not comparable across different units of area. Changes in woody, herbaceous, and total species richness were evaluated by stratum and at the 2-ha treatment level. Tree species richness was tallied as the mean number of species per 576-m' tree plot. Shrub plots within each tree plot were pooled and averaged across tree plots to determine number of shrub species per 108 m^2. Similarly, herb plots were pooled and averaged across tree plots to determine number of herb-stratum species per 6 m^2. Analysis of variance (ANOVA) for a RCB experiment and Tukey's Multiple Comparison Test were used to determine those treatments in which mean pre- vs. post-treatment plot richness values differed significantly (α=0.10).

RESULTS AND DISCUSSION

Canopy Removal

Prior to treatment, mean basal area for three sites ranged from 23.6 to 29.6 m^2/ha for the seven treatments (table 1). Mean tree dbh ranged from 13.7 to 15.7 cm. Treatment application resulted in residual basal area and dbh values that are consistent with treatment specifications. Values in the control and understory vegetation control treatments remained largely unchanged. Approximately half of the total treatment plot basal area was removed in the group selection treatment. The high-leave shelterwood plots retained only slightly less basal area than desired and exhibited an expected increase in mean dbh. The low-leave shelterwood treatment also retained slightly lower than anticipated basal area, but exhibited an expected decrease in dbh. Basal area for the leave-tree treatment was within the target range, and the large increase in mean dbh reflects the selection of saw-timber trees as residuals. Basal area within the clearcut treatment was negligible. Treatments effectively represent a variable range of canopy manipulation and stand structure, and consequently represent a full range of light conditions on the forest floor. Meier and others (1995) cited changes in forest floor light conditions as a mechanism for change in species diversity for harvested Appalachian hardwood stands.

Species Richness

In the pre-treatment condition, mean number of tree species per 576 m^2 tree plot ranged from 8.9 to 11 species (table 2). Significant reductions in tree species richness were observed in treatments associated with the highest levels of

Table I-Pre-treatment vs. post-treatment mean basal area (m^2/ha) and diameter at breast height (cm) for each of seven silvicultural treatments. Mean of Blacksburg 1, Blacksburg 2, and New Castle study sites on Jefferson National Forest, southwest VA

	Pre-treatment		Post-treatment	
Treatment	Basal area	D.b.h.	Basal area	D.b.h.
Control	23.6	13.7	23.9	13.7
Understory herbicide	27.3	14.0	28.9	16.0
Group selection	27.8	14.5	12.6	16.3
High-leave shelterwood	28.0	14.0	11.7	18.3
Low-leave shelterwood	28.9	15.7	3.0	14.5
Leave-tree	28.0	14.7	2.8	22.4
Clearcut	29.6	14.2	0.5	9.1

Table 2-Changes in tree stratum species richness, 2 years post treatment for each of seven silvicultural treatments. Mean of Blacksburg 1, Blacksburg 2, and New Castle study sites on Jefferson National Forest, Southwest VA

	Species richness (per 576 m^2)[a]		
Treatment	Pre-treatment	Post-treatment	Net change
Control	9.3	9.9	0.6
Understory herbicide	10.6	9.8	-0.8
Group selection	10.6	7.6	-3.0
High-leave shelterwood	9.2	6.6[b]	-2.6
Low-leave shelterwood	10.8	3.9[b]	-5.7
Clearcut	9.9	1.8[b]	-8.1

[a] Number of species per 576-m' tree plot.
[b] Post-treatment species richness significantly lower than pre-treatment values (a = 0.1).

canopy disturbance. The clearcut, leave-tree, and low-leave shelterwood treatments respectively retained only 1.8, 3.2, and 3.9 species/576 m^2. Absence of species from the tree plot does not reflect an absence of a species from the treatment plot, and may be a function of changes in species evenness, rather than a treatment level change in richness. Additionally, the absence of a species in the tree stratum does not preclude its existence in the shrub or herb strata.

Shrub species richness in pre-treatment plots ranged from 6.2 to 9.2 species/l08 m^2 (table 3). No change in shrub species richness in response to treatment was observed. While harvesting reduced richness of the main canopy in the tree plots, there is no reason to suspect that the shrub stratum would be similarly affected.

Neither the richness of woody species or non-woody species in the herb stratum was affected by treatment. Number of woody species ranged from 11.6 to 14.0 species/6 m^2 before treatment (table 4). The number of non-woody species ranged from 4.1 to 11.4 species/6 m^2 (table 5). Species richness was anticipated to increase within the herb stratum in response to canopy manipulation. The apparent lack of such a tendency does not mean that richness did not increase, but only that it was not detectable at such a small scale of sampling.

Results from the 2-ha walk through inventories support the claim that herb stratum species richness increased following canopy removal. Significant increases in non-woody species richness were observed in the group selection, high-leave

Table 3-Changes in shrub stratum species richness, 2 years post treatment for each of seven silvicultural treatments. Mean of Blacksburg 1, Blacksburg 2, and New Castle study sites on Jefferson National Forest, southwest VA

	Species richness[a] (per 108 m^2)[b]		
Treatment	Pre-treatment	Post-treatment	Net change
Control	9.2	7.4	-1.8
Understory herbicide	9.1	6.9	-2.2
Group selection	7.7	7.9	0.2
High-leave shelterwood	7.0	6.3	-0.7
Low-leave shelterwood	7.0	5.7	-1.3
Leave-tree	9.0	6.2	-2.8
Clearcut	6.2	4.8	-1.4

[a] No significant difference between pre- and post-treatment species richness for any treatment (a=O.l).
[b] Number of species per three 36-m^2 shrub plots.

Table 4-Changes in woody species richness in the herb stratum, 2 years post treatment for each of seven silvicultural treatments. Mean of Blacksburg 1, Blacksburg 2, and New Castle study sites on Jefferson National Forest, southwest VA

	Species richness[a] (per 6 m^2)[b]		
Treatment	Pre-treatment	Post-treatment	Net change
Control	13.6	15.4	1.8
Understory herbicide	12.9	14.0	1.1
Group selection	13.7	16.8	3.1
High-leave shelterwood	12.3	16.8	4.5
Low-leave shelterwood	11.3	16.2	4.6
Leave-tree	13.3	15.4	2.1
Clearcut	14.0	16.9	2.9

[a] No significant difference between pre- and post-treatment species richness for any treatment (a = 0.1).
[b] Number of species per six 1-m^2 herb plots.

Table 5—Changes in non-woody species richness in the herb stratum, 2 years post treatment for each of seven silvicultural treatments. Mean of Blacksburg 1, Blacksburg 2, and New Castle study sites on Jefferson National Forest, southwest VA

	Species richness[a] (per 6 m^2)[b]		
Treatment	Pre-treatment	Post-treatment	Net change
Control	10.4	10.3	-0.1
Understory herbicide	8.8	8.0	-0.8
Group selection	11.3	6.3	19.6
High-leave shelterwood	5.1	9.6	-5.0
Low-leave shelterwood	6.6	12.7	6.8
Leave-tree	11.4	18.2	4.5
Clearcut	4.1	23.7	6.1

[a] No significant difference between pre- and post-treatment species richness for any treatment (a = 0.1).
[b] Number of species per six 1-m^2 herb plots.

shelterwood, leave-tree, and clearcut treatments (table 6). Extreme variability in the response of the three replicates to the low-leave shelter-wood precluded that treatment from exhibiting significant results. Results suggest that small area sampling plots may be inappropriate for detecting changes in species richness for herbaceous species.

Walk through inventories revealed no significant changes in the number of woody species at the treatment plot level. Number of pre-treatment species ranged from 32 to 39 species/2 ha (table 7). Tree species not detected at the tree plot level on highly disturbed treatments were observed at the treatment plot level.

CONCLUSION

Initial analyses of changes in species richness demonstrate a reduction of species in the tree stratum for high-disturbance treatments. Shrub stratum species richness appears unaffected, regardless of level of overstory manipulation. Significant increases in non-woody species richness were observed at a treatment plot level, but not at the finer herb plot level.

The reported results represent only two growing seasons of what is intended to be at least a 50-year undertaking. To date, seven sites have been established and treated in the Ridge and Valley and Allegheny Plateau physiographic regions of Virginia and West Virginia. Expansion to the Piedmont region of Virginia is being considered. The initial post-treatment vegetation sampling will be complete on all treated sites by August of 2000. Study sites will continue to be sampled at periodic intervals to monitor long-term changes in plant community attributes. By coupling the vascular flora and salamander components of this study, the resulting data on rates and magnitudes of changes within these communities will serve as an assay of ecosystem conditions and recovery from disturbance resulting from forest management practices.

Table S-Changes in non-woody species richness per treatment plot, 2 years post treatment for each of seven silvicultural treatments. Mean of Blacksburg 1, Blacksburg 2, and New Castle study sites on Jefferson National Forest, southwest VA

	Species richness (per 2 ha)[a]		
Treatment	Pre-treatment	Post-treatment	Net change
Control	51	78	27
Understory herbicide	44	71	27
Group selection	50	115[b]	65
High-leave shelterwood	35	92[b]	57
Low-leave shelterwood	52	150	98
Leave-tree	36	138[b]	102
Clearcut	43	124[b]	98

[a] Number of species per 2-ha treatment plot.
[b] Post-treatment species richness significantly higher than pre-treatment value (a = 0.1).

Table 7—Changes in woody species richness per treatment plot, 2 years post treatment for each of seven silvicultural treatments. Mean of Blacksburg 1, Blacksburg 2, and New Castle study sites on Jefferson National Forest, southwest VA

	Species richness[a] (per 2 ha)[b]		
Treatment	Pre-treatment	Post-treatment	Net change
Control	37	38	1
Understory herbicide	36	39	3
Group selection	39	44	5
High-leave shelterwood	32	39	7
Low-leave shelterwood	35	44	9
Leave-tree	38	43	5
Clearcut	35	41	6

[a] No significant difference between pre- and post-treatment species richness for any treatment (a = 0.1).
[b] Number of species per 2-ha treatment plot.

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AN EVALUATION OF BIOLOGICAL CONSTRAINTS TO THE EARLY GROWTH OF NATURAL HARDWOOD REGENERATION ON NORTH CAROLINA PIEDMONT CLEARCUTS[1]

Mark A. Romagosa and Daniel J. Robison[2]

Abstract-Replicated 10 m^2 plots were installed on three clearcuts in the Piedmont to release hardwood regeneration from various biological constraints. Treatments consisted of, 1) control, 2) hand weeding, 3) insecticide + fungicide + mammal repellent (the "pesticide" treatment), and 4) hand-weeding + the pesticide treatment. Treatments were applied regularly throughout the first and second growing seasons (1997 and 1998). Heights (h), basal diameters (d), and survival/recruitment of hardwood regeneration were assessed monthly. By the end of the second growing season, the d^2h volume index for individual stems was significantly greater ($p < 0.05$) for the hand weeding + pesticide treatments than on control plots for all three sites. These differences ranged from 3 to 25 times greater among the three sites. Additionally, during year two, paired 10 m^2 plots consisting of fenced exclosures and unprotected areas were installed to estimate white-tailed deer (*Odocoileus virginianus*) browse pressure. The d^2h volume index was three times greater in the exclosure treatment.

INTRODUCTION

Hardwood regeneration may be the most important and complex phase of natural hardwood forest management. In some regions, decline in the regeneration of valuable hardwood species is of particular concern to forest managers and has become a widespread problem in the last 50 years (Lorimer 1993). Especially confounding are situations where viable seeds, seedlings, and sprouts are abundant in even-aged regeneration, yet subsequent losses prevent adequate stand establishment of desirable species. Biological constraints such as fungi (Korstian 1927), insects (Galford and others 1991), weeds, and browsing mammals (Brenneman 1983, Von Althen 1983), in addition to tree-tree competition, have been cited as reasons for insufficient hardwood regeneration; however, these constraints remain a relatively poorly understood component of the regeneration process.

Stanosz (1994) provided some insight into the constraining effects of fungal and insect pests on hardwood regeneration when he demonstrated increased survival of sugar maple seedlings by using systemic pesticides (fungicide and insecticide) to control pests. Weeds have been recognized by foresters as a hindrance to the regeneration process since the early 1900's (Walstad 1981). Moreover, competition from weeds is often considered the biological constraint that is most threatening to successful hardwood regeneration. Browsing of young trees by deer can lead to substantial declines in height growth for many important hardwood timber species (Harlow and Downing 1970, Tierson and others 1966). Furthermore, browse pressure has recently intensified due to rapidly increasing deer populations over the past 50 years (Michael 1989).

These biological constraints may lead to changes in species composition, inadequate stocking, and diminished growth and productivity, all of which contribute to delayed stand establishment and/or development. In order to effectively manage for adequate regeneration that will meet the timber demands on hardwood forests, a more complete understanding of biological constraints to hardwood regeneration is essential.

The objectives of this study were to examine the growth and survival responses of natural hardwood regeneration (seedling and sprout origin) during the first and second years following clearcutting, and to experimentally manipulate these responses by limiting some of the biological determinants of regeneration success. Replicated treatments on three sites were applied to mimic the effects of competition with non-hardwood species, browsing insects and mammals, and fungal diseases, and to measure regeneration success under various combinations of these treatments.

METHODS

Site Descriptions

Three clearcuts (Sites A, B, and C) on two forests in the lower Piedmont were selected as research sites. The forests, Schenck Memorial (Wake County) and Hill Demonstration (Durham County), are properties of the Department of Forestry at North Carolina State University. The sites were salvage clearcut during the winter of 1996/97 in response to impacts from Hurricane Fran (September 6, 1996). Clearcutting provided the sites with rising, putatively, one-year-old regeneration for this study.

Sites A and B are located within Schenck Forest and Site C is within Hill Forest. Site A was 2.5 hectares (ha) and was principally comprised of a natural stand of 89-year-old loblolly pine (*Pinus taeda*) before clearcutting. Site B was 1.4 ha and was principally comprised of a natural stand of 88-year-old hardwoods (predominantly Quercus species) prior to cutting. Site C was 1.2 ha and was principally comprised of a 42-year-old loblolly pine plantation prior to cutting. A summary of regenerating stand data is presented in Table 1.

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18. 1999.

[2] Graduate Research Assistant and Assistant Professor and Director-Hardwood Research Cooperative, Department of Forestry, North Carolina State University, Raleigh, NC 276958008, respectively.

Table l-Regenerating stand data recorded at the start of the study in July 1997

Site	Stems/ha	Seed origin	No. of species	Three most dominant species
		Percent		*Percent of total stems*
A	5,323	93	13	*Liriodendron tulipifera* (61) *Acer rubrum* (24) *Liquidambar styraciflua* (6)
B	15,477	94	11	*Liriodendron tulipifera* (70) *Acer rubrum* (13) *Quercus alba* (5)
C	6,751	49	17	*Acer rubrum* (23) *Liriodendron tulipifera* (20) *Cercis canadensis* (16) (redbud)

Experimental Design and Sampling

Fungi, insects, weeds, and browsing

mammals-Beginning in July, 1997, **four treatments were** applied during the first two growing seasons-(l) Pesticide Treatment – every six weeks **a foliar/stem** application of Ro-pel® animal repellent in 1997 and Deer-Away@ repellent in 1998; and biweekly a tank mixture of the broad-spectrum insecticide acephate (Orthene® at 1 .16 g/L water) + the broad-spectrum fungicide benomyl (Benlate® at 0.69 g/L water), (2) Weeded Treatment – biweekly shear weeds (all non-hardwoods) at ground level with hand-pruners, (3) Pesticide + Weeded Treatments, and (4) Untreated Control.

Treatment plot dimensions were 3.16 m x 3.16 m (10 m^2). Plot size was established by constructing species/area and density/area curves. These relationships suggested that a 10 m^2 plot would adequately capture all hardwood species present on the sites, but not necessarily provide an accurate estimate of stem density. However, it was decided that 10 m^2 was a logistically limiting size, and stem density findings would have to be evaluated with this consideration.

Plots were installed in randomized complete blocks. Blocks were established to minimize the effects of slope and soil changes across the sites. Site A had sufficient space to accommodate four replications (blocks) of all four treatments. Sites B and C were somewhat space-limited, and therefore included only four replications of treatments 1 and 4, and 1, 3, and 4, respectively.

Measurements were taken on a monthly basis throughout the two growing seasons- (1) Heights -from ground-line to the terminal bud (± 0.1 cm) of every stem (including individual stems within coppice clumps), (2) Diameters – at ground-line with calipers (± 0.1 mm), and (3) Stem Densities – stem count per 10 m^2 plot.

Deer exclosures-In June 1998, four replications of two additional treatments were installed at Site B. Treatments were, (1) weeding + deer exclusion and, (2) weeding only (control). Weeding consisted of shearing weeds (all non-hardwoods) at ground level with hand-pruners monthly from June to September. Fenced exclosures were constructed to prevent deer browse. To frame the exclosures, galvanized electrical conduit was cut to 1.5 m lengths and driven into the ground at the corners of the plots. Galvanized poultry wire was stretched around the conduit frame and across the top of each plot. The same measurements, as previously described, were taken on these plots.

Data Analyses

Diameter (d) and height (h) were used to calculate a volume index (d^2h) for each measured stem. Means for each plot were obtained for the volume index and the stem density data. These means were analyzed with **a** repeated measures analysis of variance within the General Linear Models (GLM) procedure of Statistical Analysis System (SAS). Means were separated according to the Ryan-Einot-Gabriel-Welsch (REGWQ) multiple comparison procedure.

RESULTS AND DISCUSSION

Fungi, Insects, Weeds, and Browsing Mammals

By September of the first growing season (1997), volume index at Sites A, B, and C began to differ ($p < 0.05$) by treatment. By September of the second growing season, stems receiving the pesticide + weeded treatment averaged 33, 11, and 2 times greater volumes than stems in control plots for Sites A, B, and C, respectively (fig. 1). Also by September of the second growing season, stems receiving the weeded treatment (Site A only) averaged 13 times greater volume than stems in control plots. The pesticide treatment (Sites A and C) did not differ ($p > 0.05$) from the control. However, figure 1 suggests the combination of pesticides and weeding results in a synergistic effect on volume growth when compared to weeding and pesticide treatments separately.

These findings suggest that competition from weeds was the primary constraint on growth, and that the impacts of fungi, insects, and mammals are more difficult to understand. While there was substantial deer browse, it did not contribute to stem mortality, and browsed stems continued

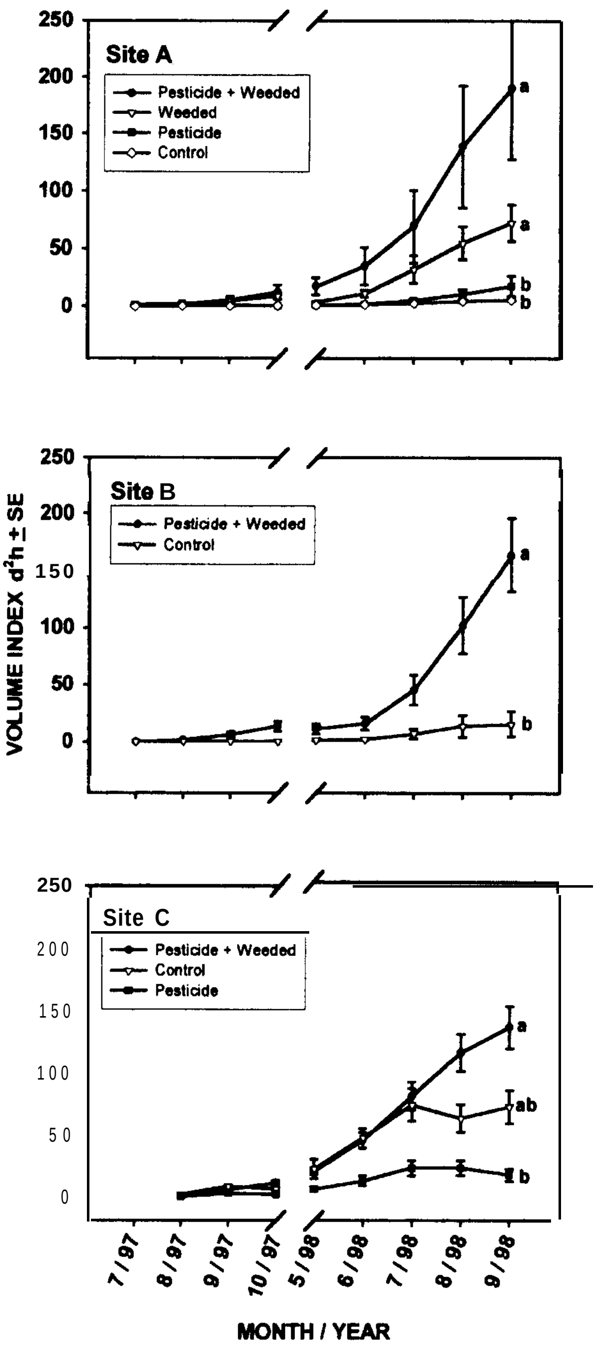

Figure I-Mean volume index for hardwoods (all species; seed- and sprout-origin) during the first and second growing seasons following clearcutting under different treatments on three North Carolina Piedmont sites; lines followed by different letters are significantly different by repeated measures ANOVA and separated by the REGWQ procedure, $p \leq 0.05$.

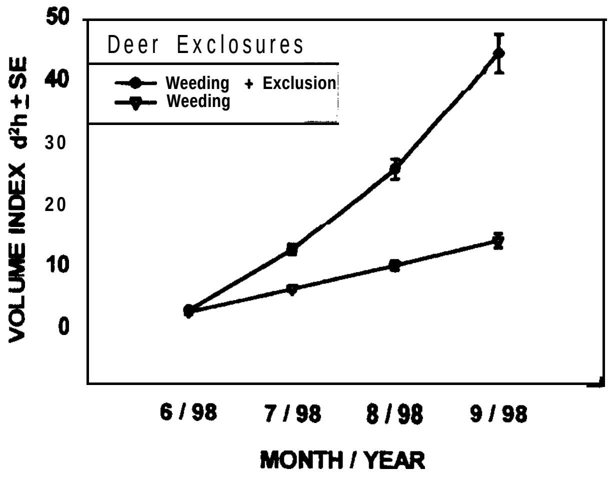

Figure 2-Mean volume index growth of hardwoods during their second growing season after clearcutting under different treatments (exclusion from deer browse) on a North Carolina Piedmont site (Schenck Forest Site B).

to grow, particularly in diameter. There was also evidence of limited insect defoliation and fungal leaf spot disease, but ot at severe levels. Analyses of treatment effects on stem density are inconclusive, as was likely due to plot size limitations (as described previously). However, had fungus, insect, or browsing mammal populations been higher, the treatments may have influenced survival/recruitment in measurable ways.

Deer Exclosures

The volume index for stems within exclosures and in control plots diverged continuously throughout the measurement period (fig. 2). The final measurement (taken in September 1998) showed the greatest difference ($p = 0.07$) between the treatments. If the deer exclusions were maintained for a few more seasons during the early stages of stand development, it is likely that the treatments will continue to diverge (Harlow and Downing 1970).

CONCLUSIONS

Competing vegetation was a significant constraint to the growth of hardwood regeneration. Weeding activities were shown to be relatively more important than pesticide applications (evaluated at Site A only). Release from competition alone provided a 13-fold increase in volume index (Site A only). The general effect of pesticides on the growth of hardwood regeneration with low pest levels is unclear; however, where the pesticide + weeded treatment was applied, growth was 2- to 33-fold greater than in the control.

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EFFECTS OF TREE SHELTERS ON GROWTH OF HARDWOOD SEEDLINGS AFTER SEVEN GROWING SEASONS[1]

Wayne K. Clatterbuck[2]

Abstract-Bare-root seedlings of six hardwood species - northern red oak, (*Quercus rubra* L.), cherrybark oak (Q. pagoda Raf.), green ash (Fraxinus *pennsylvanica* Marsh.), persimmon (Diospyros virginiana L.). black walnut (Juglans nigra L.) and yellow-poplar (*Liriodendron tulipifera* L.) were planted with and without tree shelters during the 1991-1992 planting season on an agricultural field adjacent to the Cumberland River near Carthage, TN. Annual measurements were taken through the 1998 growing season, i.e., seven growing seasons. Paired tree analysis was used to determine the effect of tree shelters on seedling survival, growth and development. Sheltered seedlings exhibited significantly greater height growth after two growing seasons as compared to the controls regardless of species. There was no significant difference in survival rates. Most sheltered seedlings had emerged from the tubes after two years. However, after seven growing seasons, heights of the sheltered and unsheltered seedlings for yellow-poplar, cherrybark oak and persimmon were not significantly different. Measurements for the other three species, green ash (*Fusicoccum* spp. canker fungus), black walnut and northern red oak (excessive deer damage) were discontinued after the fifth growing season. This study indicates that although height growth is initially greater for seedlings in shelters, this growth advantage is not maintained once the seedlings emerge from the shelters.

INTRODUCTION

Use of plastic tree shelters has been promoted in recent years as a method to enhance development of seedlings in highly competitive conditions in both urban (Jones and others 1996) and rural environments (Kittredge and others 1992, Lantagne and others 1990, Smith 1993a). Tree shelters provide two functions: (1) physically protecting seedlings from animal (primarily deer and small mammals), mechanical, and herbicide damage, and (2) improving survival and increasing the juvenile height growth of seedlings such that seedlings are more competitive with residual vegetation. Shelters have been investigated extensively as a technique to enhance the typical slow early height growth of oak seedlings (Lantagne 1996, Schuler and Miller 1996, Smith 1993b, Tuley 1985).

Several studies have indicated that early height growth of seedlings is improved because of the environment inside the shelter. A mini-greenhouse effect is created with increased temperatures (Manchester and others 1988) and increased humidities that reduce the possibility of moisture stress (Minter and others 1992, Potter 1988). Increased levels of carbon dioxide relative to ambient conditions will also augment growth (Mayhead and Jones 1991).

Although, the literature reports increased initial height growth as a result of shelters, little information is available to report if this height growth advantage is maintained. Schuler and Miller (1996) suggest that once the seedlings emerge from the top of the shelters, height growth typically will slow down and return to the rates typical of unsheltered seedlings. This study was designed specifically to compare heights between sheltered and unsheltered seedlings for several years using paired tree analysis. This paper reports differences and similarities in height growth between sheltered and unsheltered seedlings of six species after seven growing seasons.

STUDY AREA

The study was conducted in Smith County, Tennessee, about 12 miles northwest of Carthage, TN at the confluence of Dixon Creek and the Cumberland River. Soils are Cumulic Hapludolls (Arrington series) and Ultic Hapludalfs (Armour series), formed in old alluvium overlying or in residuum derived from limestone. Soils are deep, nearly level to rolling with a loamy surface layer and a loamy to clayey subsoil. Arrington soils are well-drained, but occasionally flooded, while Armour soils are on gently sloping terraces near drainages. Annual precipitation is 51 inches, usually evenly distributed in all seasons. Average site index (base age 50) ranges from 80 feet for upland oaks to 95 feet for yellow-poplar (Prater and others 1997).

The study area was a former agricultural field that was last cropped in tobacco and corn in 1990. The field was fallow during 1991. During the fall of 1991, the site was prepared for planting the following year. The site was cross-directionally disked followed by ripping in one direction. No herbicide was used during site preparation.

METHODS

The 1-O seedlings were obtained from the Tennessee Dept. of Agriculture, Division of Forestry nursery near Delano, TN. Seedlings were lifted in late January, stored in refrigerated coolers, delivered and planted on February 20, 1992. Only seedlings greater than 3/8 inch at the root collar were planted. Seedlings were planted at a IO-ft by IO-ft spacing. Six species were planted: northern red oak, cherrybark oak, yellow-poplar, persimmon, green ash and black walnut in blocks of 62 seedlings per species for a total of 372 seedlings. A 4-foot, brown Tubex® tree shelter was placed on every second seedling creating 31 pairs of seedlings (with and without shelters) for each species.

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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The only competition control used during the study was mowing the plantation once or twice a year. The shelters were removed in 1996 following the fifth growing season.

Total height of each seedling was measured after each growing season through 1998. A paired t-test was used to compare height differences between sheltered and unsheltered seedlings by each species for the 1993-l 998 growing seasons. Data were collected for the initial (1992) growing season by species block and treatment, not the designated seedling pairs. Paired t-tests of the height data for the first growing season could not be calculated and only the mean height values are presented.

Measurements on green ash, northern red oak and black walnut were discontinued after the 1996 growing season. The green ash block was infected with the *Fusicoccum* canker fungus that caused many seedlings to die back, resprout and eventually die. The canker was first detected in 1995 and affected survival and height growth the following growing season. Northern red oak and black walnut were damaged excessively by deer either from rubbing or grazing.

RESULTS AND DISCUSSION

Survival

Survival was greater than 95 percent for each of six species after five growing seasons. No significant difference was detected between survival of sheltered and unsheltered seedlings. After seven growing seasons, survival remained greater than 95 percent for cherrybark oak, yellow-poplar and persimmon and greater than 82 percent for black walnut and northern red oak regardless of the shelter treatment. Green ash seedlings were affected by the *Fusicoccum* canker with total survival of less than 40 percent after seven years. Although damage from periodic cicada (1998), deer browsing and rubbing, mowing, and *Fusicoccum* fungus influenced the height growth of individual seedlings, these seedlings were tenacious and continued to resprout with new flushes of growth during the present or successive growing seasons.

Height Growth

Height of sheltered and unsheltered pairs of seedlings was significantly different ($t_{0.05}$ level) for each species for the second (1993) and third (1994) growing seasons (table 1).

Table I-Mean heights of sheltered and unsheltered seedlings for six species over seven growing seasons

Species	Mean height						
	1992[a]	1993	1994	1995	1996	1997	1998
	Feet						
Northern red oak							
Sheltered	2.6	3.3[b]	4.2[b]	4.7[b]	5.1[b]	—[c]	—[c]
Unsheltered	1.5	1.5	1.9	2.3	2.6	—[c]	—[c]
Cherrybark oak							
Sheltered	2.7	4.3[b]	6.0[b]	6.9	9.1	11.4	14.5
Unsheltered	1.4	2.4	4.1	6.1	8.2	11.0	15.1
Green ash							
Sheltered	3.2	4.8[b]	6.3[b]	7.6[b]	8.0[b]	—[d]	—[d]
Unsheltered	1.7	2.5	4.3	5.5	6.1	—[d]	—[d]
Persimmon							
Sheltered	3.4	4.8[b]	5.9[b]	6.6[b]	7.3[b]	8.9[b]	10.4
Unsheltered	1.9	2.6	3.8	4.8	5.9	7.5	9.6
Yellow-poplar							
Sheltered	3.5	4.7[b]	6.8[b]	10.4	14.5	17.7	20.9
Unsheltered	2.5	2.8	5.2	9.2	13.7	17.8	22.0
Slack walnut							
Sheltered	2.4	3.4[b]	4.2[b]	4.9	5.1	—[c]	—[c]
Unsheltered	1.2	1.7	2.5	3.7	4.7	—[c]	—[c]

[a] Statistical comparisons could not be calculated for the initial (1992) growing season because data were not collected by paired seedlings.
[b] Height of sheltered and unsheltered pairs was significantly different ($t_{0.05}$ level) with the paired t-test.
[c] Measurements discontinued because of deer damage.
[d] Measurements discontinued because of infection from *Fusicoccum* fungus.

Most (greater than 94 percent) of the sheltered seedlings of each species had emerged from the shelters by the second growing season. However, for cherrybark oak and yellow-poplar, the difference in heights between sheltered and unsheltered seedling pairs narrowed and was statistically the same for next four growing seasons (19951998). Persimmon heights remained different until the 1998 season when there was no significant height difference between pairs. The heights of green ash and northern red oak pairs remained statistically different until measurements were discontinued in 1997. Heights of black walnut pairs were not different after the 1994 growing season.

After emergence from the shelters, the height growth advantage of tree shelters appears to diminish. The height growth rate of sheltered seedlings is the same or decreases compared to unsheltered seedlings. Many hardwood species have decurrent crown forms that promote crown expansion rather than strong terminal growth once seedlings emerge from the shelters. Thus, the height growth rate of emerging hardwood seedlings will tend to decrease. The ability of seedlings to continue strong terminal growth after emergence from tree shelters may be dependent on competing vegetation that will regulate the rate of crown spread and force more terminal height growth.

The unsheltered seedlings, with slower rates of height growth initially, increase or maintain their rate of height growth over time. After seven growing seasons, the heights of unsheltered seedlings of cherrybark oak, yellow-poplar and persimmon are similar to their sheltered pairs. Whether the unsheltered seedlings will surpass and become significantly greater in height than the sheltered seedlings is unknown. However, this study indicates that the initial height advantage of sheltered seedlings is not maintained after emergence from the shelter when compared to the unsheltered controls.

Protection

An advantage of tree shelters is protection of seedlings from animal and mechanical damage. Although deer were present throughout the study and did browse on both sheltered and unsheltered seedlings, that damage did not become substantial until the shelters were removed in 1996. Seedlings were damaged both by deer rubs and browsing. Northern red oak and black walnut had the most severe damage that height measurements were discontinued after 1996. Both of these planted species blocks were at one end of the plantation where deer were more prevalent. Although the other species did incur some deer damage, that damage was not as severe.

Some of the height differences between sheltered and unsheltered paired seedlings for all species during the first three growing seasons might be explained by deer browse reducing growth of unsheltered seedlings. However, our observations indicate otherwise. Few of the unsheltered seedlings sustained browse damage during those early years. Most damage by deer did not occur until the shelters were removed. Seedlings of cherrybark oak, yellow-poplar, green ash and persimmon were the tallest (table 1) and sustained less browsing damage.

Four-foot tall tree shelters were used in this study. Other research in areas where deer populations are greater have used five-foot shelters (Schuler and Miller 1996, Smith 1993a). The taller shelters provide less chance of deer browse, but also take longer for seedlings to emerge from the shelters.

Shelters also provide some protection from damage by equipment, such as mowing in this study, or physical damage from herbicide application for vegetation control. Shelters are easy to see and allow operators to avoid those seedlings when various treatments are taking place as well as relocating seedlings for data collection.

costs

Tree shelters are expensive. The reported cost of shelters, installation and maintenance can vary from $200 to $750 per acre depending on the number of seedlings planted per acre (Kays 1996, Schuler and Miller 1996, Crothers 1991). Generally, with such a high cost and considering ownership objectives and rate of success, a 20-foot by 20-foot spacing or about 100 seedlings per acre is optimal. Other native and natural regeneration usually will fill in the gaps between shelters. Thus, the sheltered seedlings will probably compose a proportion of the future stand. For further reference, Kays (1996) gives an excellent summary of the cost of plantation establishment with tree shelters for further reference.

Tree shelters also must be maintained at least several times a year, which adds to the cost. Poor stake durability or improper initial installation of the shelter contributes to shelters listing, being wedged, or falling over which influences the growth and form of seedlings. The rigidity of the shelter also causes stem abrasion once the seedling emerges from the top of the shelter and begins to sway in the wind. The abrasion is more apparent the longer the seedling is left in the shelter and the greater the diameter of the stem. No sign of Tubex® shelter photodegradation was evident after five growing seasons causing additional costs of cutting, removing, and disposing of shelters.

CONCLUSIONS

The results of this study suggest that although height growth is initially greater for seedlings in shelters, this growth advantage is not maintained once the seedlings emerge from the shelters. Given the high cost and the short duration of this height growth advantage, the use of shelters may not be justified unless the protection from damage provided by tree shelters outweigh the associated costs.

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THE INFLUENCE OF EARLY THINNING ON STEM TAPER IN PIEDMONT UPLAND HARDWOOD STANDS[1]

Halil I. Cakir, and Larry E. Nix[2]

Abstract-The influence of early thinning (stand density) on stem taper in an upland hardwood forest was investigated in the Clemson Experimental Forest in the Piedmont of South Carolina. Taper measurements were taken by using a tripod-mounted pentaprism equipped with a clinometer. The stem profile model of Bennett and others(1978) and Farrar(1987) was used to fit these taper data to the trees measured. Effects of low thinning and nurse tree thinning were analyzed. Stem taper of thinned crop trees was compared to that of crop trees of unthinned plots. Stem taper rates differed statistically among the trees of the thinned plots and unthinned plots. Finally, the stem profile model was integrated for prediction of the volume between any two heights on a stem. Percent volume differences among the trees of the thinned and unthinned plots were then analyzed. Results indicated that thinning effects on tree form should be considered when evaluating volume prediction equations where stem taper is integrated into the equations. Low thinnings in the poor quality, upper one third slope sites, and nurse-tree thinnings in the good quality, lower one third slope sites, improved the stem form in the lower boles of crop trees growing in the conditions of the upland hardwood forest that was investigated.

INTRODUCTION

Upland Hardwoods

Upland hardwoods occur on a variety of sites in the Piedmont of South Carolina. These stands usually are characterized by low quality stems and poor species composition resulting from past abusive cutting, such as high-grading and uncontrolled fire (Kays and others 1988). Most of the stands contain important oak species such as white oak (Quercus *alba* L.), black oak (Quercus *velutina* *Lam.),* scarlet oak *(Quercus coccinea Muench.),* and southern red oak *(Quercus falcata L).* Black gum (Nyssa *sylvatica Marsh.),* sweet gum *(Liquidambar styraciflua L.),* red maple *(Acer rubrum L.),* and yellow poplar *(Liriodendron tulipifera L.)* are also present or locally abundant. Some of the understory species are sourwood *(Oxydendrum arberoum L.),* dogwood *(Comus florida L.)* and various shrub species.

Early Thinning and Taper

One of the main purposes of early thinnings in hardwood stands is to increase growth rate, bole quality and future merchantable volume. The response of the crop tree depends on the type and intensity of thinning the stand receives (Smith 1966, Marquis and others 1992). There are wide variations in the form of the main stem of trees due to variations in taper caused by the growing conditions in the stand. Taper, which contributes to variation in volume, varies with species, diameter, stocking, age, and site quality (Husch, Miller, and Beers 1982). Minimizing tree taper produces the maximum merchantable volume for a given height and diameter. The difference of one unit of Girard Form Class amounts to approximately three percent in terms of merchantable volume (Avery and Burkhart 1994).

Volume and Taper Equations

Thinning effects on tree growth are usually evaluated in terms of volume increment. Measurements of growth response can be biased and misleading if treatment effects on stem form are not considered. Meng (1981) noted that stem form, and thus the stem volume equation, may be significantly affected by "heavy" thinning. It was shown by Lositskii (1947) that stem form is reduced by heavy thinning and tree class (size and quality) interacts with thinning intensity. Nix and Ruckelshaus(l991) studied effects of thinning on stem taper of old-field plantations of loblolly pine in the Piedmont and noted that thinning at heavy or moderate levels will not greatly reduce bole quality as measured by stem taper, and may improve form in the lower more valuable portion of the tree. Hilt and Dale's 1979 study indicated that stocking levels after thinning do not have a significant effect on the stem form of young upland oaks.

Barker(1980) noted the correlation between patterns in ring width increment along the bole and bending stress and crown growth activity. He found that bending stress appeared to regulate growth in the upper 20 percent of the bole and crown growth factors dominated in the lower bole. The application of crown ratio data to volume equations has been discussed by Farrar and Murphy(1987). Using tree crown class ratio for both loblolly and slash pine, tree volumes were determined by integrating taper equations between two points. For a given dbh and total height, a higher crown ratio was associated with less volume in the section of the stem above breast height.

Taper (stem-profile) functions are presented for natural shortleaf pine *(Pinus echinata Mill.)* trees in the West gulf area by Farrar and Murphy(l987). These functions, when integrated, permit the prediction of volume between any two heights on a stem and, conversely by iteration, the volume between any two diameters on a stem. The integrated equations generally predict cubic-foot volumes that are within 1 cubic foot of observed volume and account for at least 97 percent of the variation in the volume. They noted that Crown Ratio (CR) could be incorporated into the taper functions as a continuous variable. Their study indicated that a higher CR class generally suggests lower stem volume due to greater taper in the long crown section. Even though a high CR implies low volume, in certain lower stem sections of a high CR tree the predicted taper is less than that of a similar low CR tree and, hence, a greater volume relative to dbh and height is suggested for these sections.

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Demaerschalk (1973) discussed the desirability and the advantages of deriving taper equations from existing volume equations. It is demonstrated that the most common types of volume equations can be converted to compatible taper equations. These mathematical stem profile expressions yield tree volumes for any desired stump height and top diameter outside bark from inputs of diameter breast height outside bark and total height. He stated the necessity of a system that should be simple, accurate and flexible enough to calculate all parameters based on only a few tree characteristics which are important and easy to measure, such as diameter breast height outside bark and total height.

Segmented polynomial regression models were also applied to taper equations by Max and Burkhart(1976). They stated that the segmented polynomial models with estimated join points provided an improved description of tree taper when compared to a single quadratic taper model used throughout the stem length M'Hirit and Postaire (1985) noted that accurate estimates of individual tree volumes are needed to determine the potential value of standing trees for use as solid wood products, fiber, or fuel and also Nyland (1996). It is the intent of this research to examine such effects in young upland hardwoods on the Clemson Experimental Forest in the Upper Piedmont of South Carolina and to relate them to alternative strategies for choosing the best thinning methods and volume equations.

MATERIAL AND METHODS

Study Area

The study area is an upland hardwood stand in the Clemson Experimental Forest in the Piedmont of South Carolina. The stand was regenerated naturally as a result of clearfelling and partial burning in 1943 and thinned in 1983 at age 40 with three methods, a heavy low thinning, a "nurse" or "trainer" tree thinning and unthinned controls (Myers 1984). The stand occupies low, medium and high site quality classes relative to slope position. All trees measured were 53 years old and most of the stems were sprout origin. White oak, southern red oak, black oak, scarlet oak, black gum, sweet gum, red maple and yellow poplar are the most common species. A total of 83 standing hardwood trees were measured. Measured trees were randomly drawn from nine study plots. Three plots were located on excellent sites (Upland oak SI=75 to 85 at age 50 on lower slopes), on good sites(Upland oak SI=65 to 75), and on poor sites (Upland oak SI=55 to 65). Treatment plots were randomly drawn from each site group in an attempt to reduce the effect of site quality on the study variables.

Field Measurements

Diameter measurements were taken at breast height (4.5 feet or dbh) using a diameter tape and at 4 to 5 additional heights using an optical dendrometer (Wheeler pentaprism). The dendrometer was equipped with a clinometer for calculating the height of the optical measurement at 66 feet distance. Tests of the Wheeler pentaprism caliper indicate that upper stem diameters as high as 50 ft above ground may be read to an accuracy of 0.2 to 0.5 inch (Nix and Ruckelshaus, 1991). Selected trees were single stemmed, reasonably free of crook or sweep, visibly undamaged, and commercially desirable species. The number, species, and diameter of all woody plants were recorded on each plot within 52.7 feet radius.

Data Analysis

Multiple regression (SAS 1989) was used to fit taper data and height data to the stem-profile model given by Bennett and others(1978) and Farrar and Murphy (1987). Predicted values of stem-diameter above breast height at given heights and tree Dbh and total height were compared among thinning intensities based on the following stem-profile model:

$$d=\frac{D(H-h)}{(H-4.5)}+b_1\left[\frac{(H-h)(h-4.5)}{H^2}\right]+b_2\left[\frac{D(H-h)(h-4.5)}{H^2}\right]+b_3\left[\frac{D^2(H-h)(h-4.5)}{H^2}\right]+b_4\left[\frac{(H-h)(h-4.5)(2H-h-4.5)}{H^3}\right]$$

Where b_i are parameters to be estimated

d= predicted stem-diameter (inch), at height (h)
h= height above ground (feet)
D= diameter at breast height (inch)
H= total tree height, ground to tip of bud (feet)

Stem taper was then compared using Duncan's multiple comparison procedure (SAS 1989). Predicted values of taper were used to obtain tree volumes throughout. The stem cross-sectional area is integrated over the length desired. If one assumes that the cross sections are circular in shape, then the area in square feet when diameter is measured in inches would be as follows:

$$Area=\frac{\pi d^2}{4(144)}=0.0054d^2$$

Integrating the expression for area in square feet over the length desired in feet will give the volume in cubic feet for that segment. That is, where h, and h_2 denote the limits of integration:

$$V(ft^3)=0.0054\int_{h_2}^{h_1}d^2dh$$

RESULTS AND DISCUSSION

Average tree diameter and height for each plot are shown in table 1. Note that, average tree diameter and height is greatest in the low thinning excellent site and is the lowest in the control poor site. It is expected that low thinned trees should have greater tree volume because of the greater tree diameter and height, but less relative volume because of the higher taper due to increased wind sway and crown ratio (Barker 1980).

Growth characteristics are different for every species. As seen in table 2, yellow poplar is the dominant tree on the excellent sites, likewise scarlet oak on the good sites and southern red oak on the poor sites. Note also scarlet oak is common on the excellent and poor sites. Stem taper models shown in table 3 are significant at the 0.05 level of probability with coefficients of determination of 0.99 for all thinning treatments and control groups. This implies that upper stem functions as a continuous variable. These

Table l-Average tree heights and diameters in young upland hardwood thinning study plots in SC Piedmont

Treatment	Average d.b.h.	Total height	Site index[a]
Excellent site			
Low thinning	14.96	102.16	77
Nurse tree thinning	12.92	94.40	79
Control	12.14	98.15	77
Good site			
Low thinning	10.00	75.40	67
Nurse tree thinning	10.02	79.81	66
Control	10.85	84.00	69
Poor site			
Low thinning	9.54	70.22	60
Nurse tree thinning	9.68	69.00	63
Control	9.04	66.11	63

[a] Oak site index, base age 50.

Table P-Distribution of species by site in young upland hardwood thinning study in the SC Piedmont (from Myers 1984)

Species	Number of species		
	Site classes[a]		
	Excellent (75-85)	Good (65-75)	Poor (55-65)
Yellow-poplar	12	5	0
Black oak	3	7	0
White oak	4	8	5
Southern red oak	0	1	12
Scarlet oak	7	10	7

[a] Oak site index, base age 50.

Table 3-Regression statistics and coefficients for Bennett and others (1978) and Farrar (1987) upper stem profile models for young upland hardwood thinning study in the SC Piedmont

Treatments	RMSE"	R^{2b}	b_1	b_2	b_3	b_4
Excellent site						
Low thinning	0.44074	0.9990	-6.451786	4.991250	-0.14821	-10.78102
Nurse tree	.54130	.9978	-14.35003	7.038501	• .27203	-15.66397
Control						
Good site	.69700	.9957	1.661020	5.838840	• .26770	-16.26987
Low thinning	.39279	.9981	-4.431198	3.505529	• .12115	-9.257663
Nurse tree	.34030	.9986	-36.80051	10.077324	• .49791	-5.489679
Control						
Poor site	.67307	.9951	-105.8306	24.460978	-1 .10006	-15.66545
Low thinning	.38156	.9980	9.612383	.596372	• .03458	-5.548567
Nurse tree	.44385	.9974	64.221166	-12.00016	.659245	-5.673576
Control	.39840	.9975	-25.79712	13.010324	• .70109	-19.18149

[a] Residual mean square error (RMSE) and R^2 statistics.
[b] b, coefficients were estimated by using multiple regression analysis.

results confirm the conclusion of an earlier study (Farrar and Murphy 1897) concerning the taper functions for predicting product volumes in natural shortleaf pine. Taper curves for the treatments produced from the model are shown in figure 1 for the excellent sites, figure 2 for the good sites and figure 3 for the poor sites. Although curves of unthinned stands seem to show less taper than the others, they are not statistically different.

Profiles for each of the three thinning treatments (low, nurse tree, and unthinned) are shown starting at 4.5 foot height. On excellent sites, tree dbh is 12 inches and total tree height is 98 feet for each of the treatments. On the good sites, dbh is 10 inches and total tree height is 80 feet. On the poor sites, dbh is 10 inches and total tree height is 70 feet. Although average dbh and total tree height are different for every treatment, the same dbh and total tree height were—

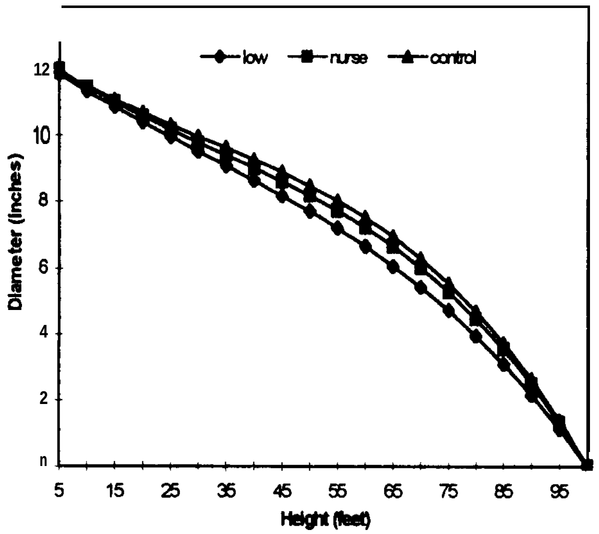

Figure I-Taper curves for thinning treatments as estimated by upper stem profile equations in the excellent sites. Legend indicates thinning treatments, low thinning, and nurse-tree thinning and unthinned.

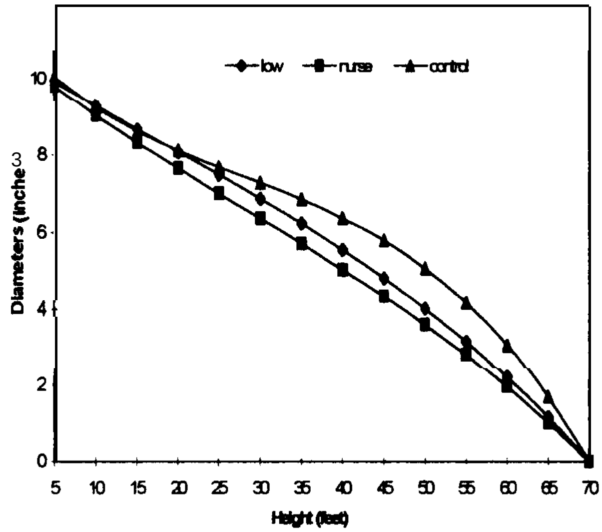

Figure 3-Taper curves for thinning treatments as estimated by upper stem profile equations in the poor sites. Legend indicates thinning treatments, low thinning, and nurse-tree thinning and unthinned.

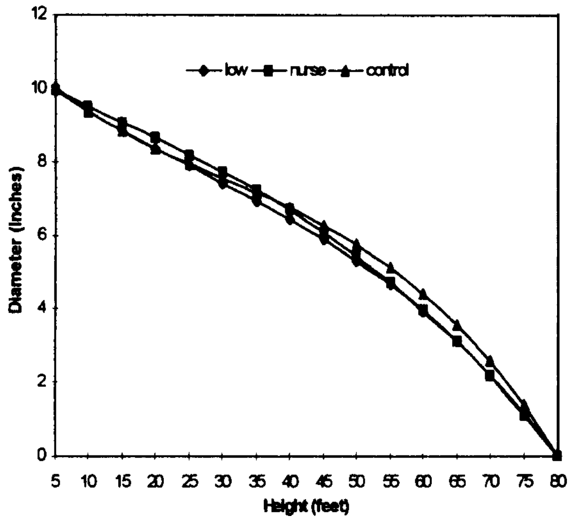

Figure P-Taper curves for thinning treatments as estimated by upper stem profile equations in the good sites. Legend indicates thinning treatments, low thinning, and nurse-tree thinning and unthinned.

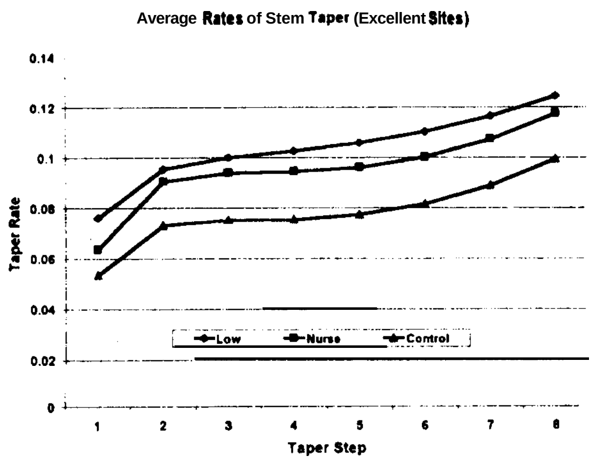

Figure 4-Rates of stem taper at each taper step for different thinning levels at age 53 for upland hardwood stands in the excellent sites (taper measurements were taken on every 10 feet of the stem; legend indicates thinning treatments and control (unthinned) plots).

chosen to more clearly distinguish the effects of thinning on taper. As shown in figures 4, 5 and 6, rates of taper (inches/feet) show treatment differences. On the excellent sites trees of the low and nurse tree thinning exhibit more taper than do those of unthinned plots. Although the average taper rates of low and nurse tree thinning trees are significantly different from those of unthinned trees at the 0.05 level of probability, these differences in rate of taper are more significant among trees of low thinning and control groups at taper step one, six and seven. However, the differences in the rate of stem taper at taper step six and seven, that is, 60 to 70 feet height, are not important, the differences in the valuable lower and middle part of the stems are.

Figure 5 shows that on good sites, trees of the nurse tree thinning have less taper than others until taper step four. Between taper steps three and four (approximately 35 feet height), unthinned trees exhibit greater taper. Low thinning trees exhibit greater rates of taper than the others on the good sites. The mean rates of stem taper for low thinning is different from those of unthinned and nurse tree thinning stands in the good sites at the 0.05 level of probability.

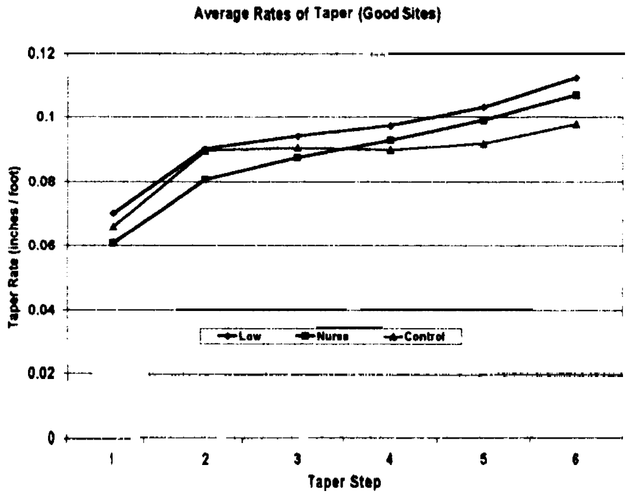

Figure 5—Rates of stem taper at each taper step for different thinning levels at age 53 for upland hardwood stands in the good sites (taper measurements were taken on every 10 feet of the stem; legend indicates thinning treatments and control (unthinned) plots).

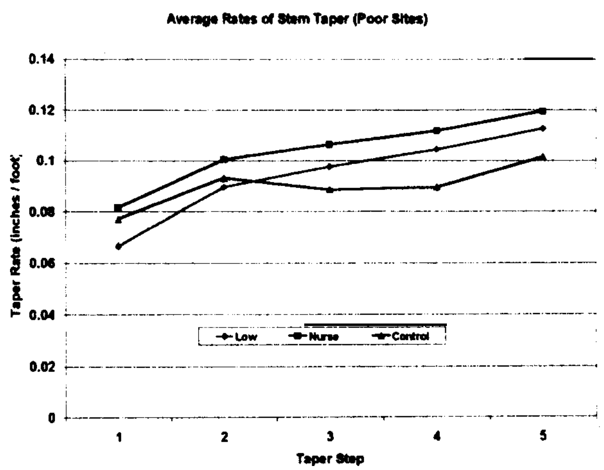

Figure 6-Rates of stem taper at each taper step for different thinning levels at age 53 for upland hardwood stands in the poor sites (taper measurements were taken on every 10 feet of the stem; legend indicates thinning treatments and control (unthinned) plots).

Especially among the low thinning and unthinned stands, these differences are more significant at taper steps five and six. At taper step one, low thinning and nurse tree thinnings exhibit significant differences in rates of stem taper at the 0.05 level of probability.

In the poor sites, the rates of stem taper for trees of low thinning and of nurse tree thinning follow an increasing pattern (fig. 5). In the poor sites, trees of the low thinning treatments have less taper than the others on the lower part of the stem. Trees of the nurse tree thinning plots unexpectedly exhibit more taper than the others, e.g. trees of the low thinning and unthinned stands. At the 0.05 level of probability, the mean rates of stem taper are significantly different. This difference is most significant at taper step four.

To show the volume differences caused by taper, or indirectly, by thinning treatments, tree segment volumes for 4.5 ft to tip, 4.5 ft to 32 ft, 4.5 ft to 16 ft and 16 ft to 32 ft segment were calculated based on the integrated taper functions for every treatment. There were significant volume differences, which were produced by the taper among the treatments. However, thinning may increase the diameter and height growth because of the reduced competition in terms of light, nutrition, water, etc. Taper induced volume differences were segregated by calculating volumes for the tree of same dbh and height for every treatment. Percent volume changes are also presented for the hypothetical example trees.

In the excellent sites, the hypothetical low thinning "tree" had 3 percent less volume in the 4.5 ft to 16 ft segment of the stem, compared to the unthinned "tree". In the 16 ft to 32 ft segment, this difference was 6 percent. Total tree volume above breast height differed approximately 11 percent between the low thinning and unthinned plots. However, in the second segment (16 ft to 32 ft) difference was 2.8 percent which was an important merchantable volume difference.

In the good sites low thinning volume above breast height was 5.2 percent less than that of the control group and the lower boles showed little volume difference compared to those of the excellent sites. The nurse tree thinning on this site caused an interesting result, unlike it did in the excellent sites, the nurse tree thinning trees had more volume than those of the unthinned control in the lower and middle segments. There was a 4.1 percent increase in volume in the 4.5 ft to 32 ft segment of the nurse tree thinning. There was a 2 percent increase in the 4.5 ft to 16 ft segment and a 6.2 percent increase in the 16 ft to 32 ft segment. Total tree volume of the nurse tree thinning above breast height was only 0.2 percent less than that of the control.

In the poor sites, trees of the nurse tree thinnings had 19.3 percent less total volume than those of the unthinned plots. Volume differences were 8 percent for the 4.5 to 32 ft segment, 3.3 percent for the 4.5 to 16 ft segment, and 12.8 percent for the 16 to 32 ft segment of the bole. Taper caused notably large differences (less volume) in every part of the nurse tree thinning boles in the poor sites. Also in the poor sites, 2.2 percent more volume was calculated for the low thinning in the lower part of the bole (4.5 ft to 16 ft) compared to the control bole. Examining figure 6 again, it appears that the low thinning has the lowest taper rate until taper step two. Rates of taper for trees of low thinnings then become greater than those of the unthinned plots just after taper step two, which is at about 22 feet height on the bole. This point is the change where trees of the control begin to show significantly more volume relative to diameter than those of the nurse tree thinnings.

CONCLUSIONS

Two problems were encountered during this attempt to determine the effects of early thinning on upland hardwood tree form. Species composition was a major problem. When dealing with hardwoods, species distribution is very different for major changes in site quality. Yellow poplar dominated in the excellent sites and responded differently to thinning than did the oaks. Thinning seemed to slightly reduce lower bole quality for yellow poplar while improving it in many cases for the oaks. Second, there was the effect of site quality on the distribution of tree growth along the bole. On good sites thinning seemed to provide extra resources for trees to respond. On poor sites there seemed to be so little resources available that even heavy low thinning could not provide more to remaining crop trees. On the excellent sites thinning seemed to do little to promote better distribution of growth, but this may have been a species interaction problem as yellow poplar is strongly excurrent. These problems were not entirely eliminated by setting up the same treatment and control plots for each of the site classes. Site quality interacted with thinning intensity on the good and poor sites where oaks dominated.

As found in this study, tree form is strongly influenced by thinning treatments. As a result of thinning, changes in taper promoted volume differences along the tree bole. In many cases early thinning caused more volume relative to diameter in the more valuable lower part of the tree and improved the bole quality. These results indicate that thinning treatments or, in most practical cases, its effects on wind sway and crown ratio(CR) must be considered when developing the taper and volume equations in hardwoods.

The early thinnings done in this study were merchantable and have not decreased stem quality appreciably in the past 11 years. Early thinnings give opportunities to landowners for producing much needed income and larger more valuable trees to enjoy later. We hope that this study will be helpful to hardwood managers in their decisions concerning early thinning in upland hardwoods.

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THE SPATIAL DISTRIBUTION OF DEAD TREES ACROSS ARKANSAS TIMBERLANDS[1]

Martin A. Spetich and James M. Guldin[2]

Abstract-Dead trees are an important part of the forest ecosystem and their attributes have been studied at the stand scale. However, their distribution over a large region has rarely been examined. In this study, the distribution and dynamics of sound wood in dead trees and the ratio of dead to live trees across the Arkansas landscape were analyzed using U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis data. These data showed that deadwood volumes followed patterns of potential timberland productivity. Values were lowest in the northwestern portion of the State and increased to the south and east. For potential timberland productivity in the range of 20-49 ft^3 per acre per year, mean deadwood volume was 52 ft^3 per acre. Where potential site productivity was high (range = 165-224 ft^3 per acre per year), mean deadwood volume was 177 ft^3 per acre. The ratio of the number of dead trees to number of live trees was not statistically significant among potential site productivity classes. Across all sites the ratio of dead to live trees was 0.089 (95 percent confidence interval = ± 0.009). Because this ratio appears to be relatively consistent over a wide range of forest conditions, it may have value as a forest health monitoring tool.

INTRODUCTION

Dead trees serve as habitat for wildlife and provide structural diversity. According to a study in southern hardwood and pine forests (Lanham and Guynn 1996), 45 bird species use standing dead trees. In the Southeastern U.S., at least 23 mammal species use standing dead trees (Loeb 1996). Forest Inventory and Analysis (FIA) surveys rated the greater density of dead trees in bottomland hardwood community types compared with pine in Arkansas (Rudis, in press), Louisiana (Rudis 1988a), and east Texas (Rudis 1988b). Reptiles and amphibians are associated with coarse woody debris, and their diversity may be linked with the quality and quantity of coarse woody debris (Whiles and Grubaugh 1996). Despite the importance of dead trees, little is known about their statewide distribution and dynamics.

An increase in deadwood volume across a gradient of increasing forest productivity (productivity for all trees ≥ 5 in. d.b.h. to a 4-in. top) has been documented for the four-State region of Indiana, Illinois, Missouri, and Iowa (Spetich and others 1999). However, the ratio of the number of standing dead trees to standing live trees remained relatively consistent across that gradient. These patterns have not been established for Arkansas forests.

Findings for Indiana, Illinois, Missouri, and Iowa have implications for forest health monitoring. Any quantifiable consistencies in number, volume, or the ratio of dead to live trees could be used as part of monitoring efforts to identify spatial and temporal forest health trends. Observed values that fall outside normal ranges could be used as indicators of change in forest tree health. Thus, a quick examination of inventory data could help identify potential health problems in a timely manner.

This study examines deadwood abundance and its relationship to potential timberland productivity in Arkansas. The four objectives in this study follow: (1) illustrate the spatial distribution of potential timberland productivity across the Arkansas landscape using a variation of the Delaunay triangulation method; (2) quantify the net volume and spatial distribution of dead trees across the State; (3) determine what trends, if any, exist between deadwood and potential forest productivity: and (4) examine similarities and/or differences of these results with other studies.

METHODS

The 1995 statewide forest inventory database for Arkansas was used in this analysis (London 1997). Data used in this study were restricted to trees ≥ 5 in. d.b.h. in stands of sawtimber size and of natural origin as defined in the Eastwide Forest Inventory Data Base: Users Manual (Hansen and others 1992). We limited data to stands of natural origin, thereby excluding planted stands. Planted stands in Arkansas are typically managed in ways that are not conductive to natural snag development. The resulting sample included 1,402 forest inventory plots from across the State. Mean forest conditions were computed for all plots in a county. Countywide means were used to quantify the statewide distribution in dead tree volume, potential forest site productivity, and the relationship of dead to live trees.

Mean values for forests in each county were plotted across the State using the mean latitude and longitude values for all plots within each county. Statewide contour maps of potential forest site productivity, dead tree volume, and the ratio of the number of all dead to live trees were created using commercially available software (RockWare Utilities 1995).

Additionally, means of deadwood volume and the ratio of dead trees to live trees were calculated for each of six forest site productivity classes. Kruskal-Wallis one-way analysis of variance on ranks test was used to test the hypothesis that dead tree abundance does not differ among productivity classes.

RESULTS

Potential wood productivity followed a gradient across Arkansas (fig. 1). Lowest productivity values (< 65 ft^3 per acre per year) were located in the northwest and increased

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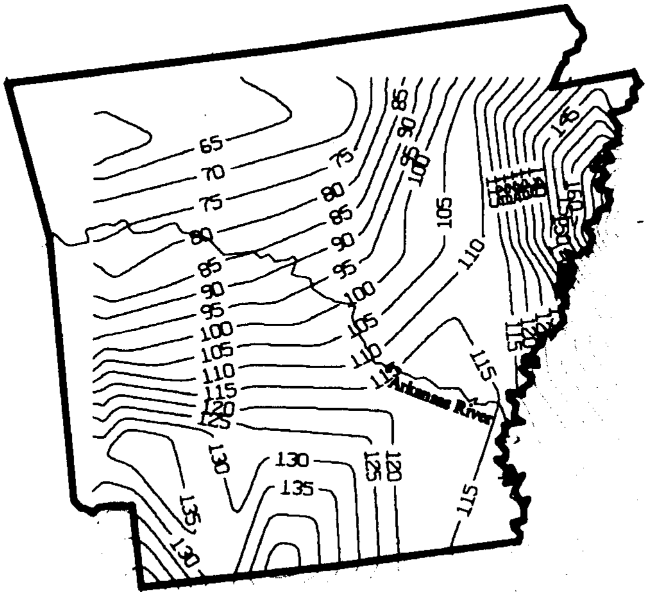

Figure l-Patterns of potential productivity of live commercial tree species for forests of sawtimber size and of natural origin. **Isolines** were calculated from site productivity (ft^3 per acre per year) for each county [Source - FIA data (London 1997)].

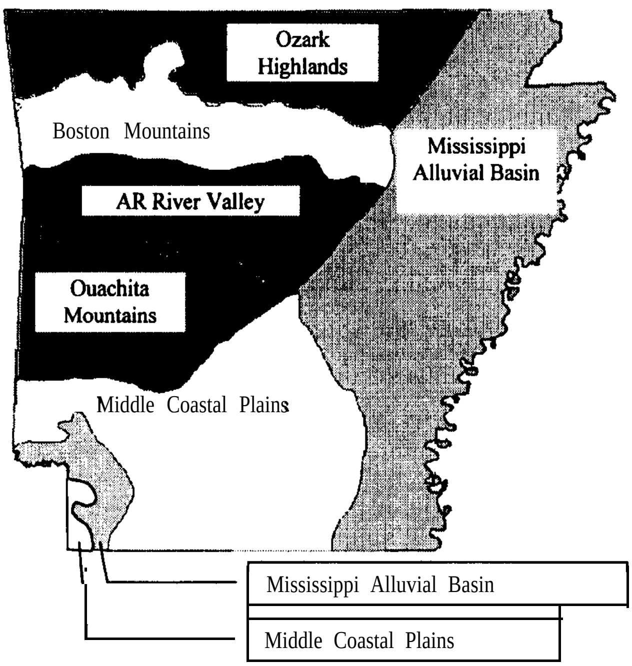

Figure 2-Ecological sections of Arkansas as defined by Keys and others (1995).

to the south and east. With the exception of the Arkansas River Valley, calculated productivity values correspond with the expected relative productivity of the ecological regions in the State, (Keys and others 1995) (figs. 1 and 2). Other factors may also influence this trend.

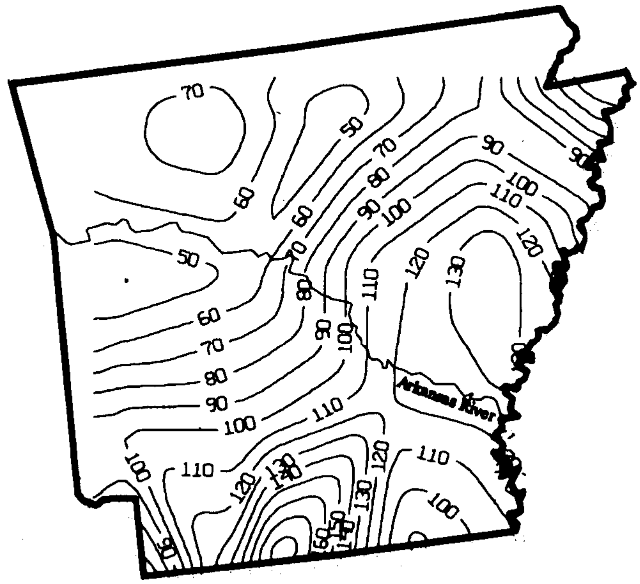

Figure 3-Dead tree volume (ft^3 per acre) for trees $\geq$ 5 in. d.b.h. in stands of sawtimber size and of natural origin.

With the exception of the Arkansas River Valley and parts of northwestern Arkansas, total volume of dead trees in these forests increased with increasing site productivity (fig. 3). Mean deadwood volume was as low as < 50 ft^3 per acre in northwest Arkansas and increased to $\geq$ 160 ft^3 per acre in south-central Arkansas.

Mean deadwood volumes were grouped by each of the six potential wood productivity categories. Deadwood volume differed significantly among several of the six potential wood productivity groupings (fig. 4). Deadwood volume clearly increased with increasing potential productivity (fig. 4).

The mean ratio of the number of dead trees divided by the number of live trees (fig. 5) ranged from 0.06 to 0.12 over most of the State (up to 0.21 in the northeast corner and ranging from 0 to 0.24 for county means). This is not as clearly related with site productivity (fig. 1). Visually, this ratio appears to increase with increasing productivity in the south-central portion of the State. However, the ratio did not differ significantly among the six site productivity classes statewide.

DISCUSSION

In a study of deadwood character of upland forests, Spetich and others (1999) reported a trend in forest productivity for the Midwest. They theorized that similar gradients exist throughout the country. Their regional productivity gradient illustrated what had only been an intuitive concept based on field and experimental experiences. This study is further proof that these productivity gradients exist across other forests of the United States. These trends in forest productivity should be particularly useful in developing hypotheses of trends in forest character because of the integrating effect of productivity. Productivity is a fundamental integrator of the effects of soil quality, disturbance, climate, potential evapotransporation,

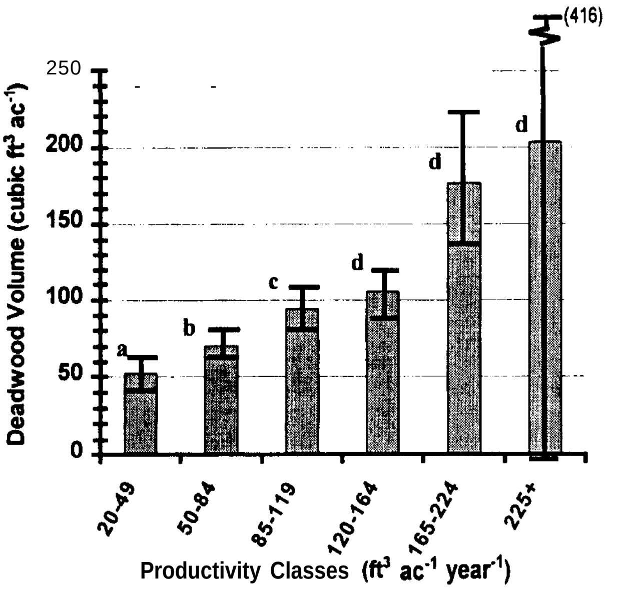

Figure 4-Relationship of potential timberland productivity classes to mean dead tree volume. Site productivity classes of values included (ft^3 per acre per year) are indicated by the range. Mean dead tree volumes are among all plots within that range. Bars with the same superscript do not differ significantly at the 0.05 level (based on Kruskal-Wallis one-way analysis of variance on ranks). Cross bars represent the 95 percent confidence interval (Cl) for snag volume within each productivity range. The Cls for ranges 165-224 and 225+ are wider because sample sizes were smaller (84 and 16 plots respectively).

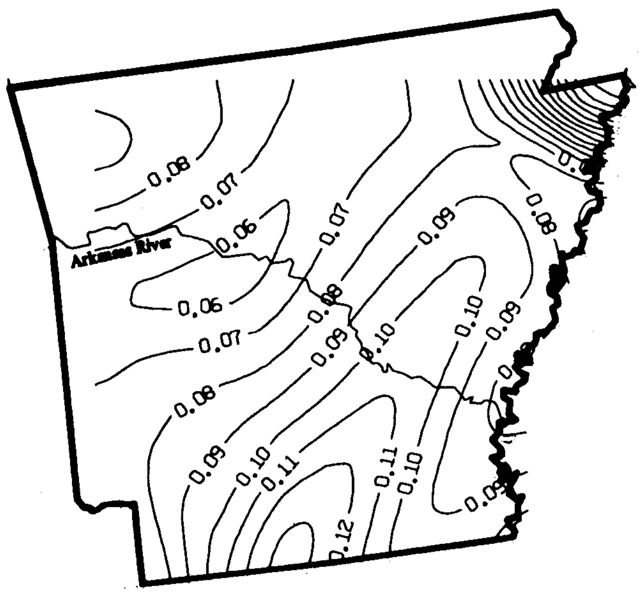

Figure 5—Ratio of dead to live trees for trees ≥ 5 in. d.b.h. in stands of sawtimber size and of natural origin. Isolines were calculated from mean ratio for all qualifying plots within each county.

topography, geology, organisms and all other factors that impact forest tree growth and the overall character of the forest ecosystem. Therefore, trends in regional site productivity should continue to be a useful tool in the prediction and examination of change in forest character over a region.

That dead tree volume increased with increasing potential productivity is not surprising. Forests with high productivity values should accumulate large amounts of biomass, which in turn, should lead to large dead tree volumes. The amount of coarse-woody-debris base energy has been described as a functional component of forest productivity (Huston 1996). In comparing dead tree volume (fig. 3) with the productivity trend (fig. 1) dead tree volume does not increase with increasing site productivity in the northeastern portion of the State. The most obvious factor that would potentially influence this trend is the region's proximity to Memphis, TN. Low dead tree volume may be related to the cutover character and high value of bottomland hardwoods in proximity to this urban center, or firewood use and other demands. This low deadwood volume is also notable, because when all high productivity plots (> 120 ft^3 per acre per year) are compared (fig. 4), volume of sound wood in dead trees is significantly greater than for the three lowest productivity ranges (all < 119 ft^3 per acre per year). Even a cursory examination of the productivity map illustrates potential site productivity values > 160 ft^3 per acre per year near the Memphis area, but dead tree volume ranges from 90 to 100 ft^3 per acre.

The two 50 ft^3 per acre lines are notable in that they also do not follow productivity trends well. Lower-than-expected values of dead wood volume are difficult to interpret. One plausible explanation is that the active management tactics in the area preclude development of deadwood, either through management that keeps trees alive longer or through closer utilization of trees prior to mortality. Other explanations may be equally plausible.

The ratio of dead to live trees in northern Arkansas is comparable to values reported in a study of undisturbed second-growth sites in southern Missouri (Spetich and others 1999). In that study the mean snag-to-live-tree ratio among eight Missouri Ecosystem Project forests was 0.08. Figure 5 shows the same ratio for Northwestern Arkansas and within 2 percent for most of the remaining area of northern Arkansas. This ratio of dead snags to live trees may also be related to forest type. At $P<0.05$ the hardwood forest type differed significantly from the pine forest type. However, the oak-pine forest did not differ significantly from either the hardwood or pine forest types. It should also be noted that the Arkansas study includes all trees that died since the last inventory and, therefore, is likely to include some trees that have fallen to the ground.

The consistency of the ratio of dead to live trees may be useful in monitoring forest tree health. Forest managers could use this information to screen inventory data for dead/live tree ratios that indicate a potential forest tree health problem. Statewide, the mean dead/live ratio was 0.089 (95 percent confidence interval = ±0.009). On similar sites with large inventories, dead/live ratios significantly > 0.1 may indicate potential forest tree health problems, which could prompt further investigation.

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COMMUNITY COMPOSITION IN CANOPY GAPS AS INFLUENCED BY PRESENCE OR ABSENCE OF RHODODENDRON MAXIMUM[1]

Christopher T. Rivers, David H. Van Lear, Barton D. Clinton, and Thomas A. Waldrop[2]

Abstract-The process of gap formation and recolonization plays an important role in the structure and composition in southern Appalachian forests. The understory composition existing before a disturbance will shape successional patterns of the future stand. *Rhododendron* maximum is native to the southern Appalachians and exists as a major understory component in cove forests. Its frequency of occurrence has been increasing over the past century due to the demise of the American Chestnut, heavy logging at the turn of the century, and suppression of fire. Increasing densities of *R.* maximum reduced species richness and coverage in the regeneration layer and reduced recruitment into understory and midstory strata. Woody and herbaceous species regenerated poorly, if at all, under *R. maximum's* dense canopy. Only shade-tolerant woody species like *Tsuga canadensis,* and *Acer rubrum* regenerate in *R.maximum* thickets, and their densities are markedly decreased.

INTRODUCTION

In the southern Appalachians forest canopy disturbance occurs frequently (Runkle 1982). Magnitude of disturbance varies greatly from hurricanes removing complete stands to a single limb dying. Removal of part of the canopy layer creates a void in the integrity of the canopy, which Barden (1989) defines as a canopy gap. The process of canopy gap formation and recolonization plays a substantial role in determining structure and composition of southern Appalachian forests. Understory composition existing before the disturbance will shape successional patterns of the future stand (Clebsch and Busing 1989).

R. maximum is native to the southern Appalachians (Bowers 1960) and exists as a major understory component. Its frequency of occurrence has been increasing over the past century due to changes in natural and anthropogenic disturbance factors (McGinty 1972; Phillips and Murdy 1985). Its increase in abundance and range is reducing species richness and altering patterns of succession (Baker and Van Lear In Press).

Effects of various sized forest gaps on understory vegetation have been studied extensively (Runkle 1982, Canham 1989, Clebsch and Busing 1989, Poulson and others 1989, Phillips and Shure 1990, Runkle and others 1992). However, little is known regarding the effects of *R. maximum* on gap succession in the southern Appalachians (Hedman and Van Lear 1994).

The most comprehensive and detailed investigations of *R. maximum* have occurred at the Coweeta Hydrologic Laboratory near Franklin North Carolina (McGinty 1972; Monk and others 1985; Phillips and Murdy 1985). McGinty *(1972)* suggests *R. maximum* did not occur as frequently in the early 1900's as it does now. Native Americans initially used fire as a management tool (Cronon 1983), which may have controlled the occurrence of *R. maximum.* European settlers continued this practice for clearing land and driving game. Exclusion of fire in this century is considered a disturbance and a change in historical management, since fire was historically present throughout the landscape (Monk and others 1985, Phillips and Murdy 1985, MacCleery 1992, Baker and Van Lear In Press) and may have contributed to the up slope migration of *R. maximum.*

Historically, *R. maximum* occurred primarily in riparian zones out of competitive necessity, but fire suppression and other factors allowed it to spread up slope, often to ridge tops. Fire probably top killed *R. maximum* and allowed other species a chance to grow ahead of its resprouting. Frequent fire, especially in the growing season, could have completely killed individual stems (Baker and Van Lear 1998).

As a result of the increasing abundance of *R. maximum,* southern Appalachian cove forests will probably experience a significant structural and compositional change over the next century (Hedman and Van Lear 1994, Clinton 1995, Baker and Van Lear In Press). *R. maximum* often has by far the highest importance value of all understory species in the southern Appalachians (Hedman and Van Lear 1994, Baker and Van Lear In Press). Although scattered overstory and midstory trees are found in the regeneration layer under *R. maximum* canopies. Vigorous thickets of *R. maximum* are capable of suppressing this regeneration. However, *Acer rubrum* and *Tsuga canadensis* are sometimes capable of establishing and competing under a *R. maximum* canopy (Clinton and others 1994).

The objective of this study was to determine effects of *R. maximum* on community composition and species richness in various-sized canopy gaps in cove forests of the southern Appalachians.

METHODS

Study Site Locations

This study was conducted in the Blue Ridge Mountain Physiographic province of the southern Appalachian Mountains. Sites were located in Andrew Pickens Ranger District of Sumter National Forest in Oconee County, South Carolina along Slatten Branch in the Ellicott Rock Wilderness Area; Tallulah Ranger District of the

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Chattahoochee National Forest in Rabun County, Georgia along Thomas Creek; Pisgah Ranger District of the Pisgah National Forest in Transylvania County, North Carolina along Pigeon River and Looking Glass Creek in the Shining Rock Wilderness; Wayah Ranger District of Nantahala National Forest in Clay county, North Carolina along the Tallulah River and Beech Creek; and in Towns County Georgia, along Mill Creek in the Southern Nantahala Wilderness. Elevation of study sites ranged from 518 to 758 m.

Historical Land Use

In this study most gaps were located in United States Forest Service Wilderness areas. There is no vegetation management, with the exception of fire suppression, allowing natural processes to determine the composition and distribution of plant species.

Plot Delineation and Physical Characteristics

Reconnaissance of the southern Appalachian area was conducted in the spring of 1998 to locate gaps in which to determine effects of *R. maximum.* Sites selected contained wind-thrown trees in the riparian area that created canopy gaps. To determine the effect of different densities of *R. maximum* on species richness in the regeneration layer, *R. maximum* thicket densities were classified into separate density categories (table l), as described by Baker (1994).

Table l-Density and basal area of *R. maximum* by thicket density category (Baker and Van Lear in press)

Thicket density	Basal area	Number of stems
	m²/ha	*x 1000/ha*
High	*11-22*	*8-17*
Medium	5-11	5-10
Low	*2-5*	*3-6*
Scarce	*o-2*	*o-3*

In this study no gaps were sampled with a “High” density rating. Gaps met the following criteria: 1) gap-making tree(s) must have been upper canopy trees at the time of gap formation, 2) gaps must be naturally occurring, 3) gaps must be less than 7 years old, 4) gaps must occur on only one site type, i.e., mesic, and 5) gaps were restricted to a linear zone no greater than 35 m from a stream. Gap age was estimated by examining the internodal growth of previously suppressed growth-determinant individuals within the gap.

Twenty-two gaps of varying size were selected, with eleven containing *R. maximum* with a minimum density of 2000 stems/ha and eleven where this species was mostly absent. Gap size was measured using the extended gap method suggested by Runkle (1982). Distance across the widest part of the gap, and a shorter distance perpendicular to the first, coinciding with the center of the disturbance were measured. Using the formula for the area of an ellipse gap area was determined. Gap size (40 m^2-286 m^2) ranged from one-tree openings to larger gaps made from the death of six trees.

Vegetation Sampling

Vegetation was sampled during the summer and fall of 1998. Bases of gap-surrounding trees were at least 1 O-cm ground line diameter (gld), denoting that they were no longer saplings. Vegetation was sampled along two gradients: 1) longest distance across the gap, and 2) a shorter distance perpendicular to the first with the intersection of the two gradient lines coinciding with the center of the disturbance. Advanced regeneration and new seedlings were inventoried in 1 -m wide transects located along each of the two principle gradient lines. These transects were further divided into l-m lengths where frequency was recorded to distinguish vegetative preference from the center of the gap towards the undisturbed forest. Percent cover of *R. maximum* **was** visually estimated and placed into Braun-Blaunquet category classes for the individual 1-m^2 sections and averaged to determine total percent cover for that gap. Percent cover classes were determined using Barbour and others (1987). The area of the gap was determined using the formula for an ellipse. Species nomenclature followed Radford and others (1968).

All stems cl 0 cm (to the nearest cm) gld were considered understory and all stems >10 cm gld were considered either midstory or overstory. Stems <1 cm were considered part of the regeneration layer. Species densities (stems/ha) and basal areas (m^2/ha) were recorded to calculate Importance Values of each understory species using relative density and relative frequency. Midstory Importance Values were determined from relative density and relative basal area. Importance value combines density and size to a weighted contribution per species to community composition.

In this study most individuals in sample plots were identified to the species level. When species level could not be determined, identification was made to the genus level, which was consistent across all plots.

Data Analysis

The relationship of site characteristics and *R. maximum* density (stems/ha, BA/ha) was determined using linear regression analysis. Linear regression was also used to determine relationships and compare seedling height in gaps with *R. maximum* present and absent. The relationship of species richness and density to percent cover of *R. maximum* was determined using non-linear regression analysis. Differences among absent, scarce, low, and medium thicket density plots were tested for significance using analysis of variance (ANOVA; SAS 1987) followed by t-tests. All statistical comparisons were conducted at the a = 0.05 significance level.

RESULTS AND DISCUSSION

Gap Vegetation

In the Southern Appalachian Mountains *R. maximum* **is** the dominant subcanopy species, occupying approximately 30 million ha (Nilsen and others 1998). Expansion of this species is a concern for ecologists and hardwood forest managers because recruitment of canopy tree seedlings is inhibited under cover of *R. maximum.* Potential causes include reduced seed rain by *R. maximum* foliage. Nilsen and others (1998) found that seedling presence and fitness were affected by low light, indirect effects of inhibited mycorrhizal synthesis, lower bacterial or invertebrate activity and competition for resources. A limited number of competing species can exist under a canopy of *R. maximum,* but usually only at low population levels. It is debatable whether or not in the absence of disturbance they can grow through the dense *R. maximum* canopy.

Midstory Vegetation

Stems >1 cm gld-Gaps containing *R. maximum* had little midstory vegetation other than this thicket-forming ericaceous shrub. *Tsuga canadensis, Halesia Carolina, Tilia americana,* and *Hamamelis virginiana,* in descending order, were next most important in gaps containing *R. maximum.* Adjacent overstory species composition differs from these species and demonstrates non-random replacement under a canopy of *R. maximum.* Barden (1980) found a similar trend in his study of replacement in cove forests in the southern Appalachians.

Gaps where *R. maximum* was absent contained *Hamamelis virginiana, Tsuga canadensis Acer saccharum* and *Fagus grandifolia* in descending importance. *Hamamelis virginiana* was usually found as stump sprouts with very rapid growth. It had a high frequency of occurrence in plots, contributing to its overall high importance value.

Species richness and density were significantly lower in gaps containing a midstory dominated by *R. maximum.* Species richness averaged 18.7 species in gaps with *R. maximum* and 51.9 without (fig. l), while density averaged 9.1 individuals/m^2 in gaps with *R. maximum,* significantly lower than 50.9 individuals/m^2 in gaps without (fig. 2). Average midstory species richness decreases significantly from *7.7* species in open gaps to 1 .1 species in *R. maximum* gaps (fig. 1) demonstrating that advanced regeneration was not present at the time of gap formation and subsequent seedling growth was inhibited. Average midstory density was also significantly lower, 1 .0 and 0.1 for gaps without and with *R. maximum,* respectively (fig. 2). Shade-intolerant midstory species were almost completely eliminated and shade-tolerant species were severely reduced to levels where little to no recruitment into the overstory could occur. Total tree regeneration was higher in gaps containing little to no *R. maximum* than in gaps containing *R. maximum,* which agrees with the findings of Phillips and Murdy (1985) and Clinton and others (1994).

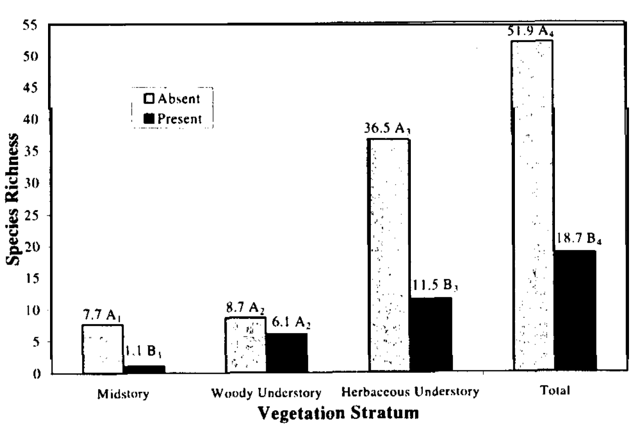

Figure l-Relation between species richness and vegetation stratum with *R.* maximum present and absent in southern Appalachian cove forest gaps. (Means with the same letter and subscript were not significantly different at 0.05 level).

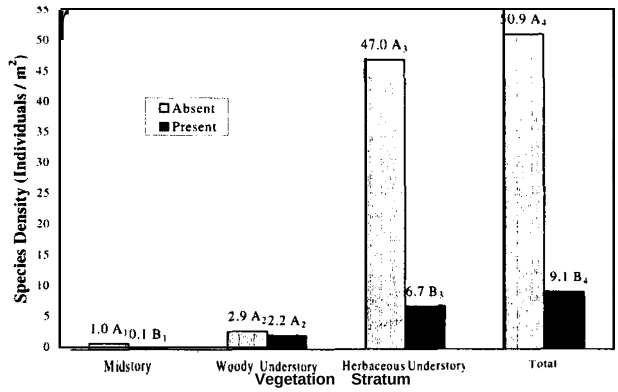

Figure 2-Relation between species density and vegetation stratum with *R. maximum* present and absent in southern Appalachian cove forest gaps. (Means with the same letter and subscript were not significantly different at 0.05 level).

Understory Vegetation

Woody species-Acer *rubrum, Liriodendron tulipifera, Betula lenta, and Tsuga canadensis* were the most important woody species in gaps containing *R. maximum. Acer rubrum*, *Betula lenta, Liriodendron tulipifera,* and *Quercus rubra* in gaps without *R. maximum* were most important. Brokaw (1985) found that shade tolerant species were dense in all gap sizes, which agrees with our findings.

Average woody-species richness and density in gaps with *R. maximum* were not significantly lower than open areas. Richness decreased from 8.7 species to 6.1 and density decreased from 2.9 individuals/m^2 to 2.2 from open to *R. maximum* gaps, respectfully (fig. 1 and *2). Acer rubrum*, *Liriodendron tulipifera,* and *Betula lenta* are the three most important species in gaps whether or not *R. maximum* was present.

Lack of significance in species woody richness is probably due to high germination percentages of understory woody species which are capable of sprouting in small transient patches of light. However, species density data show that few of these sprouting individuals are capable of survival in gaps dominated by *R. maximum.*

Acer rubrum seedlings may be able to grow into the midstory with less difficulty than the other species due to their greater shade tolerance. The species is currently present in the midstory. Most other seedlings present, including *Betula* and *Liriodendron* seedlings, will likely succumb to detrimental effects of *R. maximum* and never reach mid- to upperstory positions.

Herbaceous species-Most important herbaceous species in gaps containing *R. maximum* were *Tiarella cordifolia, Smilax rotundifolia, Polystichum acrosticoides, Mitchella repens* and *Viola blanda.* Gaps with *R. maximum* absent contained *Tiarella cordifolia, Thelypteris noveboracensis, Polystichum acrosticoides, Thalictrum clavatum,* and *Solidago curtisii*, in decreasing order of importance. All these species are typical mesic constituents, and are moderately shade tolerant.

Herbaceous species were most adversely affected by increases in *R. maximum* density with average richness decreasing significantly from 36.5 to 11.5 species as *R.*

maximum density increased (fig. 1). Average species density decreased from 47.0 to 6.7 individuals/m^2 (fig. 2).

Vegetational Relationships

As *R. maximum* density increased the number of potential overstory species decreased. Similarly, richness and density of potential midstory and understoty species decreased. Herbaceous species experienced the most dramatic decrease (fig. 1 and 2). These findings indicate that future diversity of Appalachian cove forests will be reduced as *R. maximum* coverage increases. The high density of herbaceous species in the lower density thickets diminishes the relative importance of midstory and overstory species. Herbaceous vegetation may also be a detriment to regenerating overstory species.

CONCLUSIONS

In gaps where *R. maximum* dominated the shrub layer, mid/understory development and diversity were restricted. Species richness and density were significantly lower in gaps containing *R. maximum* and richness and density of the herbaceous layer was also dramatically reduced. *Tsuga canadensis* and *Acer rubrum* were the most dominant species inventoried in gaps with *R. maximum.*

Species of varying degrees of tolerance to understory conditions are capable of establishment in small to medium size canopy openings in the absence of an evergreen understory. Continued and increasing presence of *R. maximum* in the mid-story will eventually contribute to the decrease of species richness in the overstory and alter forest structure and composition.

ACKNOWLEDGMENTS

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Intensive Management of Bottomland Hardwoods

Moderator:

BERT CREGG
Union Camp Corporation

THIRTY YEARS OF SHORT-ROTATION HARDWOODS RESEARCH[1]

Klaus Steinbeck[2]

Addressing the meeting's theme "Silvicultural Research-A Retrospective," the following invited paper presents a history of short-rotation hardwoods research.

Abstract-Thirty-four years afler its conception, short-rotation hardwood forestry is going operational. This paper traces the history of the concept, from when it was dubbed "Silage Sycamore" to today's intensively managed plantings. Initially conceived as an efficient means of producing fiber, it also aroused interest as an alternate energy source. A summary of sycamore and sweetgum yields under different management regimes is presented. With the increased demand for fine paper, short rotation hardwood plantations are operational in the western USA. In the Southeastern US, hardwoods are being planted increasingly on upland sites which remain trafficable in wet weather.

HISTORICAL OVERVIEW

The occasion was the 8th Southern Forest Tree Improvement Conference which was held in Savannah, GA in June 1965. A field trip to the Plant Introduction Station, where kenaf and bamboo were being evaluated as new fiber sources, was part of the program. Four Georgia foresters (C. L. Brown, A. M. Herrick, R. G. McAlpine, and H. E. Ruark) met after hours in Herrick's hotel room for a libation. Thus fortified, they wondered why we should import bamboos when we had fast-growing, native hardwood species which regrew rapidly after they were cut. They could be planted and harvested like an agricultural row crop. "Silage sycamore" was born (McAlpine and others 1966), although officially it was named Project JB 545 because Jim Beam is what they were drinking in Room 545 of the old DeSoto Hotel in Savannah that night.

As a result of this brainstorming, University of Georgia and US Forest Service researchers established a series of hardwood plantations in 1966 on a variety of sites. They began to screen species, to evaluate spacings, and different rotation lengths (Steinbeck and others 1972). But hardwood pulpwood was plentiful and cheap in the late 1960's and early 1970's and the research generated little interest.

In 1973 the OPEC cartel turned off the world's oil spigots and thereby stimulated assessments of alternate energy sources. Wood emerged as one of several promising alternatives to oil. The Energy Research and Development Administration (ERDA), a forerunner of the Department of Energy, sponsored research to estimate total biomass production rates, conversion efficiencies and other factors relating to wood as an energy source. The Department of Energy then initiated its Short-Rotation Woody Crops program, sponsoring feasibility studies and research throughout the United States.

The 1990's brought increased demands for fine paper, especially computer printout paper. Several wet-weather winters and increased regulations affecting operations in wetlands created spot hardwood shortages. Those forest industries which had to have hardwood fiber for their particular products began planting hardwoods, often on sites which remain operable in winter. Boise Cascade and Potlatch Corporation each manage more than 20,000 acres of short-rotation, irrigated and fertilized cottonwood plantations in eastern Washington. More than thirty years after its conception, short-rotation forestry has become operational.

EXPERIMENTAL FINDINGS

Initial Species Screening and Spacing Studies

Three species were selected for study in Georgia at the outset. Yellow poplar (*Liriodendron* tulipifera), sweetgum (*Liquidambar styraciflua*), and American sycamore (*Platanus occidentalis*) were chosen for their thin bark, disease resistance, and ability to grow on a wide range of sites (Steinbeck and Brown 1976). Bare-root, 1-O seedlings were planted at 1 x4, 2x4 and 4x4 foot spacings on an upland Piedmont site and harvested at 1, 2, and 4 year intervals. Yellow poplar grew slowly on this upland site and was eliminated from further consideration at that time. However, with today's intensive cultural practices it deserves a second look. It is resistant to many herbicides which would facilitate competition control. Sweetgum also grew slowly during its first 3 years in the field and was deemed unsuitable for rotations of less than 4 years. In later years we planted red maple (*Acer rubrum)* on a small scale and found that it survived well but initiated height growth very slowly and erratically. Black locust (*Robinia pseudoacacia)* was devastated by the locust borer *(Megacyllene robiniae).*

Sycamore and sweetgum emerged as the most promising species. Sycamore sprouts consistently grew about 7 feet in height annually. Its stumps usually produced about 2 dozen sprouts, which thinned themselves naturally to <5 during the first growing season. The number of sycamore sprouts which ultimately survived on each stump increased with the spacing and decreased with rotation length. Yields of woody biomass (stems, branches, and bark) averaged 2.9 oven-dry tons/acre/year and increased with increasing rotation length (up to 4 years) and wider (4x4 foot) spacings. Bark content was high, it ranged from 19 percent of the total dry weight for the one-year-old sprouts to 13 percent for the four-year-old ones (Steinbeck and Brown 1976). Kraft pulping evaluations showed that the fiber produced by these young trees was suitable for the production of fine paper (Steinbeck and Gleaton 1974).

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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Rootstock mass for sycamore stumps which were coppiced annually averaged only 7.1 oven-dry tons/acre, whereas those coppiced on 2-year and 6-year rotations averaged 10.2 and 11.2 tons/acre, respectively (Steinbeck and Nwoboshi 1980). Annual harvests led to depleted root stocks, low yields above ground, and high nutrient removals in the harvested material. Therefore very short rotations at very close spacings made little sense. Sycamore and sweetgum emerged as viable for short-rotation management.

Second Generation Studies: Effects of Different Harvesting Cycles on Woody Biomass Yields

In 1978 a trial was initiated to determine the effects of different harvesting cycles on woody biomass yields. Sycamore and sweetgum were planted at a 4x8 foot spacing on a broad upland ridge in the upper coastal plain in Tattnall County, Georgia. The soils on the site were Leefield and Fuquay loamy sands with very acid, friable sandy loam B-horizon at about 24 inches. These soils are low in natural fertility (Site Index, 83 feet for slash pine) and organic matter (Anon. 1980).

By today's standards, cultural treatments were modest. The trees were fertilized with 800 lbs/acre of 10-10-10 in each of the first two years after planting and with 500 lbs in the fourth year. Since the soils were low in phosphorus, 80 lbs of elemental P were also added during the first year. Both mechanical and chemical weed control was attempted during the first growing season but was only partially successful.

Three harvesting cycles were evaluated during the 15 years following planting: 1) Allow trees to grow uncut for 15 years; 2) Harvest at ages 4 and again at age 15; and 3) Harvest at ages 4, 10, and 15 years.

Sweetgum produced significantly more woody biomass than sycamore, an average of 2.1 oven-dry tons/acre/year compared to 1.57 tons for sycamore. Regardless of whether the stands were allowed to grow uncut or were cut three times during the 15-year period, total above-ground woody biomass yields did not vary significantly within species. Crown closure generally occurred during the first growing season after coppicing sycamore and in the second season for sweetgum. Therefore the duration of complete site occupancy was high, even in the plots which were harvested frequently. This may account for the uniform biomass yields across harvesting treatments. At any rate, short-rotation hardwood culture emerged as flexible system with regard to harvest scheduling. This flexibility could prove to be especially valuable when upland short-rotation stands are used as "emergency" stands for wet weather harvests. They can be stored on the stump if not needed or harvested sooner when supplies are short.

Effects of Harvest Season on Subsequent Yields

Wood must be available to feed a pulp mill or power plant throughout the year. This means that some stands may have to be cut at times of the year when resprouting will not be optimal. Every forestry student learned in basic silviculture that the best time to cut hardwoods to minimize regrowth is late spring and early summer. But little research has been done to quantify the degree of loss or to see whether the extent of the decrease differs among species. When sweetgum and sycamore were harvested monthly throughout the year, those which were cut in May, June and July produced less woody biomass than trees cut in the other nine months of the year. One year after harvest in the May to July timespan sycamore produced 40 percent and sweetgum 23 percent less woody biomass than trees cut during the rest of the year. These differences narrowed somewhat over time. But five years after harvest sycamore yields were still down by 23 percent and sweetgum's by 14 percent (Steinbeck, in press)

Yields of Sycamore and Black Locust Mixtures

Nitrogen fixing species have been used as nurse crops to increase the growth of the main crop species. Increases in total soil N have been demonstrated under plantations which were at least 15 years old (Mclntire and Jeffries 1932; Chapman 1935). When sycamore and black locust were grown in both pure plots and in mixture in the Georgia Piedmont, the four-year mean annual increments in pure plantings of either species was about 2 tons/acre/year. The mixed plots yielded only 1.3 tons (Dickmann and others 1985). Two-thirds of the woody biomass production of the mixed plots consisted of black locust. Apparently young black locust coppice grew so rapidly that it used not only the nitrogen it fixed but also competed successfully for other soil N. Ike and Stone (1958), also could not demonstrate increases of total soil N beneath 5- to 1 O-year-old black locust stands. The strategy of mixing two intolerant species with similar growth rates failed to increase total biomass production. Mixing fast growing intolerants with slower growing, tolerant species may be more successful in increasing total production.

Energy Balances

In order to be a viable alternative energy source, the energy production of forest stands must exceed energy inputs. There was little difference in the caloric content of the wood of different tree species on a dry weight basis. The wood of nine hardwood species averaged 4,777 calories/gram with a range of less than 4 percent between the species with the highest (*Acer negundo)* and lowest (Liquidambar styraciflua) dry weight caloric content (Neenan and Steinbeck 1979). This uniformity simplifies species selection for energy plantations-the species with the highest dry weight production/acre/year will also yield the most energy. When the energy expenditures in site preparation, planting, fertilization, disking etc. were added up and compared to the energy content of the wood produced while still on the stump, sycamore averaged about 15 g-calories of energy output for every g-cal input (Steinbeck 1981). This was very similar to the energy out/in ratio of 16 achieved by intensively managed cottonwood in the Lake States (Zavitkovski 1979).

Third Generation Studies: Yields under Intensive Culture

Demand for fine paper skyrocketed with the advent of the Personal Computer and its appetite for print-out paper. Log trucks loaded with hardwoods have become a common sight and hardwood pulpwood actually is worth something. But hardwoods are located mostly in the mountains and pulp mills in the distant coastal plains. Many private landowners don't want their hardwoods cut, even though they are perfectly willing to regard pines as a crop and cut them. Wet winter weather renders many hardwood sites inaccessible for harvest. These dual pressures of decreasing availability and increasing demand dictate that methods for growing more hardwood fiber on fewer acres be developed. Due to management restrictions and operability limitations on typical bottomland hardwood sites, short-rotation culture should be practical on less than optimal, i.e. upland sites. Therefore a field trial to investigate the biomass production potential of sycamore and sweetgum under putative optimum nutritional and soil moisture conditions was initiated.

The site in Tattnall County was clearcut and sprout growth initiated in early 1994. A drip irrigation system was installed through which liquid fertilizer dissolved in the irrigation water (fertigation) could be applied. Four treatments were installed: 1) No irrigation with estimated optimum fertilization (500 Ibs of 20-l O-l O/acre + minor elements annually) 2) No irrigation with fertilization at double the estimated optimum annual rate; 3) Irrigation with estimated optimum fertilization (100 gal of 1 O-5-5 liquid per acre plus minor elements) annually; and 4) Irrigation with fertilization at double the estimated optimum rate annually. The irrigated plots received about 60 inches of well water during the growing season in addition to the natural rainfall.

Over a 5-year span (1994-1998) sycamore consistently produced an average about 5.6 oven-dry tons and sweetgum about 4.4 tons/acre/year of woody biomass. Therefore the wood production of sycamore under intensive cultivation more than tripled and that of sweetgum more than doubled compared to the previous, less intensive cultivation regimen on the same site. This also represented a reversal in the ranking of productivity of the two species, because, in the 2nd generation study, sweetgum had been more productive under less intensive cultivation than sycamore.

Somewhat surprisingly, neither irrigation nor the higher fertilizer rate affected yields significantly. Even though the site experienced month-long summer droughts in 1995 and 1996, soil moisture seems not to have been limiting growth on the non-irrigated plots. This may have been due to the heavier textured B-horizon. And even though minor elements were applied, it is possible that one of them became limiting when the major ones were provided at the higher level.

SUMMARY

Thirty-four years have gone by since the idea of short-rotation hardwood culture was conceived by four foresters who were able and willing to think unconventionally. The system they imagined has proven feasible, even though the very close spacings and very short coppicing cycles they initially envisioned were impractical. The system proved flexible in terms of consistent yields under various spacings and rotation ages. The fiber produced is suitable for fine paper production. Energy outputs of short-rotation plantations exceeded energy inputs. Both sycamore and sweetgum reacted favorably to fertilization on an upland site. Cottonwood fiber farms are operational in the Pacific Northwest and short-rotation hardwood system is also eliciting interest in the Southeast.

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ECONOMICS OF AFFORESTATION WITH EASTERN COTTONWOOD (*POPULUS DELTOIDES*) ON AGRICULTURAL LAND IN THE LOWER MISSISSIPPI ALLUVIAL VALLEY'

John A. Stanturf and C. Jeffrey Portwood[2]

Abstract-Higher prices for hardwood stumpage and changes in agricultural policies may favor afforestation on sites in the Lower Mississippi Alluvial Valley (LMAV) which are suitable for Eastern cottonwood (*Populus deltoides* Bartr.). We examined the potential returns to a landowner growing cottonwood on three soil classes common to the LMAV. We specified the conditions under which we think such afforestation projects will be successful. Afforestation with cottonwood was a profitable investment under most conditions. Including federal cost-share, available under the Conservation Reserve Program (CRP), greatly increased profitability. Landowners interested in establishing oak-dominated forests can offset costs by interplanting cottonwood and red oak. Long-term management for cottonwood pulpwood can be profitable if coppice is included. On lower productivity sites, coppice is probably necessary.

INTRODUCTION

The Lower Mississippi Alluvial Valley LMAV has undergone the greatest conversion of bottomland hardwood forests to agriculture in the United States. Forest clearing occurred as recently as the 1960 and 1970's in response to increasing prices for soybeans (Sternitzke 1976). Today, some land that was cleared is available for afforestation. The Wetlands Reserve Program (WRP) and Conservation Reserve Program (CRP) are two federal programs that provide cost-sharing and easement payments for afforestation. Only the CRP, however, routinely allows planting cottonwood. The economics of cottonwood plantations has changed in the 15 years since Anderson and Krinard (1985). Advances in chemical weed control technology have made it possible to grow stands on heavy clay soils to pulpwood rotations. Nevertheless, landowners must be committed to carrying out the full suite of site preparation and cultural practices to insure establishment of a fully stocked stand.

DATA AND METHODS

The methods for culturing cottonwood considered here are used operationally by Crown Vantage at the Fitler Managed Forest in Issaquena County, Mississippi. These techniques were developed from research (McKnight 1970) and experience. Costs are typical for nonindustrial landowners in the LMAV and based on our experience.

Site Preparation

Afforestation in the LMAV generally occurs on land converted from soybeans. Ideally, site preparation begins immediately following soybean harvest. If soybeans are combined with chopping and shredding, plant residues are a fine debris and pose no problems for afforestation. The first step in site preparation is double discing (discing in two passes, each perpendicular to the other). The cost of $5 per acre per pass only includes operator wages and fuel, as we assume that the landowner is a farmer and already has the needed equipment. Next, the soil is ripped in the planting row with a straight shank to facilitate planting. Cost is estimated at $10 per acre. If a traffic pan has developed, subsoiling must be done in the previous year. The distance between plants within a row (12 ft) is marked by pulling a bar in another pass perpendicular to the planting row. This treatment is necessary to insure uniform spacing within and between rows to allow effective cultivation during the growing season. Marking costs $5 per acre. Nitrogen fertilizer as a liquid is added to the planting slit made by the ripping shank in the same pass. This requires specialized equipment to place the fertilizer 18 to 20 in. deep in the slit. Currently this costs $15 per acre for 80 Ibs. of nitrogen. Site preparation should be completed in the fall. On Sharkey (Vertic Haplaquepts) and other expanding clay soils, undergoing several wetting and drying cycles is essential for the slit and drying cycles (from precipitation) in order for fine particles to fill the slit. Otherwise, soil drying in the spring and summer will cause the soil to crack along the planting slit, exposing tree roots to desiccation. These treatments, including fertilization, cost $40 per acre.

Planting

Cottonwood cuttings of 16- to 18-in. lengths are planted by hand from December through March. Espacement for 12 ft by 12 ft results in 302 stems per acre. Improved cuttings are available for approximately $200 per thousand cuttings. Material costs are $60.40, and labor costs are $18 per acre for planting.

Cultural Treatments

Control of competing vegetation is critical during the first growing season because cottonwood is extremely intolerant of shading. A pre-emergent herbicide is sprayed in a 3-ft band centered on the planting row. This should be done over the top of dormant cuttings, between December and mid-February. Chemicals presently used are Goal 2XL, 64 oz per acre and Gramoxone Extra (non-crop label), 32 oz per acre. These chemicals cost $10.88 and $2 per acre, respectively, in 1998-99. Chemicals can be applied in a tank mix with 80-20 nonionic surfactant, 1 percent solution, costing $0.25 per acre. This can applied with ground equipment, such as a rubber-tired, 90 horsepower farm tractor. Readiness to spray is critical, as sufficient dry periods are scarce at this time of year. A banded spray of

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Goal at 32 oz per acre ($5.44) is used for emergent broadleaves later in the spring.

Beginning May 1, mechanical competition control begins. A treatment consists of two passes perpendicular to each other. Mowing, discing, and bush hogging are equally effective, and each cost $5 per acre per pass. Two treatments in the first growing season are likely to be needed. As many as four treatments may be required.

Johnson grass *(Sorghum halepense* (L.) Pers.) is a serious competitor and additional steps may be needed for its control. Cottonwood leaf beatle (*Chrysomela scripta* F.) may defoliate young plants and cause mortality. Spot applications for both these pests may be sufficient during the first year, but costs are estimated for banded application. For control of these pests, over the top application of Fusilade (for control of Johnson grass) at 24 oz per acre ($6) and Sevin XLR Plus (for control of cottonwood leaf beatle) at 16 oz per acre ($3.75) is effective. These chemicals can be applied in tank mixture with 80-20 nonionic surfactant at 1 percent ($0.25). With application costs of $5 per pass included, costs of cultural treatments the first year total $63.57.

In the second growing season, mechanical competition control by cross discing will be needed if cottonwood plants are less than 6 ft tall. If cottonwood is greater than 8 ft tall, then discing may be unnecessary. Plants between 6 ft and 8 ft tall may benefit from discing in the second year. Estimated costs for two passes were $10 per acre.

Interplanting

The primary objective in afforestation for many nonindustrial landowners is enhancing wildlife habitat, particularly for game animals and waterfowl (Jones and others, In press). We believe it is possible to accomplish this quickly by interplanting suitable red oak species between every other row of cottonwood (Schweitzer and others 1997, Stanturf and others 1998, Twedt and Portwood 1997). Because mechanical weed control for 1 or 2 years is necessary to establish cottonwood, we delay planting the red oak until the beginning of the third growing season. If height growth of the cottonwood is sufficient the first year, however, oaks can be interplanted at the beginning of the second growing season. Interplanting between every other row of cottonwood allows directional felling of the cottonwood at the end of the pulpwood rotation and avoids damage to the oak seedlings. Because the oak is on a 12 ft by 24 ft spacing (151 stems per acre), labor costs for hand planting are estimated at half that of cottonwood ($18 per acre). Cost of oak seedlings has increased with greater demand in recent years but we estimate that bareroot 1-O Nuttall oak *(Quercus nuttallii* Palmer) seedlings can be purchased for $0.25 per seedling, thus material costs are $37.75 per acre.

Coppice

For some landowners, allowing harvested stumps to resprout will be advantageous, as a second rotation on the same root system can be obtained for a small investment. Because of multiple sprouting, thinning stumps back to two sprouts in the winter after the third growing season has been customary. Up to 10 sprouts are removed from each stump. Recently, Crown Vantage has harvested every other row in a plantation in the winter, which encourages sprouting. After sprouting has clearly been successful, usually one or two growing seasons, the residual trees are harvested in the summer to discourage resprouting. On small ownerships, this may not be cost effective, so we estimated hand pruning at $32 per acre.

Taxes and Administration

Property tax rates are greater for agricultural than forest land and vary considerably among and within the States in the LMAV. We used estimates provided by Amacher and others (1997): $4.50 for Arkansas, $1.83 for Mississippi, and $1.44 for Louisiana annually per acre. Administration costs were assumed to be $1 per acre annually. We assume timber severance taxes are the responsibility of the timber buyer or harvester.

Cutover

If the landowner's objective is to grow pulpwood through several rotations, greater site preparation costs will be incurred for cutover land than for afforestation of agricultural land. Higher costs will result from shearing stumps close to the ground, piling into windrows, and burning. Site preparation discing with the heavier equipment needed for cutover land is also more expensive. Costs for these operation are $190 for shearing, piling, and burning and $35 per acre for site preparation discing. This allows the necessary mechanical weed control with lighter farm equipment and avoids damage to young plants from flying chunks of wood, as well as damage to cultivators and discs. Subsequent cultural treatments are the same as those previously listed.

Production Data

Yield data for cottonwood plantations are from the Fitler Managed Forest in northwest Mississippi. We selected three stands which represent soils suitable for growing cottonwood but varying in productivity. These stands are all on old field sites, protected by the river levee, with good survival. All were planted with the technology previously described: improved planting stock, fertilized at site preparation, and treated with the new herbicide technology. The stand on the Commerce soil (Aeric Fluvaquents) represents the highest productivity sites. The medium productivity sites are represented by the Tunica-Bowdre soils (Vet-tic Haplaquepts-Fluvaquentic Hapludolls). The Sharkey soil represents the lowest productivity sites. Stand characteristics are described in detail in Table 1.

Growth and Yield

The best available growth and yield model for plantation cottonwood is that of Cao and Durand (1991). This is a compatible growth and yield model that uses the Sullivan and Clutter (1972) equation form for predicting cubic-foot volume yield and projecting volume from site index, initial age, and basal area. The model was the basis for an Excel spreadsheet called Cotton, prepared by Cao for Crown Vantage in 1994. We used this software to estimate volume to a 3-inch top and yield of green tons per acre for each stand for pulpwood rotations of 10 and 11 years. No model exists for coppice rotations but experience at Fitler suggests that merchantable yield from a coppice is about half that from planting because multiple sprouts result in small, unmerchantable stems. We disregarded any timber value of the interplanted oaks, assuming the landowner's interest would be creating wildlife habitat only.

Prices and Cost Sharing

Stumpage price for cottonwood was centered at $10 per green ton, the average price paid by Crown Vantage. This is higher than the average hardwood stumpage as reported in

Table l-Characteristics of the stands we selected to represent soil/site productivity classes and their estimated yields at rotations of 10 and 11 years; stands were age 3 years when measured

	Commerce	Tunica-Bowdre	Sharkey
Site Index (base age IO), ft	80	73	66
Basal area, ft^2 per acre	29	17	15
Stems per acre	276	252	260
Survival, percent	91	83	86
Tons per acre, age 10	68.58	50.24	42.05
Cumulative annual increment (green tons per acre), age 10	7.52	6.29	5.36
Mean annual increment (green tons per acre), age 10	6.86	5.02	4.21
Tons per acre, age 11	75.42	56.05	47.01
Cumulative annual increment (green tons per acre), age 11	6.84	5.81	4.96
Mean annual increment (green tons per acre), age 11	6.86	5.1	4.27

Timbermart South but reflects the lower cost of pulping cottonwood as compared to other hardwoods in the process used by Crown Vantage. In our analysis, we varied the value for stumpage at $8, $10, and $12 per green ton.

Afforestation is seldom attractive without the cost-sharing available through the CRP because of the initial capital costs, the lack of an annual return, and greater perceived risk. Although the CRP is federally financed, reimbursement rates and allowable practices are set by individual States. We gathered current information on CRP cost sharing for Mississippi, Louisiana, and Arkansas from their respective State offices of the Natural Resources Conservation Service. They all customarily reimburse a landowner up to 50 percent of establishment costs. Reimbursement rates are summarized in Table 2.

Analyses

Our interest was in both short- and long-term evaluations. For short-term investment analysis, we used Net Present Value (NPV) and Internal Rate of Return (IRR) to compare several scenarios for every combination of soil type (yield) and State (taxes and cost share reimbursement). Our base case assumed a real discount rate of 4 percent (Clutter and others 1992) and no inflation. Internal rate of return was estimated using a 10 percent cost of capital. We examined the impact of rising costs and stumpage by inflating stumpage and costs equally at 3 percent annually, and a scenario where stumpage grew faster than costs (5 percent versus 3 percent). In another set of scenarios, we adjusted for risk by using a discount rate of 8 percent. Analyses were performed using the Project Investment Analysis template available in Lotus 1-2-3- Release 5.

For long-term analyses, we examined three management scenarios which began with afforestation without cost share under the CRP. In the most intensive scenario, the landowner cleared and planted after each rotation. In the moderately intensive scenario, coppice followed afforestation, but thereafter the landowner cleared and planted after each rotation. The least intensive scenario assumed the landowner coppiced for a rotation, then cleared and coppiced. To allow sufficient time for all harvesting and site preparation activities, we assumed a l-year delay between harvest and replanting. Land expectation value or bare land value (BLV) was derived for each scenario (Clutter and others 1992).

Table 2-Conservation Reserve Program reimbursements in Arkansas, Mississippi, and Louisiana per acre; total cost share is for establishment costs, reimbursed at the rate of 50 percent of expenses for 303 stems per acre

	Arkansas	Louisiana	Mississippi
	----------	Dollars	----------
Site preparation	21 .00	10.00	16.00
Planting	.20/seedling		70.00
Seedling material		.26/seedling	
Herbicide		22.00	
Total cost-share reimbursement for establishment	40.80	55.39	43.00
Annual soil payment	35.00	45.00	44.00

RESULTS

Base Case

Afforestation with cottonwood appears to be profitable under most conditions (tables 3, 4, 5). The combination of low productivity Sharkey soil, stumpage at $8 per green ton and higher land taxes in Arkansas, however, result in negative NPVs (table 5). When the real interest rate of 4 percent is doubled to account for risk, even the moderately productive Tunica-Bowdre soils have negative NPV when stumpage is low (tables 3, 4, 5). Internal rates of return for Sharkey soil with medium stumpage level range from 6.32 percent in Arkansas (highest taxes) to 7.75 percent in Louisiana (lowest taxes).

Interplanting is included as an expense. Under most conditions of low productivity (Sharkey or Tunica-Bowdre soils), low to mid stumpage ($8-$10 per ton), high taxes (Arkansas), or combinations, including interplanting lowers NPV to negative values. Including cost share payments under the CRP makes NPV positive under all the conditions we assumed (data not shown). Cost share payments were assumed to be made for 9 of the 11 years of the rotation (no payments made in year 0 when site preparation occurs, or in harvest year) and totaled more than the costs accrued under the base case (no inflation or risk adjustment).

Table 3-Net present value of afforestation scenarios in Arkansas by soil/productivity class, values are without cost-share incentives from CRP

	Values								
	Sharkey			Tunica-Bowdre			Commerce		
Stumpage	8	10	12	8	10	12	8	10	12
	Dollars								
Base	(8)	46	101	34	100	165	130	219	308
Base, risk adjustment (4%)	(62)	(26)	10	(34)	10	53	29	88	147
Base + interplant		(1)	53		52	117	82	171	260
Inflate 3%	(56)	129	202	(13)	200	288	240	360	480
Inflate 3%, interplant	55	76	150	112	148	236	188	308	428
Inflate costs 3%, stumpage 5%	117	206	295	187	293	399	342	487	632
Inflate costs 3%, stumpage 5%, and interplant	65	154	243	135	241	347	290	435	580

Table 4-Net present value of afforestation scenarios in Louisiana by soil/productivity class, values are without cost-share incentives from CRP

	Values								
	Sharkey			Tunica-Bowdre			Commerce		
Stumpage	8	10	12	8	10	12	8	10	12
	Dollars								
Base	19	73	128	61	126	192	156	245	335
Base, risk adjustment (4%)	(40)	(4)	32	(12)	31	74	51	110	169
Base + interplant	(29)	26	80	13	79	144	109	198	287
Inflate 3%	86	159	233	143	231	319	271	391	511
Inflate 3%, interplant	34	107	181	91	179	267	219	339	459
Inflate costs 3%, stumpage 5%	150	239	328	219	326	432	374	519	664
Inflate costs 3%, stumpage 5%, and interplant	96	185	274	166	272	378	321	466	611

Table 5—Net present value of afforestation scenarios in Mississippi by soil/productivity class, values are without cost-share incentives from CRP

	Values								
	Sharkey			Tunica-Bowdre			Commerce		
Stumpage	8	10	12	8	10	12	8	IO	12
	Dollars								
	15	70		58					
Base	(43)	(7)	124	(15)	123	188	153	242	331
Base, risk adjustment (4%)	(33)		30		29	72	48	107	166
Base + interplant		22	77	IO	75	141	105	194	284
inflate 3%	82	155	229	87	227	315	267	387	507
inflate 3%, interplant	30	103	177	214	175	263	215	335	455
Inflate costs 3%, stumpage 5%	144	233	322		320	426	369	514	659
inflate costs 3%, stumpage 5%, and interplant	92	181	270	162	268	374	317	462	607

inflation Scenarios
inflating costs and stumpage without changing the discount rate made all scenarios profitable (tables 3, 4, 5). Actual stumpage yields increased 34 percent when inflated at 3 percent annually, and increased 63 percent when inflated at 5 percent annually. The effect on NPV depended upon productivity, with a proportionally greater increase on the lower productivity Sharkey soil. For example, in Louisiana when stumpage is based on the initial rate of $10 per green ton, the percentage increase in NPV for Sharkey is 118 percent for 3 percent inflation and 227 percent for 5 percent inflation. On the higher productivity Commerce soil, the NPV increases are 60 percent and 112 percent for the 3 and 5 percent inflation factors, respectively.

Long-Term Timber Management
After the initial afforestation of agricultural land, the landowner interested in long-term timber management is faced with the decision of whether to include coppice rotations. The results of the three scenarios we evaluated are shown by State and soil series in tables 6, 7, 8. The high cost of site preparation of a cutover forest stand, as compared to afforestation of bare agricultural land, greatly affects profitability. On the low productivity Sharkey soil (tables 6, 7, 8), positive BLV is obtained only when stumpage is high or coppice rotations are included. Even when inflation is included, the highest BLV occurs when management is alternating clearcut and plant with coppice (data not shown).

On the medium productivity Tunica-Bowdre soils, alternating clear and plant with coppice produces positive BLV even at the lowest stumpage rate. If costs and stumpage are inflated 3 percent annually, the highest BLV are still produced by alternating clearcutting with coppice. if stumpage is inflated at 5 percent annually, the highest BLV is obtained with just one coppice rotation following afforestation.

The higher productivity Commerce soils can be managed profitably with the most intensive practices (tables 6, 7, 8) but the choice of management regime with the highest BLV is sensitive to stumpage prices. At the highest stumpage rate, there is little difference in BLV between management regimes. At the highest inflation rate (5 percent), the most intensive regime (clearcut and plant every rotation) produces the highest BLV.

DISCUSSION
Under most conditions, it is profitable to afforest with cottonwood. Stumpage, volume yields, and taxes all influence profitability in the short and long-terms. Cost share programs such as the CRP, considerably enhance profitability, especially on lower productivity sites. Cost share can offset risk as well as provide an annual income. A landowner interested in afforestation primarily for wildlife should consider interplanting cottonwood and oak: the yield from one cottonwood pulpwood rotation can offset the costs of afforestation even without cost share.

Long-term timber management for pulpwood can be profitable if coppice is included. On lower productivity sites, coppice is probably necessary. A landowner has more options, however, on the higher productivity sites. Sawtimber management is a possibility although Anderson and Krinard (1985) were not optimistic unless real stumpage increased. Profitability could be increased by increasing the merchantable yield of coppice. Lowering the cost of site preparation on cutover land would probably do the most to increase attractiveness of converting agricultural land to timber management. Two potential developments that may increase profitability are new herbicides that can be applied during the growing season or transgenic clones with herbicide tolerance. in either case, mechanical cultivation for weed control would no longer be necessary, and expensive site preparation could be avoided.

Two potential sources of income were omitted from our analysis. Annual payments for hunting leases could more than offset annual costs for taxes and administration. Fee hunting leases for forest land in the “delta” area of northwest Mississippi average approximately $5 to $7 per acre per year (Personal communication. Stephen C. Grado. 1999. Assistant Professor of Forest Economics, Mississippi State University, P.O. Box 9681, Mississippi State, MS 39762).

Table 6-Bare land value (BLV) for long-term timber management scenarios in Arkansas by soil productivity classes, values are for the base case with no inflation in cost or stumpage

	Values								
	Sharkey			Tunica-Bowdre			Commerce		
Stumpage	8	10	12	8	10	12	8	10	12
	Dollars								
			18	(173)	14				
Clear and plant	(294)	(138)		(53)		200	99	354	608
Coppice once	(162)	(22)	119		115	282	190	418	646
Alternate coppice and clear and plant	(70)	59	188	30	184	338	252	462	671

Table 7-Bare land value (BLV) for long-term timber management scenarios in Louisiana by soil productivity classes, values are for the base case with no inflation in cost or stumpage

	Values								
	Sharkey			Tunica-Bowdre			Commerce		
Stumpage	8	IO	12	8	IO	12	8	IO	12
	Dollars								
Clear and plant	(218)	(62)	94	(97)	90	276	175	430	684
Coppice once	(85)	55	195	24	191	359	266	494	722
Alternate coppice and clear and plant	7	136	265	107	261	415	329	538	747

Payments for carbon sequestration have been made in the Tropics, in anticipation of a market for trading carbon credits by industries that produce greenhouse gases (Amacher and others 1997).

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Table 8-Bare land value (BLV) for long-term timber management scenarios in Mississippi by soil productivity classes, values are for the base case with no inflation in cost or stumpage

	Values								
	Sharkey			Tunica-Bowdre			Commerce		
Stumpage	8	10	12	8	10	12	8	10	12
	------------------------- Dollars -------------------------								
Clear and plant	(228)	(72)	84	(108)	80	266	166	420	674
Coppice once	(95)	45	185	14	181	349	257	485	713
Alternate coppice and clear and plant	(3)	126	255	97	251	405	319	528	738

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PRE- AND POSTEMERGENT APPLICATIONS OF IMAZAQUIN FOR HERBACEOUS WEED CONTROL IN EASTERN COTTONWOOD PLANTATIONS: SECOND YEAR RESULTS[1]

Andrew W. Ezell, Jeff Portwood, and Harry Quicke[2]

Abstract-Eastern cottonwood (*Populus deltoides*) is capable of rapid growth and commercial production. However, this species is extremely sensitive to competition and requires some form of competition control throughout the first growing season. Imazaquin is a herbicide which demonstrates a wide spectrum of herbaceous weed control and could be an excellent option for use in young cottonwood plantations. Preemergent applications are required for early season control and will typically maintain a first-year planting until May or June. At that time, a postemergent application or mechanical cultivation is required. In this project, imazaquin was applied in both preemergent and postemergent screening trials at three rates. The result of these replicated studies were the basis for the 1997 and 1998 field trials which included postemergent applications of imazaquin alone and in a tank mix with pendamethalin. All applications were over-the-top of the planted cottonwoods. Results from the screening trials demonstrate that imazaquin gives excellent competition control with no damage to the cottonwoods. Postemergent applications of imazaqinlpendamethalin mixtures resulted in slight foliar phytotoxic symptoms, but had no negative effects as a preemergent application. When postemergent applications are made to areas which have not received preemergent treatment, competition control is drastically reduced. Imazaquin has excellent potential for both pre- and postemergent application over young cottonwoods, but preemergent treatment is essential if postemergent applications are to be most effective.

INTRODUCTION

Eastern cottonwood is a tree species capable of rapid growth when planted on appropriate sites and given sufficient cultural treatment to ensure establishment and early development. This species is extremely sensitive to all forms of competition, and one of the greatest threats to successful establishment of cottonwood plantations is competition from undesirable vegetation. The successful establishment of eastern cottonwood plantations depends on a wide variety of factors including sufficient site preparation, critical attention to spacing, use of properly prepared cuttings, and competition control. In addition to competing for the resources of the site, undesirable vegetation also increases the difficulty of early cultivation by decreasing the operator's ability to see the planted row. Historically, mechanical cultivation was the only competition control used in cottonwood plantations and while this form of cultivation may be important for soil aeration and competition control, it can result in serious injury and/or mortality to young cottonwood sprouts. Any delays in mechanical cultivation which are caused by inclement weather and unacceptable site condition only result in greater growth and development of competing vegetation and concomitant increased growth loss and damage to the eastern cottonwood.

Previous studies have demonstrated the efficacy of preemergent herbicide applications for eastern cottonwood plantations and the impact on first-year survival. This paper will discuss the efforts to develop alternatives for both pre- and postemergent competition control.

Imazaquin is a herbicide which has demonstrated control on a wide spectrum of herbaceous plants. This material also had great potential for crop tolerance by the cottonwood. This paper reports on the initial screening trials and subsequent field examinations regarding the use of imazaquin in either pre- or postemergent applications over planted eastern cottonwood cuttings.

STUDY OBJECTIVES

The objectives of these combined field studies were as follows:

(1) to evaluate the efficacy of imazaquin for herbaceous weed control in either preemergent or postemergent applications.

(2) to evaluate the crop tolerance response of eastern cottonwood to various rates of imazaquin applied at either preemergent or postemergent timings.

MATERIALS AND METHODS

Study Sites

All screening trials were conducted on Fitler Managed Forest which is approximately 30 miles north of Vicksburg, MS. The 1997 postemergent field trials were installed both at Fitler Managed Forest and on Westvaco Corporation land which is located near Wickliffe, Kentucky, and the 1998 trials were installed on private land approximately 10 miles south of Vicksburg, MS.

Treatments

Between 1992-1995, imazaquin was applied in the form of Scepter herbicide at the rate of 0.125, 0.25, and 0.50 lb ae/A in both pre- and postemergent screening trials (hereafter referred to as "screening trials"). In the 1997 postemergent field'trials, imazaquin was applied in the form of Scepter 70 DG at the rate of 0.11, 0.22, and 0.44 lb ae/A. In addition, a tank mix of 0.22 lb ae/A imazaquin and 2 lb ai/A pendamethalin was applied in 1997. In 1998, the tank mix of imazaquin and pendamethalin was repeated as a preemergent application followed by imazaquin application (0.25 lb ae/A) at "first flush" and 60 days after treatment

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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(DAT) timings. All treatments in all studies were replicated three times with each treatment applied over-the-top of the planted cottonwoods. Preemergent applications were completed in January (applied prior to bud break), and postemergent treatments were applied in mid-May (applied after leaves developed and actively growing).

Applications were completed with a CO_2-powered backpack sprayer utilizing a TK2.5 Floodjet nozzle in the screening trials and a 4-nozzle boom with 8002 tips in the 1997 and 1998 field trials. All treatments used a total spray volume of 20 gallons per acre, and no surfactant was added to any of the mixtures. Each treatment plot was a swath 6 feet wide and 300 feet long with the planted cottonwoods serving as the center line of the treated plot.

Evaluation

Plots were evaluated at 30, 60, 90, and 120 DAT in the preemergent screening trials for both competition control efficacy and crop tree damages. In the postemergent trials, evaluations were completed at 7, 30, 45, 60, and 90 DAT for the same variables. All evaluations were completed by ocular estimates, and crop trees were examined closely for any damage symptoms including foliar discoloration or necrosis, fasciculation, rosetting, stunting, or terminal die back.

RESULTS

Screening Trials

None of the treatments damaged the cottonwoods in any test. All the treatments provided good competition control with the 0.25 and 0.50 lb rates providing excellent control for 90 DAT (table 1). A rate response was evident by the 90 DAT evaluations, and after that time, residual control in the 0.50 lb treatment was significantly greater than the other rates in the preemergent trials. The 0.25 and 0.50 lb rates both exhibited greater residual activity in the 90 DAT evaluations for the postemergent screening trial (table 1).

Table I-Percent clear ground in imazaquin screening plots over eastern cottonwood (average all reps)

	Evaluation timing (DAT)[a]			
Treatment	*30*	*60*	*90*	*120*
Lb ae/acre	Percent			
Preemergent				
0.125	73	70	53	13
.25	77	75	60	20
.50	80	80	67	33
Postemergent				
.125	70	66	27	—
.25	80	66	43	—
.50	85	66	50	—

[a] DAT = days after treatment.

The level of competition control at 60 and 90 DAT is a significant item for comparison to the 1997 study. The postemergent screening trial was installed on an area which had received operational preemergent treatment. In 1997, the study was installed on areas which had not received any preemergent applications at either study location.

1997 Field Trial

Weed control in the 1997 study was poor when compared to the earlier screening trials. At 60 DAT, average percent clear ground ranged from 20 to 33 percent at Fitler and 10 to 17 percent at Wickliffe for the imazaquin treatments (table 2). Adding pendamethalin increased competition control, but could result in a negative growth response when applied to actively growing cottonwoods. When compared to the 60-70 percent clear ground at 60 DAT in the screening trials, the importance of preemergent applications is clearly demonstrated if optimum efficacy is to be obtained.

Table P-Percent clear ground in the 1997 imazaquin field trials at 60 DAT[a] evaluation time (average all reps)

		Location	
Herbicide	Rate	Fitler	Wickliffe
	Lb/acre	*---Percent---*	
Scepter 70 DG	0.11 ae	20	17
Scepter 70 DG	.22 ae	20	10
Scepter 70 DG + Pendamethalin	.22 ae 2.00 ai	56	32
Scepter 70 DG	.44 ae	33	33

[a] DAT = days after treatment.

1996 Field Trials

The competition control results for 1998 were strongly influenced by river flooding and Johnsongrass (table 3). At 60 DAT, the plots were 43-50 percent clear with some broadleaves and the onset of Johnsongrass infestation. Grass control in cottonwood plantations is usually not considered a problem and is successful using grass herbicides such as Fusilade®, Vantage@, or Select@ over the top of cottonwoods. However, the Mississippi River flooded in May 1998 making plots inaccessible. This flooding did not inundate the plots and Johnsongrass thrived. By 100 DAT, Johnsongrass covered 75-80 percent of the plot surfaces. The imazaquin had done an excellent job of controlling competition other than Johnsongrass on the site.

Table 3-Percent clear ground in 1998 imaraquin field trials (average all reps)

Herbicide	Rate	Evaluation time 60 DAT[a]	100 DAT[b]	120 DAT[b]
	Lb/acre	---------------*Percent*-------------		
Scepter 70 DG + Pendulum[c]	0.25 ae 2.00 ai	43.3	16.7	28.3
Base treatment + Scepter 70 DG (first flush)	0.25 ae	50.0	13.3	21.7
Base treatment + Scepter 70 DG (60 DAT)	0.25 ae	46.7	13.3	15.0

[a] DAT = days after initial treatment.
[b] Plots occupied by johnsongrass.
[c] Base treatment for all imazaquin plots.

SUMMARY

Overall, imazaquin has demonstrated an exceptional combination of competition control and crop tolerance in these field studies. Scepter now has an approved label for use in cottonwood plantation management.

Specific points of interest from these field tests include:

(1) Imazaquin did not damage eastern cottonwood in either preemergent or postemergent applications.

(2) A slight rate response was evident, but 0.22 lb ae/A provided adequate control.

(3) Preemergent control is essential if optimal results are to be obtained from postemergent applications.

(4) Grass control is essential when these species reach competitive levels.

(5) Tank mixes with pendamethalin should be used as preemergent applications for best results.

IRRIGATED AND UNIRRIGATED EASTERN COTTONWOOD AND WATER OAK IN A SHORT ROTATION FIBER SYSTEM ON A FORMER AGRICULTURAL SITE[1]

Jimmie L. Yeiser[2]

Abstract-Seedlings from an open-pollinated family of water oak (Quercus *nigra* L) and cuttings from *Populus* clones of eastern cottonwood *(Populus deltoides* Bartr. ex Marsh) and hybrid poplar *(P. trichocarpa* Torr. and Gray X P. *deltoides* Bartr. ex Marsh.) were tested on a Perry clay soil in east central Arkansas (St Francis County). The test site received a preplant application of 100 pounds of nitrogen per acre and weed control for two growing seasons. Unirrigated and irrigated test families were monitored for survival and growth through age two. Some *Populus* clones survived best when irrigated and other clones when unirrigated. All test material exhibited significantly more volume per planted tree when irrigated. After two growing seasons, irrigated exceeded unirrigated saplings with enhanced mean performance for height, diameter, and volume per planted tree of 3.1 feet, 0.6 inches and 19.9 feet^3, respectively. Hybrid poplars exhibited more uniform early growth.

INTRODUCTION

In the Northwest, environmental and political factors plus Japanese competition in domestic markets have contributed to record demands and prices for hardwood and softwood fiber. With limited fiber supply there, national and international demand shifted to southern forests. This has contributed to record demands and prices for pine and hardwood timber and fiber.

The 1996 Farm Bill reduces the support price of various agricultural commodities over the next seven years. Marginal, fine textured soils, that were traditionally in soybean production, may become less profitable and in need of an alternative crop. Short rotations of eastern cottonwood (Populus *deltoides* Bartr. ex Marsh.) are a possible alternative to soybeans and have the potential for integrated, agroforestry production as well.

Over 3 million acres of fine-textured "Sharkey-clay-type" soils occur in the Mississippi Delta with the potential for conversion to short rotation fiber systems. Most intensive plantations in cottonwood production today are on highly productive sites. Research is needed that examines the potential of eastern cottonwood on marginal sites receiving intensive culture such as furrow irrigation.

OBJECTIVE

The objective of this study was to compare the survival and growth of furrow irrigated and unirrigated Populus clones and water oak seedlings growing in an intensive short-rotation on a fine textured, moderately drained, former agricultural site.

METHODS

The study was installed on a remote 15-acre site in east central AR (St. Francis County) near Pine Tree. The soil there was a Perry clay (Gray and Catlett 1966). This site had been in a crop rotation system for soybeans, wheat-soybeans, and grain sorghum since 1981.

One-half of the area was bedded, planted, and furrow irrigated. The second half of the study plots was subsoiled and planted without irrigation. Levees were constructed to furrow irrigate 7.5 acres, protect the remaining 7.5 acres from irrigation water, and secure the entire study from other unwanted waters. Data for soil type, crop planting date, program activation date, daily temperature, and rainfall were entered into a soybean irrigation scheduler (Tacker et al 1996) to predict soil moisture deficits. Clones were irrigated when a 2-inch soil moisture deficit existed, i.e. when two inches of rainfall were required to bring the top 12 inches of soil to field capacity. The study was irrigated three times during each of the 1997 and 1998 growing seasons.

A one-time application of fertilizer (100 pounds of nitrogen per acre) was injected approximately 20 inches in depth in the unirrigated area. An equivalent amount of liquid fertilizer (100 pounds of nitrogen per acre) was surface-sprayed in a two-foot band and covered with a 20-inch bed on the irrigated portion of the study area. Early competitors were controlled with a preplant, broadcast application of oxyfluorfen+glyphosate (Goal®+Roundup® 5 pints+1 quart).

Test clones included cuttings from hybrid poplar (P. *trichocarpa* Torr. and Gray X P. *deltoides* Bartr. ex Marsh.) clones 49-l 77 and 1529, from Texas cottonwood clones S13C20 and S7C15, as well as from Stoneville, MS clones ST72, ST1 24, ST1 63, ST148 or Delta View (a mixture of Stoneville clones). An open-pollinated family of water oak *(Quercus nigra* L.) was also planted for testing. Cuttings were planted on a 1 O-feet X 1 O-feet spacing in treatment plots containing eight rows and seven trees in a row. Internal to each treatment plot was a measurement plot of six rows with five trees per row, leaving one row of border trees around each plot.

Mechanical weed control was maintained for two growing seasons by disking down row middles. Weeds around seedlings were removed by hand or hoe or treated with directed applications of glyphosate (Roundup@) or glufosinate (Finale@).

The study was installed according to a split-plot design. The whole plot effect was irrigation and the split-plot effect was water oak and Populus clone. Six randomized complete blocks were installed perpendicular to slope with clones

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-16, 1999.

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assigned randomly within each block. Treatment effects were analyzed using an analysis of variance with means separated using Duncan's New Multiple Range test. All tests were conducted at the $p=0.05$ level.

Clones were measured initially and at the end of each growing season for total height and diameter (dbh). Analyses were conducted to detect differences in survival, height, diameter, and volume per planted tree. Height and diameter measurements were expressed in feet and volume computed as $volume = height * dbh^2$. Dead trees and trees less than 4.5 feet tall were assigned a volume of zero.

RESULTS AND DISCUSSION

First-year survival (1996) was low and considered unacceptable (< 50 percent) for irrigated and unirrigated plots of clones ST1 63, S7C15, ST72, Delta View, and ST148. For these plots surviving stems were rogued and stump cut surfaces treated in February with .001 quarts of concentrated Garlon 3A per inch of diameter. Plots were replanted with the same clone. On opposite sides in the bed row and two feet from the newly planted cutting, holes were punched with a IO-inch dibble. Holes were filled with ammonia nitrate at 50 pounds of nitrogen per acre and covered. Weed control in newly planted plots was maintained as described above. Control of unwanted ramets by Garlon 3A was excellent with 100 percent control. This effort improved survival overall by about 10 percent across all clones.

The analysis that follows is for data comparing survival and growth for the same age since planting, although some first-year clone measurements were from 1996 or 1997 growing-seasons. Year effects are confounded but may not be too serious since competition was controlled and fertilizer and water applied.

Survival

The main effect, irrigation, did not significantly influence survival at age one (1997) or two (1998) (tables 1 and 2). Survival averaged 64 percent for irrigated and unirrigated plantings. The clone by irrigation interaction was statistically significant for hybrid poplar 49-177, which survived 18 percent better if irrigated than unirrigated. Cottonwood clones ST1 24 and ST1 63 each exhibited 10 percent better survival if unirrigated. High investments in intensive cultures render large initial stocking differences highly undesirable. Data, at age two, suggest planting hybrid poplar clones (49-177, 1529) provides better stocked stands than planting cottonwood clones from Texas (S13C20, S7C15) or Stoneville (ST 124, ST-163, ST-148 or Delta View).

Growth

For height and diameter, irrigation was a significant source of variation at age one and two (tables 1 and 2). After one growing season, furrow irrigation provided more *Populus* height than no irrigation by 2.1 feet. Height growth differences increased to 3.1 feet by the end of two growing seasons. Similarly, *Populus* irrigated clones yielded 0.18 inches more diameter at age one and 0.6 inches more dbh after two growing seasons than unirrigated clones. All clones, except Delta View, exhibited larger diameters at age one when irrigated than when not irrigated (table 1). At age two, diameters for all clones including Delta View, were greater when irrigated than unirrigated.

Volume per planted tree at age one was best for the hybrid poplar, 1529. The Texas clone, S7c15, the Stoneville clone, ST124, and the hybrid poplar clone, 49-l 77 were intermediate. The Texas clone, S13C20, and Stoneville clones St72, ST1 63, ST148 and Delta View exhibited the least *Populus* growth. Oak growth was the least of all test material.

Clone rank for growth at age two changed little from age one with the exception of hybrid poplar 49-l 77 which moved from the fourth best performer at age one to the second best performer at age two. At ages one and two, volume per planted tree was enhanced by irrigation for all clones. At age two, irrigated out performed unirrigated test material with enhanced mean performance for height, dbh and volume of 3.1 feet, 0.6 inches and 19.9 $feet^3$ per tree, respectively.

The most significant result to date may be in survival and early stand development of cottonwoods versus hybrid poplars. For example, the hybrid poplars survived and performed best when irrigated. Thus, of the 180 ramets of 49-l 77 planted, 159 survived and 151 of these exceeded 4.5 feet in height after one growing season (table 1). Similar values were observed for irrigated hybrid poplar 1529. In contrast, cottonwood clones ST124, ST163 and ST148 survived and performed best when unirrigated. Even there, only 53 of 95, or 23 of 133 or 6 of 116, respectively, unirrigated ramets survived and exceeded 4.5 feet in height at age one. Clearly, the hybrid poplars survived and initiated more desirable early stand development than the clones of eastern cottonwood, regardless of origin.

Table I-Age one mean survival, height (n=number of trees), diameter (n=number of trees), and volume per planted tree for an open-pollinated water oak family and for cottonwood and hybrid poplar clones growing with and without furrow irrigation near Pine Tree, AR

	Survival		Height[a]			
Clones	Irrigated[b]	Unirrigated[b]	Irrigated[b]		Unirrigated[b]	
	Percent		Feet	No.	Feet	No.
49-177	88.3a	71.1abc	7.1b	159	5.5c	127
1529	72.8b	78.9a	8.2a	131	6.5a	142
S13C20	61.1c	61.1cde	7.0b	110	6.1b	110
ST72	67.8bc	67.8bc	5.5cd	122	2.4ef	122
S7C15	67.2bc	64.4bcd	5.5cd	121	2.7e	116
ST124	42.2e	52.8e	7.9a	76	4.9d	95
ST1 63	64.4bc	73.9ab	5.0e	116	2.7e	133
ST148	59.4cd	64.4bcd	5.5de	107	2.2f	116
Delta View	50.6de	55.6de	5.7c	91	2.5ef	100
Oak	69.4bc	51.7e	1.6f	125	1.5f	93
Mean[c]	64.3a	64.2a	5.8a		3.8b	

	Diameter[a]				Volume[a]	
	Inches	No.	Inches	No.	Ft³	
49-I 77	0.53cd	151	0.32cd	96	1.87c	0.39bc
1529	.69a	124	.44ab	117	3.32a	1.22a
S13C20	.51cd	104	.39bc	79	1.27d	.61b
ST72	.48d	81	.28d	16	.93de	.04e
S7C15	.63b	64	.45ab	16	2.59b	.29cd
ST124	.73a	73	.37bc	53	2.13bc	.44bc
ST163	.52cd	51	.29d	23	.87de	.07de
ST148	.42e	71	.28d	6	.51ef	.02e
Delta View	.53c	59	.49a	10	.83de	.10de
Oak	.00	0	.00	0	.00	.00
Mean[c]	.56a		.38b		1.43a	.32b

[a] Irrigated versus unirrigated means for Delta View d.b.h. is not significantly different (Duncan's New Multiple Range Test, p = 0.05). All other irrigated versus unirrigated contrasts by clone for height, d.b.h., and volume are significantly different (Duncan's New Multiple Range Test, p = 0.05).

[b] Means within a column sharing a letter are not significantly different (Duncan's New Multiple Range Test, p =0.05).

[c] Attribute means within a row and sharing the same letter are not significantly different (Duncan's New Multiple Range Test, p = 0.05).

Table 2-Mean survival, height (n=number of sample trees), diameter (n=number of trees), and volume per planted tree at age two for an open-pollinated water oak family and for cottonwood and hybrid poplar clones growing with and without furrow irrigation near Pine Tree, AR

Clones	Survival		Height[a]			
	Irrigated[b]	Unirrigated[b]	Irrigated[b]		Unirrigated[b]	
	----- Percent -----		Feet	No.	Feet	No.
49-177	88.3a	70.5ab	16.2b	159	14.1b	127
1529	72.8b	78.9a	19.8a	131	15.7a	142
S13C20	60.6cd	61.1bcd	15.1d	109	12.3c	110
ST72	67.8bc	67.8bc	12.1de	122	8.5f	122
S7C15	62.2cd	63.3bc	12.5d	112	8.7ef	114
ST124	42.2e	51.1de	16.6b	77	11.4d	92
ST163	61.1cd	70.6ab	11.8e	110	9.2e	127
ST148	56.1d	64.4bc	12.1de	101	7.9g	118
Delta View	50.6cd	55.6cd	11.8de	104	8.6f	105
Oak	62.2cd	47.8e	3.9f	112	2.2h	86
Mean[c]	63.10a	64.0a	13.3a		10.2b	

Clones	Diameter[a]				Volume[a]	
	Inches	No.	Inches	No.	------- Ft^3 --------	
49-177	2.0b	158	1.7b	127	58.31b	34.94b
1529	2.5a	131	1.9a	142	98.14a	54.27a
S13C20	2.0b	108	1.5c	108	39.80c	23.60c
ST72	1.4cd	118	.6e	118	24.84de	3.0ef
S7C15	1.5c	105	.7d	106	28.34d	5.06e
T124	2.3a	77	1.4c	90	42.13c	16.92d
ST163	1.3d	106	.7d	121	19.52e	4.43ef
ST148	1.3cd	98	.6e	113	16.60e	2.53ef
Delta View	1.3cd	99	.6de	92	19.13e	3.35ef
Oak	.3e	8	.0d	4	.00	.00
Mean[c]	1.7a		1.1b		34.68a	14.81 b

[a] All irrigated versus unirrigated means per clone are significantly different (Duncan's New Multiple Range test, p = 0.05).
[b] Means within a column sharing a letter are not significantly different (Duncan's New Multiple Range Test, p = 0.05).
[c] Attribute means within a row and sharing the same letter are not significantly different (Duncan's New Multiple Range Test, p = 0.05).

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Intermediate Hardwood Management

Moderator:

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STAND STRUCTURE AND SPECIES COMPOSITION IN BOTTOMLAND HARDWOOD FORESTS OF EAST TEXAS[1]

A. Gordon Holley, Leslie A. Dale, Brian P. Oswald, and Gary D. Kronrad[2]

Abstract-Bottomland hardwood forests, growing on the flood plains of rivers and streams, comprise about 14 percent (1.6 million acres) of the total commercial forest land in East Texas. These stands represent high values for a variety of forest uses such as timber production and wildlife habitat. However, information on these forests is not as complete as that of the southern U.S. For this study, data from 445 ten-factor variable radius inventory points were used to characterize stand structure, species composition and the general condition of bottomland hardwood forest throughout East Texas. The importance of this information and its impact on management practices is discussed.

INTRODUCTION

Bottomland hardwood forests, growing on the flood plains of rivers and streams, comprise approximately 14 percent (1.6 million acres) of the total commercial forest land in East Texas. Properly managed, these forests could provide quality lumber, veneer and pulp, along with providing good wildlife habitat for a variety of species. Historically, bottomland hardwood forests of East Texas have been declining in area at an average annual rate of 0.8 percent. This lose is primarily due to conversion to pine plantations, increased logging activities, and land development. The Conservation Reserve Program has helped limit this decline by encouraging landowners to reforest their bottomlands (Sims 1989). Within the last 15 years the southern United States has seen an increase in the demand in hardwood products for both domestic and export markets. Since 1975, the world demand for US hardwood logs, veneer, and lumber has quadrupled (Araman 1989).

Historically, East Texas bottomland forests had been subjected to high-grading practices leaving forest composed of primarily undesirable tolerant species and trees of poor form. Bottomland hardwoods in East Texas have long been considered low-quality, with little or no commercial value. As such, the majority of these forests have received little or no management since high-grading years before. The increase in hardwood markets has helped in changing the outlook for these resources. Several forest products industries are now beginning to look more seriously at their bottomland hardwoods. However, the low quality stigma remains. Most of the research performed on bottomland hardwoods in the south often did not involve stands in East Texas and consequently little is actually known about the structure or composition of these forests. The objective of this paper was to explore the stand structure and species composition of the bottomland hardwood forests of East Texas.

METHODS

During the summers of 1993, 1994, and 1995 bottomland hardwood stands were sampled within ownership of Temple-Inland, Champion, International Paper and USDA Forest Service. Sample stands were located in Angelina, Anderson, Cherokee, Hardin, Houston, Jasper, Nacogdoches, Newton, Orange, Sabine, San Augustine, Shelby, and Trinity counties. Eighty-four study sites were chosen to represent bottomland hardwood stands common to the region. Within these stands 443 temporary sample points were systematically located using a three by five chain grid. All trees being recorded as "in" using a 1 O-factor prism were utilized in this study. Data such as species, diameter at breast height (d.b.h.), total tree height, merchantable height, crown width, and log grades were recorded. An increment core was also extracted for age determination and growth analysis.

Analysis included estimates of stocking using Goelz's (1995) stocking guide for southern bottomland hardwoods and Putnam and others (1960) stocking classification system. Goelz developed the stocking guide using the data of Putnam and others (1960). The form of the guide was taken from Gingrich (1967), except the B-line is based on Putnams's suggested residual stocking rather than minimum full stocking. Putnam's classification system is based on species preference, log grade, crown class, and tree vigor. In use, the system classifies trees as preferred stock, reserve stock, cutting stock, or cull stock. These classes can then be used to establish the cutting priority in commercial thinnings or other partial cuttings.

RESULTS

A total of 4913 trees from 34 general species were sampled during the three year measurement period. Table 1 shows the number of samples and the percent of occurrence for each of the 34 species. Because of low observations for some of the species, the sample was reduced to seven overall species groups of Oaks, Sweetgum, Blackgum, Elm, Ash, Pine, and Miscellaneous (table 2). The Miscellaneous category is made up primarily low occurrence and non-commercial species. As shown in table two, over 61 percent of the sample is made up of oaks. If the oaks and sweetgum are combined, over 75 percent of the bottomland hardwood forests are composed of the most commercially viable species. The miscellaneous group is the only other group containing ten percent or more of the total number of species. This group is composed mainly of understory commercially undesirable species.

The 3027 trees in the oak group was divided into their individual species to show the distribution (table 3). Sixty-eight percent of the oak population is made up of willow, cherrybark, and water oaks. These three oak species are also some of the most commercially desirable oaks in the region.

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

[2] Visiting Scientist, Forest Resources institute, Arthur Temple College of Forestry; and Research Associate, Associate Professor, and Professor, Arthur Temple College of Forestry, Stephen F. Austin State University, Nacogdoches, TX 75964, respectively.

Table l-Number of trees and percent of total sample by species observed

Species	Number of trees	Percent of sample	Species	Number of trees	Percent of sample
Ash	109	2.22	Magnolia	4	0.08
Basswood	3	0.06	Maple	88	1.79
Beech	19	0.39	Nuttall oak	10	0.20
Black walnut	4	0.08	Overcup oak	285	5.80
Blackgum	243	4.95	Pawpaw	2	0.04
Cherry bark oak	565	11.50	Pine	94	1.91
Cypress	22	0.45	Post oak	10	0.20
Eastern redbud	1	0.02	Red oak	5	0.10
Elm	110	2.24	River birch	13	0.26
Gum bumelia	5	0.10	Sugarberry	27	0.55
Hawthorne	3	0.06	Cow oak	142	2.89
Hickory	126	2.56	Sweetbay	13	0.26
Holly	32	0.65	Sweetgum	813	16.55
Honey locust	3	0.06	Sycamore	8	0.16
Hophorn beam	33	0.67	Water oak	540	10.99
Horn beam	111	2.26	White oak	101	2.06
Laurel oak	350	7.12	Willow oak	1,019	20.74
Total				4,913	100.00

Table P-Number of trees and percent of total by reduced species groups

Species group	Number of trees	Percent of occurrence
Oaks	3,127	61.6
Sweetgum	813	16.5
Blackgum	248	5.0
Elms	110	2.4
Ash	108	2.2
Pine	94	1.9
Miscellaneous	513	10.4
Total	4,913	100.0

Table 3-Number of trees and percent of total of oak species

Species	Number of trees	Percent of occurrence
Willow oak	1,019	33.7
Cherrybark oak	56	18.7
Water oak	540	17.8
Laurel oak	350	11.6
Overcup oak	285	9.4
Cow oak	142	4.7
White oak	101	3.3
Nuttall oak	10	.3
Post oak	10	.3
Southern red oak	5	.2
Total	3,027	100.0

The number of trees sampled by one inch diameter classes is shown in Figure 1. A high percentage of the sample is from sawtimber size trees. This number could be somewhat misleading due to the sampling method of using prism points which may discriminate against smaller diameter trees. When these numbers are converted to per acre values the expected “reverse J shaped” curve indicative of an uneven or all aged forest occurs (fig. 2). The aforementioned size discrimination is evident on the extreme left side of Figure 2, where there appears to be a smaller number of smaller diameter trees.

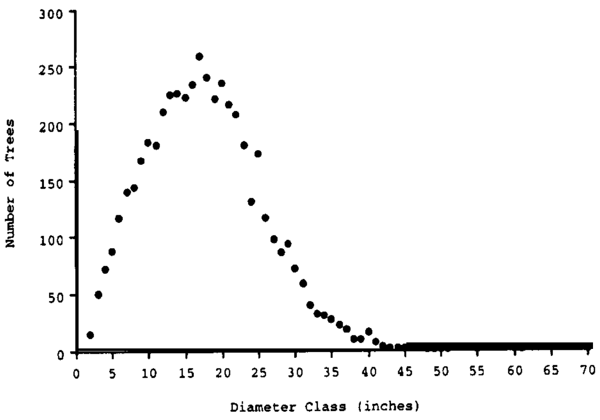

Figure l-Number of sample trees by one inch diameter classes.

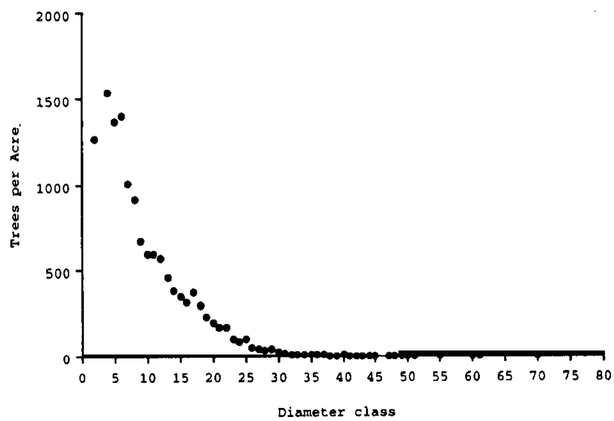

Figure P-Trees per acre values by one inch diameter classes.

Average trees within each species group are all within sawtimber size (table 4). Pine, oaks, and sweetgum had the largest average diameters and the greatest heights. With the exception of the pine group, ranges for both diameter and height spanned from small, probably young trees to large fully mature trees. The smallest pine tree sampled was in the sawtimber diameter class. The elm and miscellaneous groups contained the smallest diameters and shortest trees.

Stocking

Stocking estimates were calculated for each of the 84 sampled stands using the following equation developed by Goelz (1995):

$$Stocking = 0.01373(TA) + 0.096(TA[DqMean]) + 0.00378(TA[DqMean^2]) \quad (1)$$

Where:
TA = Trees per acre
DqMean = Quadratic mean diameter

Fifty percent of the stands sampled had greater than 100 percent stocking (table 5). Almost 36 percent of the stands were stocked at a level between 80 and 99 percent, meaning approximately 86 percent of the stands were either fully or overstocked.

Tree Classification

Each tree in the sample was classified using Putnam and others (1960) tree species classification system. Over 75 percent of the trees in the sample were in the class A species group and 16 percent in the class B Group. The class A group can be composed of species such as water, willow, white or cherrybark oaks, Pines, and sweetgum. Class B groups might be composed of overcup and southern red oaks, blackgum, or Tupelo. Approximately seven percent of the trees sampled fell into the less or undesirable C and D groups.

Each tree within each of the 84 stands was subjected to the species classification system to determine the mean stocking level by species class (tables 6 and 7). The average stand in the East Texas bottomland hardwood

Table 4—Means and ranges for DBH and heights by species groups

Species groups	Mean d.b.h.	Range	Mean height	Range
	------- *Inches* --------		------- *Feet* --------	
Oaks	19.79	2.5 - 70.5	89.67	8 - 163
Sweetgums	15.65	2.9 - 61.0	83.77	16 - 141
Blackgum	13.37	2.1 - 39.1	66.10	15 - 135
Elm	11.96	3.0 - 28.5	58.22	16 - 125
Ash	14.69	2.6 - 35.4	74.42	25 - 150
Pine	21.74	9.6 - 34.9	97.97	50 - 133
Miscellaneous	12.12	1.6 - 38.8	58.10	9-127

Table 5—Stocking levels of all stands sampled

Stocking	Number of stands	Percent of sample
Percent		
> 100	42	50.0
80-99	30	35.7
< 80	12	14.3
Total	84	100.0

Table 6-Number of trees and percent of sample within four species classification groups

Tree classification group	Number of trees	Percent of occurrence
A	3,757	76.5
B	808	16.4
C	172	3.5
D	176	3.6
Total	4,913	100.0

forest contains just under 76 percent of the most commercially desirable class A tree species and approximately 16 percent of the class B species. Less than 17 percent of the average stand is comprised of the class C and D species. Also the average stand is overstocked with a mean stocking percentage of approximately 109 percent.

DISCUSSION

It appears that most bottomland hardwood stands in East Texas are overstocked and are in need some management decisions. Although these stand may be overstocked they at least appear to be overstocked with more commercially desirable species. The myth of East Teas bottomland hardwood being undesirable and of poor quality may be in jeopardy. Although this study did not address tree quality issues, at least with high quality species there should be an adequate seed source for future stands. Good seed sources combined with proper management decisions may lead to improved stand and tree quality.

Table 7-Mean stocking by species classification

Species class	Mean stocking	Range	Percent of mean stocking
	Percent		
A	75.95	39.10 - 127.18	69.75
B	16.27	2.11 - 54.94	14.95
C	6.77	.95 - 35.67	6.22
D	9.90	1.25 - 30.45	9.09
Total	108.89		100.00

Bottomland stands in East Texas are commonly referred to as “mixed” bottomland hardwoods. With 80 percent of the trees sampled being oaks and gums, perhaps “oak-gum” forest may be a better descriptor.

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THIRD-YEAR GROWTH AND BOLE QUALITY RESPONSES TO THINNING IN A RED OAK-SWEETGUM STAND ON A MINOR STREAMBOTTOM SITE IN WEST-CENTRAL ALABAMA[1]

James S. Meadows and J.C.G. Goelz[2]

Abstract-Four thinning treatments were applied to a red oak-sweetgum (Quercus spp.-*Liquidambar styraciflua* L.) stand on a minor streambottom site in west-central Alabama in 1994: (1) unthinned control: (2) light thinning to 70-75 percent residual stocking; (3) heavy thinning to 50-55 percent residual stocking; and (4) B-line thinning to desirable residual stocking for bottomland hardwoods, as recommended by Putnam and others (1960). The thinning operation was a combination of low thinning and improvement cutting to remove most of the pulpwood-sized trees as well as sawtimber-sized trees that were damaged, diseased, of poor bole quality, or of an undesirable species. Prior to treatment, the stand averaged 196 trees per acre with a basal area of 121 ft^2 per acre. Quadratic mean diameter was 10.7 in., while stocking averaged 107 percent across the 24-acre study area. Light thinning reduced stand density to 83 trees and 82 ft^2 of basal area per acre, increased quadratic mean diameter to 13.5 in., and reduced stocking to 69 percent. Heavy thinning reduced density to 49 trees and 64 ft^2 of basal area per acre, increased quadratic mean diameter to 15.5 in., and reduced stocking to 52 percent. B-line thinning produced stand characteristics intermediate between those resulting from light and heavy thinning. Thinning increased 3- year diameter growth of residual trees, across all species, but there were no significant differences among the three levels of thinning. Thinning also increased diameter growth of codominant trees, but not dominant trees, when averaged across all species. All levels of thinning, except heavy thinning, increased the production of new epicormic branches on the butt log, across all species, but all levels of thinning resulted in fewer than four new branches afler 3 years. All levels of thinning increased epicormic branching on sweetgum, but only B-line thinning increased epicormic branching on red oak and only light thinning increased epicormic branching on hickory (*Carya* spp.). In general, the production of new epicormic branches on the butt log was greatest on low-vigor, lower-crown-class trees.

INTRODUCTION

Thinning regulates stand density and dramatically increases diameter growth of residual trees. Growth of individual trees has been improved in several hardwood forest types such as central upland oaks (Hilt 1979, Sonderman 1984b), Allegheny cherry-maple (*Prunus* spp.-Acerspp.) (Lamson 1985, Lamson and Smith 1988), and mixed Appalachian hardwoods (Lamson and others 1990). In general, the heavier the thinning, the greater the diameter growth response of individual trees. However, very heavy thinning may reduce residual stand density to the point where stand-level basal area growth and volume growth are greatly diminished. Site occupancy is less than optimum because the stand does not fully realize the potential productivity of the site. Recommended minimum residual stocking levels necessary to maintain satisfactory stand-level growth and to ensure full occupancy of the site are 46 to 65 percent in central upland oaks (Hilt 1979) and 45 to 60 percent in cherry-maple stands (Lamson and Smith 1988). 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, whereas a residual stocking level of 33 percent created a severely understocked stand that will be unable to fully occupy the site for many years to come (Meadows and Goelz, in press).

Degradation of bole quality of residual trees is also sometimes associated with increased thinning intensity. In upland oaks, the number and size of live and dead limbs on the boles of residual trees increased significantly as residual stocking decreased (Sonderman 1984a). On the other hand, Sonderman and Rast (1988) found that the production of epicormic branches on residual oak stems decreased with increasing thinning intensity. The proportion of dominant and codominant trees in the residual stand increases as the intensity of thinning increases. These vigorous, upper-crown-class trees are less likely to produce epicormic branches than are less vigorous, lower-crown-class trees (Meadows 1995). Consequently, a properly designed thinning should improve average bole quality throughout the residual stand. In many stands, however, there may be a trade-off between improved diameter growth and the potential for adverse effects on bole quality of residual trees as thinning intensity increases and residual density decreases.

In most mixed-species hardwood forests, a combination of thinning and improvement cutting is also used to improve species composition of the residual stand (Meadows 1996). In general, the goal is to decrease the proportion of low-value trees and thus increase the proportion of high-value trees. Although most important at the first thinning, improvement of species composition and residual bole quality should also be a major consideration at all subsequent thinnings in mixed-species stands.

These four components of thinning-increased diameter and volume growth of individual trees, increased stand-level basal area and volume growth, maintenance or enhancement of bole quality, and improved species composition-are critically important for the profitable management of hardwood stands for high-quality sawtimber production. Thinning regimes should ideally be designed to optimize value of the stand, thereby synthesizing these four components. However, because maximization of all four components is not likely, some compromises or trade-offs in expected benefits must be accepted.

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Research on thinning in southern bottomland hardwood forests is lacking. General guidelines, such as those recommended by McKnight (1958), Johnson (1981), Meadows (1996), and Goelz and Meadows (1997) are available, but are based more on experience and observation rather than on specific research results. To effectively manage southern bottomland hardwood stands for high-quality sawtimber production, we need quantitative thinning guidelines that include recommendations on: (1) timing of thinning, (2) intensity of thinning, and (3) marking guidelines designed to optimize value of the stand.

This study is the first in a series of thinning studies in red oak-sweetgum stands on minor streambottom sites across the South. The series will consist of at least 12 studies installed over 1 O-l 5 years; all studies in the series will use similar study designs, treatments, and methods. This initial study, as well as all individual studies within the series, was designed to determine the effects of several levels of thinning on: (1) growth and bole quality of individual trees and (2) stand-level growth, development, and yield. The results from the entire series of studies will be combined to: (1) develop practical guidelines for the intermediate management of southern bottomland hardwood stands; (2) evaluate the applicability of several levels of recommended residual stocking across a wide 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 within the floodplain of the Tombigbee River in northeastern Sumter County, near Aliceville, in west-central Alabama. This bottomland tract is near Lake Hollalla and is owned by Gulf States Paper Corporation. The site is subject to flooding during the winter and spring months, but floodwaters generally recede in a few days.

Soils across most of the study site belong to the Ochlockonee series, but there are small areas of Falaya soils in the lower areas. The Ochlockonee soils are well-drained, but the Falaya soils are somewhat poorly drained. Infiltration and permeability rates are moderate to rapid across the site. Both soils have moderate-to-high natural fertility and high available water capacity. Texture in the upper soil horizon across the study area is silt loam to fine sandy loam. Soil pH is very strongly acid and ranges from 4.5 to 5.5 across the site.

The study area is located on a highly productive site suitable for the production of high-quality hardwood sawtimber. Broadfoot (1976) reported average site indexes of the Ochlockonee soils to be 110 ft at 50 years for water oak and 112 ft at 50 years for sweetgum, and estimated site index for cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.) to range from 100 to 120 ft at 50 years. The Falaya soils are only slightly less productive. Site indexes are reported to average 101 ft at 50 years for water oak, 111 ft at 50 years for sweetgum, and 108 ft at 50 years for cherrybark oak (Broadfoot 1976).

The study area is entirely within a 74-acre stand composed primarily of red oak, sweetgum, and hickory. The stand was about 60 years old at the time of study installation and exhibited no evidence of previous harvesting activity. Based on an inventory by company personnel in 1993, sawtimber volume averaged 6,520 bd ft per acre (Doyle scale), of which 81 percent was red oak, and pulpwood volume averaged 12.5 cords per acre (Personal communication. Sam Hopkins. 1993. Research Manager, Gulf States Paper Corporation, P.O. Box 48999, Tuscaloosa, AL 35404). We classified the study area to consist of a small-sawtimber stand on a high-quality site, with high initial stocking.

Plot Design

Plot design followed the recommendations for standard plots for silvicultural research, set forth by the USDA Forest Service Northeastern Forest Experiment Station (Marquis and others 1990). Each individual treatment was uniformly applied across a 2.0-acre, rectangular treatment plot that measured 4 by 5 chains (264 by 330 ft). One 0.8acre, rectangular measurement plot was established in the center of each treatment plot. Each measurement plot was 2 by 3 chains (132 by 198 ft), providing a l-chain buffer around each. The entire study covered an area of 24 acres.

Treatments

Based on the stocking guide for southern bottomland hardwoods developed by Goelz (1995), we used four levels of residual stocking as the treatments in this study: (1) an unthinned control: (2) light thinning to 70 to 75 percent residual stocking; (3) heavy thinning to 50 to 55 percent residual stocking; and (4) B-line thinning to desirable residual stocking following partial cutting in well-managed, even-aged southern bottomland hardwoods, as recommended by Putnam and others (1960).

A combination of low thinning and improvement cutting was used to remove most of the pulpwood-sized trees as well as sawtimber-sized trees that were damaged, diseased, of poor bole quality, or of an undesirable species. Modified hardwood tree classes (Meadows 1996, Putnam and others 1960) formed the cutting priority for each treatment. Trees were removed from the cutting stock and cull stock classes first and then from the reserve growing stock class when necessary, until the target residual stocking was met.

Three replications of the four levels of thinning were applied in a randomized complete block design to the 12 treatment plots (experimental units) in September 1994. A contract logging crew directionally felled all trees with a mechanized feller and used rubber-tired skidders to remove the merchantable products in the form of longwood. Most of the material cut was marketed as pulpwood.

Measurements

We conducted a preharvest survey to determine species composition and initial stand density on each O.&acre measurement plot. We recorded species, diameter at breast height (d.b.h.), crown class, and tree class on all trees greater than or equal to 3.5 in. d.b.h. Based on hardwood tree classes as defined by Putnam and others (1960) and modified by Meadows (1996), we marked the stand for thinning to the target residual stocking prescribed for each treatment. The length and grade of all sawlogs, as defined by Rast and others (1973), and the number of epicormic branches on each 16-ft log section were recorded on those trees designated as "leave" trees. We also measured merchantable height, height to the base of the live crown, and total height on a subsample of leave trees. Crown class, d.b.h., and the number of epicormic branches on each 16-ft log section were measured annually for the first 3 years after thinning. First-year responses to the thinning treatments were reported by Meadows and Goelz (1998).

RESULTS AND DISCUSSION

Stand Conditions Prior to Thinning

We found no significant differences among treatment plots in any preharvest characteristics. Prior to thinning, the stand averaged 196 trees and 121 ft^2 of basal area per acre, with a quadratic mean diameter of 10.7 in. The average stocking of 107 percent exceeded the level (100 percent) at which thinning is recommended in southern bottomland hardwood stands (Goelz 1995). Although the stand was dense, most of the larger, upper-crown-class 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. Little sunlight reached the forest floor, except in small gaps created by the death of scattered trees throughout the stand. In short, the stand needed thinning but was not stressed to. the point of stagnation at the time of study installation.

The study area was contained within an even-aged, mixed-species stand dominated by red oak, hickory, and sweetgum. Several species of red oaks, principally water, cherrybark, and willow (*Quercus phellos* L.) oaks with lesser amounts of southern red (Q. *falcata* Michx.) and Shumard (*Q. shumardii* Buckl.) oaks, accounted for about 45 percent of the basal area and were found primarily in the upper canopy. Quadratic mean diameter of red oaks was 16.1 in. Shagbark hickory [*Carya ovata* (Mill.) K. Koch] and mockernut hickory [C. *tomentosa* (Poir.) Nutt.] together accounted for about 25 percent of the basal area. Hickories were found primarily in the mid-canopy, but scattered individuals occurred in the upper canopy. Sweetgum comprised about 12 percent of the basal area and occurred primarily as lower-crown-class trees. Other species scattered throughout the stand included white oak (C?. *alba* L.), overcup oak (Q. *lyrata* Walt.), swamp chestnut oak (Q. *michauxii Nutt.),* green ash *(Fraxinus pennsylvanica* Marsh.), and various elms (*Ulmus* spp.). Along with small hickories and sweetgum, red mulberry *(Mows rubra* L.), American hornbeam *(Carpinus caroliniana* Walt.), and maples dominated the understory.

Stand Development Following Thinning

Light thinning reduced stand density to 83 trees and 82 ft^2 of basal area per acre, increased quadratic mean diameter to 13.5 in., and reduced stocking to 69 percent. It removed 62 percent of the trees and 31 percent of the basal area. Heavy thinning reduced density to 49 trees and 64 ft^2 of basal area per acre, increased quadratic mean diameter to 15.5 in., and reduced stocking to 52 percent. It removed 73 percent of the trees and 43 percent of the basal area. B-line thinning reduced stand density to 65 trees and 86 ft^2 of basal area per acre, increased quadratic mean diameter to 15.6 in., and reduced stocking to 70 percent. It removed 68 percent of the trees and 37 percent of the basal area. B-line thinning was similar to light thinning in terms of basal area and stocking of the residual stand, similar to heavy thinning in quadratic mean diameter of the residual stand, and intermediate between the two in trees per acre contained in the residual stand. All thinning treatments produced stand characteristics significantly different from the unthinned control. Average d.b.h. of trees removed during the logging operation ranged from 7.1 in. in the light thinning treatment to 8.3 in. in the B-line thinning treatment. Overall average d.b.h. of trees removed was 8.0 in.

Thinning also improved species composition of the residual stand. All thinning treatments increased the proportion of red oak and decreased the proportions of both sweetgum and hickory within the residual stand. Most of the sweetgum and hickory removed from the stand were lower-crown-class trees.

Stand conditions did not change significantly during the 3 years following thinning (table 1). A few trees died in all of the plots, except those subjected to heavy thinning where no mortality occurred. Mortality was greatest after B-line thinning (9.2 percent over 3 years), but was similar following light thinning (6.0 percent) and in the unthinned control (6.5 percent). A few trees were destroyed during the logging operation, but most of the mortality occurred as windthrow. These changes in trees per acre were not significantly different among treatments.

Stand-level basal area growth and increases in stocking and quadratic mean diameter, although not significantly different among treatments, indicate that the stand may be recovering faster from heavy thinning and B-line thinning than from light thinning (table 1). We observed small increases in stand-level basal area in the lightly thinned and unthinned stands (2 ft^2 of basal area growth in the 3 years

Table I-Stand conditions and individual tree diameter growth 3 years after application of four thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability

Treatment	Trees	Basal area	Stocking	Quadratic mean diameter	Diameter growth
	No./ac	*Sq ft/ac*	*Percent*	*------ Inch --------*	
Unthinned	172a	119 a	103a	11.3 b	0.24 b
Light thinning	78 b	84 bc	70 b	14.2 ab	.46 a
Heavy thinning	49 c	69 c	56 c	16.4 a	.56 a
B-line thinning	59 bc	90 b	73 b	16.7 a	.61 a

following each treatment). However, larger increases of 5 and 4 ff were found as a result of heavy thinning and B-line thinning, respectively. In fact, basal area growth in the heavily thinned stand was great enough that its total basal area is now statistically similar to the total basal area in the lightly thinned stand, a situation not found 1 year after treatment (Meadows and Goelz 1998). A similar trend was observed for the changes in stocking among the four treatments. All treatments also produced increases in quadratic mean diameter, with heavy thinning and B-line thinning again resulting in the largest increases (0.9 in. and 1 .1 in., respectively), as compared to 0.5 in. and 0.7 in. in the unthinned and lightly thinned stands, respectively.

Diameter Growth

For the first time since study installation, we detected significant differences between the thinning treatments and the unthinned control in cumulative diameter growth of individual trees, but there were no differences among the three levels of thinning 3 years after treatment (table 1). Cumulative diameter growth of trees in the thinned stands averaged about 2 to 2.5 times greater than the average diameter growth of trees in the unthinned stand.

Individual species groups varied significantly in their diameter-growth response to the four treatments (fig. 1). Three-year cumulative diameter growth of residual red oaks (primarily water, cherrybark, and willow oaks) in the thinned stands was nearly twice as great as that in the unthinned stand and ranged from 0.83 to 0.86 in. across the three levels of thinning. Thinning also more than doubled diameter growth of residual sweetgum trees, but response was less than that observed among red oaks. Diameter growth of hickory was relatively poor, but the largest increase occurred in response to heavy thinning.

None of the three levels of thinning increased diameter growth of dominant trees, when averaged across all species, but heavy thinning and B-line thinning did increase diameter growth of codominant trees by about 40 to 45 percent (fig. 2). Both the heavy and B-line thinning treatments more than

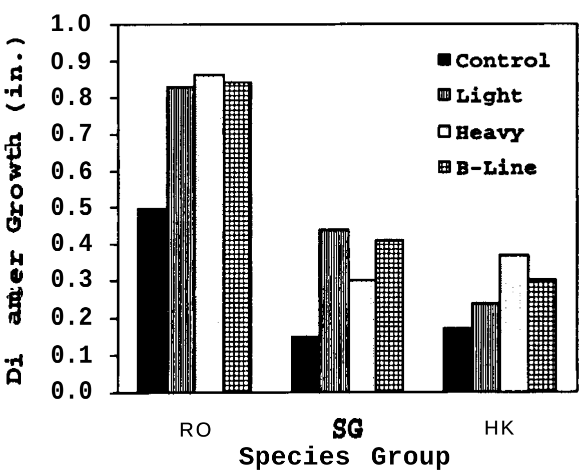

Figure l-Diameter growth of residual trees, by species group, during the first 3 years after application of four thinning treatments (RO = red oak, SG = sweetgum, HK = hickory).

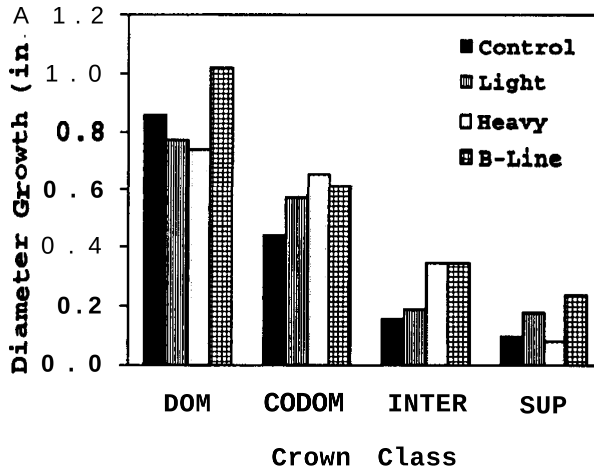

Figure 2—Diameter growth of residual trees, by crown class, during the first 3 years after application of four thinning treatments (DOM = dominant, CODOM = codominant, INTER = intermediate, SUP = suppressed).

doubled diameter growth of intermediate trees. Light thinning produced no or only small increases in diameter growth across these three crown classes. Diameter-growth response of suppressed trees was erratic across treatments primarily because thinning removed most of these inferior trees.

It is clear that all three levels of thinning successfully increased diameter growth of residual trees within the first 3 years following thinning. At this time, we are unable to detect any significant differences among these three levels, when compared across all trees, across species groups, or across crown classes. However, heavy thinning and B-line thinning appear to produce the greatest increases in diameter growth, at least in some circumstances. Perhaps differences among the three levels of thinning will become more evident in the future.

Epicormic Branching

Because we removed most of the trees of poor bole quality during the thinning operation, residual trees in the thinned stands, on average, had significantly fewer epicormic branches on the butt log 3 years after thinning than did trees in the unthinned stand (table 2). However, all levels of thinning, except heavy thinning, significantly increased the production of new epicormic branches on the butt log, even though trees in all treatments averaged fewer than four new branches during the first 3 years after thinning. Production of new epicormic branches varied greatly among individual trees. Some of the high-vigor trees produced no new branches, while many others produced only a few. Low-vigor trees, on the other hand, generally produced many new epicormic branches. Production of new epicormic branches, especially on the butt log, seems to be a delayed consequence of thinning. Meadows and Goelz (1998) reported that trees in all treatments averaged less than one new epicormic branch during the first year after treatment in this study. Our subsequent observations indicate that the majority of new epicormic branches were produced during the second year and that production of new branches during the third year was negligible. However, most new epicormic

Table 2-Number of epicormic branches on the butt logs of residual trees 3 years after application of four thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability

Treatment	Total epicormic branches	New epicormic branches
	Number	
Unthinned	6.9 a	1.4 b
Light thinning	4.1 b	3.0 a
Heavy thinning	3.2 b	2.1 ab
B-line thinning	5.2 ab	3.5

branches produced during the first and second years survived through the third year.

Among the major species groups, only B-line thinning increased the production of new epicormic branches on the butt logs of red oaks and only light thinning increased epicormic branching in hickories (fig. 3). In contrast, all levels of thinning greatly increased the production of new epicormic branches on the butt logs of sweetgum trees. Because light thinning retained a high proportion of low-vigor trees, epicormic branching on sweetgum following this treatment seemed particularly high. The observation that the majority of these new branches were produced during the second year following thinning held true across all three species groups. It is important to note that heavy thinning had no significant effect on the production of new epicormic branches on the butt logs of either red oaks or hickories, even though Meadows (1995) categorized most bottomland red oaks as highly susceptible to epicormic branching and speculated that hickories were moderately susceptible. Nearly all of the residual red oaks and hickories in the heavily thinned stand were high-vigor, upper-crown-class trees that are generally less likely to produce epicormic branches than are trees in poor health.

Production of new epicormic branches on the butt log also varied among crown classes, across all species (fig. 4). In general, new epicormic branches were more frequent on the boles of lower-crown-class trees than on the boles of upper-crown-class trees, especially for trees in the thinned stands. We observed the same trend for the total number of epicormic branches on the butt log (fig. 5). Dramatically more epicormic branches were found on the boles of

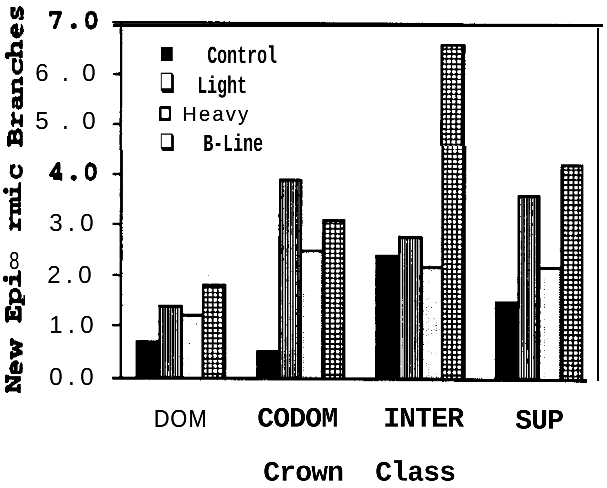

Figure 4-Number of new epicormic branches produced on the butt logs of residual trees, by crown class, during the first 3 years after application of four thinning treatments (DOM = dominant, CODOM = codominant, INTER = intermediate, SUP = suppressed).

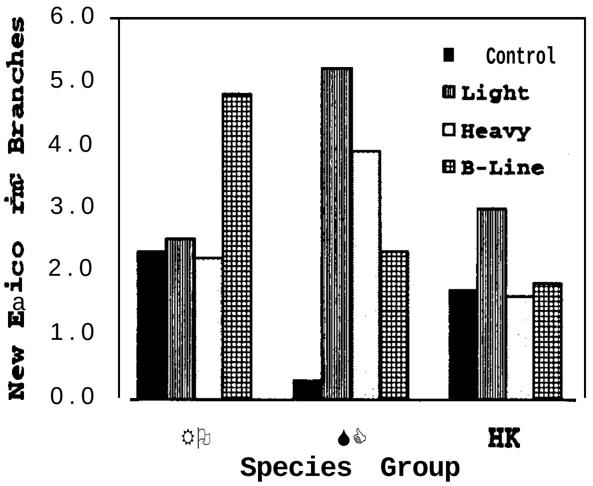

Figure 3-Number of new epicormic branches produced on the butt logs of residual trees, by species group, during the first 3 years after application of four thinning treatments (RO = red oak, SG = sweetgum, HK = hickory).

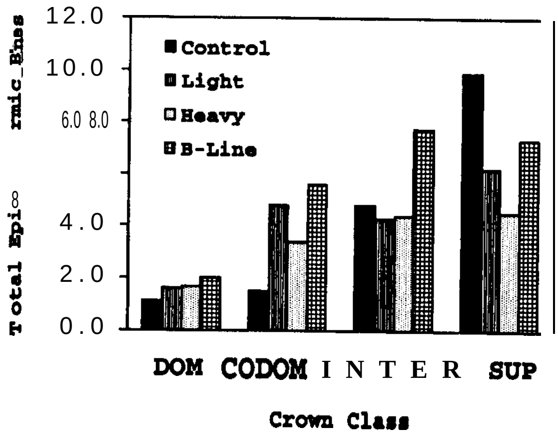

Figure 5-Total number of epicormic branches on the butt logs of residual trees, by crown class, 3 years after application of four thinning treatments (DOM = dominant, CODOM = codominant, INTER = intermediate, SUP = suppressed).

intermediate and suppressed trees than on the boles of dominant and codominant trees, even in the unthinned stand. This observation indicates that epicormic branches are often produced in response to increased stress and reduced vigor, even in undisturbed stands.

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 disturbance or stress is controlled by the species and initial vigor of the particular tree. Meadows (1995) noted that hardwood species vary greatly in their likelihood to produce epicormic branches and provided a classification of the susceptibility of most bottomland hardwood species to epicormic branching. Meadows (1995) also hypothesized that tree vigor is the mechanism that controls the production of epicormic branches when a tree is subjected to some type of disturbance or stress. It follows, then, that healthy, vigorous trees, even of susceptible species, are much less likely to produce epicormic branches than are trees in poor health. Our observations in this study that epicormic branching varied not only by species but also among crown classes strongly support these hypotheses.

CONCLUSIONS

None of the treatments significantly affected stand-level growth and development. However, the stand appears to be recovering faster from heavy thinning and B-line thinning than from light thinning. Although none of the increases were statistically significant, these two treatments produced greater stand-level basal area growth and greater increases in stocking and quadratic mean diameter, when compared to light thinning and the unthinned control.

Thinning increased diameter growth of residual trees, but there were no significant differences among the three levels of thinning. The greatest diameter-growth response occurred within the red oak group, but all levels of thinning doubled the diameter growth of sweetgum as well. None of the three levels of thinning increased diameter growth of dominant trees, but heavy thinning and B-line thinning increased growth of codominant trees by about 40-45 percent. Light thinning produced only moderate increases in diameter growth of codominant trees.

All levels of thinning, except heavy thinning, significantly increased the production of new epicormic branches on the butt logs of residual trees. However, trees in all treatments averaged fewer than four new branches during the first 3 years after thinning. All levels of thinning increased the production of epicormic branches on sweetgum, but only B-line thinning increased epicormic branching on red oak and only light thinning increased epicormic branching on hickory. In general, the production of new epicormic branches was greatest on low-vigor, lower-crown-class trees.

Although these third-year results are not definitive, it appears that heavy thinning produced the combination of stand density and structure that best promoted rapid stand-level growth and individual-tree diameter growth, with the least adverse effect on epicormic branching and bole quality of residual trees, B-line thinning also promoted rapid stand-level growth and rapid diameter growth of residual trees, but had a more detrimental effect on epicormic branching, particularly of red oaks, that may eventually lead to reductions in both log grade and stand value. Although light thinning increased diameter growth of residual trees, it had little or no effect on stand-level growth and development, and led to large increases in new epicormic branches on both sweetgum and hickory.

Heavy thinning removed nearly all of the small-diameter, low-vigor, lower-crown-class trees, whereas B-line thinning and, to a greater degree, light thinning retained increasingly larger proportions of these inferior trees. Consequently, heavy thinning concentrated diameter growth on large, healthy trees that contributed greatly to stand-level growth and minimized the production of new epicormic branches. Both B-line thinning and light thinning retained sufficient numbers of lower-crown-class trees to impede stand-level growth and to increase the risk of epicormic branching.

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PRECOMMERCIAL THINNING IN A RED OAK-SWEETGUM STAND ON THE SALINE RIVER FLOODPLAIN'

Sean Blackburn, Brian R. Lockhart, and David Blaylock[2]

Abstract-Precommercial thinning was conducted in a bottomland red oak (Quercus spp.)-sweetgum (*Liquidambar styraciflua*) stand in the Saline River floodplain in south-central Arkansas. Three thinning levels, 125 best trees per acre (tpa), 250 best tpa, and 500 best tpa plus an unthinned control were replicated four times in 1979 in a 15-year-old stand. Nineteen-year results showed average diameters and heights were greater for the heaviest thinned treatment compared to unthinned controls. Few differences existed among the other thinning treatments and the 125 best tpa or controls. Differences in diameters did exist between thinning and no thinning when only the 50 largest trees per acre were analyzed. These results indicate that precommercial thinning may be a viable silvicultural tool for managing young bottomland hardwood stands with a high density of red oak.

INTRODUCTION

Successful management of natural bottomland hardwood stands for sawtimber production should focus on maintenance of desired species composition, growth rates and development of high-quality logs (Meadows 1996). Precommercial thinning is a potential tool that can be used to promote good growth and development of bottomland hardwood stands, especially if the species composition is heavy to oak early in the stand's life. Pre-commercial thinning is a silvicultural treatment conducted in a young stand before it is of a merchantable size (Smith and others 1997). Advantages of a precommercial thinning include: (1) to provide the opportunity to select desired future crop trees early in the life of the stand, (2) to help maintain the health of individual trees, (3) to increase the crown volume (especially in the oak component) which in turn should increase tree diameter due to increased leaf area and food production, and (4) to ease future harvesting operations by creating a larger area for equipment maneuverability thereby reducing potential damage to residual crop trees (Smith and others 1997). The primary disadvantage of precommercial thinning is that it is usually too expensive for hardwood management, especially if the objective is quality sawtimber production. A recent cost estimate for precommercial thinning operations was about $80 per acre depending on the stand and the type of equipment used in the operation (Dubois and others 1999). Another disadvantage is the general lack of knowledge concerning responses of bottomland hardwood species to precommercial thinning. Therefore, the objective of this study was to determine if precommercial thinning will promote the growth and development of crop trees in a young bottomland red oak stand. The hypothesis was that precommercial thinning would increase the growth of the residual crop trees and that the greater the intensity of precommercial thinning, the greater the response.

MATERIALS AND METHODS

Study Site

The study site is located in Grant County, Arkansas on land owned by the International Paper Company (IPCO). It is located on a high flat in the Saline River floodplain near the Arkansas Game and Fish Commission's Lee's Ferry Public Access. The soils are composed of Ochlockonee very fine sandy loam (USDA 1966) with a site index for cherrybark oak (Quercus *pagoda)* about 115 feet at base age 50. Common bottomland hardwood species included water oak (Q. *nigra*), cherrybark oak, and sweetgum (*Liquidambar styraciflua*) in the overstory and American hornbeam (*Carpinus caroliniana*) in the understory (table 1).

History

The area, 267 acres, was clearcut and sheared in 1964 using a K-G blade mounted on the front of a HD-16 tractor. Prior to this harvest, the area was logged in the 1920's which released the American hornbeam already present in the understory. American hornbeam, 2-12 inches dbh (diameter breast height; 4.5 feet above the ground), averaged 340 stems per acre by 1964. This high density of American hornbeam resulted in this study initially being called the AIronwood Site Conversion@. The original study objective was to naturally re-establish desirable hardwoods (primarily red oaks) on this ironwood flat. All stems 14 inches and smaller were severed in the shearing operation following the 1964 harvesting resulting in a complete clearcut. Two years following the treatment, there were 1,251 stems of natural hardwood reproduction per acre. Desirable species, including red oaks, comprised 743 (59 percent) stems per acre and the less-desirable species comprised 508 [41 percent; American hornbeam and American holly (*Ilex opaca*) stems per acre (table 2; unpublished 1967 IPCO internal report on file at the School of Forest Resources, University of Arkansas - Monticello). The desirable species were recognized as rapidly outgrowing the less-desirable species in 1966.

Treatments

A precommercial thinning study was implemented on the site in 1979, 15 years after the clearcut and shearing operation. Records indicated that a dense stand of red oak was developing at this time. There were three thinning treatments plus an untreated control. The treatments were to thin to the best 125 tpa (trees per acre: 500T), the best 250 tpa (250T), and the best 500 tpa (125T). All treatments were replicated four times in a completely randomized design.

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Table l-Distribution of trees (percent) by species and codominant crown classification in a pre-commercial thinning study on the Saline River floodplain, Grant County, Arkansas

Species	All trees	Codominants
Water oak	39	60
Cherrybark oak	23	9
Sweetgum	6	34
Others"	11	18

[a] Other species include blackgum *(Nyssa sylvatica)*, winged elm *(Ulmus alata)*, American hornbeam *(Carpinus caroliniana)*, green ash *(Fraxinus pennsylvanica)*, sugarberry *(Celtis laevigata)*, and sycamore *(Platanus occidentalis)*.

Table 2-Regeneration composition in 1966, 2 years following clearcutting and shearing operations on the Saline River floodplain, Grant County, Arkansas

Species	Stems per acre	Height range	Average height
		······ *Feet* ······	
American hornbeam	499	l- 5	2
Sweetgum	254	l-lO	3-5
Green ash	133	2- 6	3
Willow oak	114	l- 5	2-3
Water oak	95	l- 5	2-3
Cherrybark oak	82	l- 5	2-3
Persimmon	22	2- 6	4
Overcup oak	19	l- 5	2-3
American holly	9	2- 4	3
Baldcypress	9	l- 3	2
Sycamore	6	3-10	5
Winged elm	6	2- 4	3
Sugarberry	3	l- 3	3
Total	1,251		

The treatments were imposed in 0.2-acre square plots with an interior O.l-acre circular plot in each replicate. The 0.1-acre plots contained the residual trees to be measured for response to the treatment, and the remaining acreage served as a buffer between the treatments. The heaviest thinning (125T) was conducted more as a cleaning than a precommercial thinning because all trees within a nine-foot radius around the selected crop tree were removed. This release resulted in more trees than just the 12-13 per 0.10-acre plot being left on each plot. Details of how trees were harvested and/or removed for each treatment were not available. Re-measurements of the study were taken in 1984 and again in 1988; however, this data along with the 1979 pre-treatment data is currently unavailable. Additional measurements were conducted in January 1998 and 1999. Measurements in 1998 included plot relocation, and distance and azimuth to all trees $3.6 in dbh. A four-inch dbh class was used as the minimum diameter as these were the smallest trees which had visible tree tags. Measurements in 1999 included diameter, crown classification (dominant, codominant, intermediate, and suppressed; Smith and others 1997), height, and merchantable height to a four-inch top diameter. All height measurements were conducted using a Criterion 3000 laser surveyor instrument.

Analyses

Analysis-of-variance was used to determine if differences existed in diameter, total height, and merchantable height between treatments for all trees, codominant trees, codominant red oak trees, and the five largest trees by diameter for each plot. An assumption used in these analyses was that pre-treatment conditions were similar across all plots. Only three trees were classed as dominant trees on the study site so these trees were included with the codominant trees in analyses concerning the upper canopy. Analyses of the five largest trees per plot (O.l-acre plots) was used to determine if differences existed in crop trees by treatment assuming 50 crop trees per acre at maturity. Significance was determined using an alpha level of .05. If a significant difference was found, then Duncan=s Multiple Range Test was used for mean separation. All analyses were conducted using PC-SAS (SAS 1985).

RESULTS AND DISCUSSION

Diameter

Precommercial thinning lead to larger average diameters for the thinned plots compared to the controls (table 3). Additionally, average diameters for the two higher-intensity thinnings (125T and 250T) were larger compared to the lower-intensity thinning (500T). These differences were expected given that the 500T treatment and the controls contained smaller, shade-tolerant species including American hornbeam that were thinned in the 125T and 250T treatments. However, a response to thinning can be inferred as the average diameter of the codominant trees in the heaviest thinned plot (125T) was greater than the unthinned controls 19 years after precommercial thinning (table 2).

Table 3-Diameter (inches) for all trees, codominant trees, codominant red oaks, and largest five trees in diameter by pre-commercial thinning treatment on the Saline River floodplain, Grant County, Arkansas.

	Pre-commercial thinning treatment			
	125	250	500	Control
All trees	8.5ab	9.3a	8.1b	6.6c
All codom.	12.8a	12.1ab	11.7ab	11.1b
Codom. oaks	12.7a	12.2ab	11.8ab	II.lb
Five largest	14.0a	13.4a	13.5a	11.8b

Means followed by a similar letter within a row are not different at p≥0.05.

The two lighter thinned treatments (250T and 500T) were not different than either the 125T or controls. Similar results were found with just codominant red oaks. Looking at just the largest five trees per plot, precommercial thinning did result in larger average tree diameters compared to not thinning, 19, 14, and 14 percent for the 125T, 250T, and 500T compared to controls, respectively. Goelz and others (1998) found a 27-37 percent increase in diameter of water tupelo (*Nyssa aquatica*) three years after precommercial thinning. Smith and Lamson (1983) also found increases of 0.2-0.4 inches in diameter of Appalachian hardwoods three years following precommercial thinning. A lower percent increase in the present study, especially compared to Goelz and others (1998), may reflect that after 19 years the upper canopy trees in the 500T and controls are catching up in diameter to the trees in the heavier thinned treatments.

Height

Precommercial thinning also lead to greater average tree heights compared to not thinning (table 4). Total heights for the 250T were greater than the 125T and both these treatments were greater in height than the 500T and control treatments. This height difference again reflects the presence of midstory, shade-tolerant species such as American hornbeam in the control and 500T treatment as no difference was found in the heights of only the codominant trees, codominant red oaks, or the five largest trees per plot. Lower heights for the 125T compared to the 250T may reflect too intensive a thinning early thereby allowing trees in the 125T to expand their crowns early at some expense to height growth. The lack of any differences in the upper canopy is not surprising since density generally has little effect on height growth of upper canopy trees within a range of densities (Smith and others 1997).

Merchantable Height

Precommercial thinning also had an effect on the merchantable height (to a four-inch top) of bottomland hardwood trees 19 years following thinning (table 5). Trees in the 125T and 500T had significantly greater merchantable lengths compared control treatments. Why a difference did not occur in the intermediate thinning treatment (250T) compared to any of the other treatments including the controls is unknown. No difference was found in merchantable heights of the codominant trees and red oak codominant trees although the heaviest thinning did result in larger merchantable lengths of the five largest trees compared to intermediate levels of precommercial thinning and no thinning.

Table 4—Total height (ft) for all trees, codominant trees, codominant red oaks, and largest five trees in diameter by pre-commercial thinning treatment on the Saline River floodplain, Grant County, Arkansas

	Pre-commercial thinning treatment			
Trees	125	250	500	Control
All	67b	72a	61c	59c
All codominant	82a	82a	82a	81a
Codominant red oaks	82a	82a	83a	81a
Five largest	84a	85a	85a	81a

Means followed by a similar letter within a row are not different at $p \geq 0.05$.

Table 5—Merchantable height (ft) to a 4-inch top for all trees, codominant trees, codominant red oaks, and largest five trees in diameter by pre-commercial thinning treatment on the Saline River floodplain, Grant County, Arkansas

	Pre-commercial thinning treatment			
Trees	125	250	500	Control
All	42a	39ab	41a	34b
All codominant	52a	46a	49a	48a
Codominant red oaks	52a	46a	50a	48a
Five largest	54a	47b	52ab	47b

Means followed by a similar letter within a row are not different at $p \geq 0.05$.

MANAGEMENT IMPLICATIONS

Precommercial thinning may be a viable silviculture tool in bottomland red oak-sweetgum stands. Results from this study showed that differences in diameter still existed 19 years after treatment for the more intensive thinning (125T) as compared to no thinning. Merchantable height differences also existed between the intensive pre-commercial thinning and no thinning, leading to the probably differences in cubic foot volume, although volumes were not calculated.

A question then arises as to when should a forest resources manager consider precommercial thinning as a silvicultural tool in bottomland red oak stands. Stand composition plays a major role in answering this question. A mixed-species bottomland hardwood stand can sometimes be beneficial to red oak growth and development. Various species have different rates of height growth and different shade tolerances. Species with rapid early growth will appear to dominate the stand at the expense of the red oaks (Oliver 1981). Later, red oaks will stratify above these species through Anormal stand development@ and eventually dominate the stand (Oliver 1976, Clatterbuck and Hodges 1988, Johnson and Krinard 1988, Kittredge 1988). This stratification process was observed where river birch (*Betula nigra*), sweetgum, and American hornbeam were the initial dominants following clearcutting of a bottomland hardwood stand near the Saline River. After 28 years, bottomland red oaks including cherrybark oak, water oak, and willow oak were assuming dominance of the stand along with some sweetgum (Johnson and Krinard 1988). In this type of stand, precommercial thinning may not be a viable option if quality sawtimber is the primary objective. Red oak species will benefit from this stratification process and eventually assert themselves above many of the other species and occupy the dominant crown position. The shading caused by the other species early in the stand development process help to shape the desired red oak trees in both merchantable heights and log quality.

On the other hand, precommercial thinning may be necessary in young, relatively pure bottomland red oak stands. In these stands, early intra-specific and intra-genus competition (competition within a species or genera) exerts a different type of stratification. Red oaks competing throughout their life do not necessarily exert dominance above each other. Continued competition beginning early in life may increase stress in potential crop trees resulting in the appearance of epicormic branches, an undesirable characteristic for optimal log quality. Precommercial thinning in this situation may alleviate the early crown congestion and release individual red oak crop trees by providing more growing space with less competition.

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THINNING IN A 28-YEAR-OLD WATER OAK PLANTATION IN NORTH LOUISIANA: SEVEN-YEAR RESULTS[1]

James S. Meadows and J.C.G. Goelz[2]

Abstract-A 21-acre, 28-year-old water oak (*Quercus nigra* L.) plantation on an old-field loessial site near Winnsboro. LA, was subjected to three thinning treatments during the winter of 1987-88: (1) no thinning, (2) light thinning to 180 dominant and codominant trees per acre, and (3) heavy thinning to 90 dominant and codominant trees per acre. Prior to thinning, the plantation averaged 356 trees and 86 ft^2 of basal area per acre, with a quadratic mean diameter of 6.7 in. Thinning reduced stand basal areas to 52 and 34 ft^2 per acre for the light and heavy thinning treatments, respectively. After 7 years, thinning did not significantly increase stand-level basal area growth, but both thinning treatments produced shifls in stand structure. Diameter distributions of thinned stands were skewed to the larger diameter classes and crown class distributions of thinned stands were skewed to the upper crown classes. Both thinning treatments increased diameter growth of residual trees, but there were no significant differences between the two levels of thinning. Diameter growth of residual trees in the lightly thinned stand averaged 1.63 in. after 7 years, whereas those in the heavily thinned stand averaged 2.02 in. on this relatively poor site. Trees in the unthinned stand grew an average of only 1.04 in.

INTRODUCTION

Information on growth and development of southern oak plantations greater than 20 years of age is lacking. Most past research on oak plantations emphasized the development of suitable techniques for successful plantation establishment (Allen and Kennedy 1989, Kennedy 1993), but subsequent growth was generally followed for only a few years.

Through the Conservation Reserve Program and the Wetland Reserve Program, many thousands of acres of marginal cropland in the South have been reforested, primarily to various oak species (Kennedy 1990). As these oak plantations develop and mature, the demand for information on how to manage them will increase. Land managers will need practical guidelines on thinning and other intermediate silvicultural operations. However, information on growth and yield, pattern of stand development, and the response of older oak plantations to silvicultural operations is sparse. Consequently, few guidelines currently exist for successful management of these older plantations.

For these reasons, a thinning study was established in the winter of 1987-88 in two 28-year-old water oak plantations in north Louisiana. The study was designed to determine the diameter growth and stand structure responses of water oak to three levels of thinning. Stand parameters of the plantations prior to thinning were previously described by Krinard and Johnson (1988). Meadows and Goelz (1993) reported fourth-year responses to thinning.

METHODS

Study Area

The plantations were established in 1960 on old agricultural fields of loessial soil on the Macon Ridge landform in Franklin Parish east of Winnsboro, LA. The fields were under continuous cultivation for several decades prior to the establishment of the oak plantations. The two plantations encompass 21 acres (a 14.5acre tract and a nearby 6.5-acre tract). Both tracts are privately owned.

Both fields were planted at the rate of approximately 950 water oak seedlings per acre. Initial spacing was variable, but appears to have been about 5 x 9 ft. No cultivation or other means of weed control was conducted after planting at either site.

The plantations are located on the Calhoun-Calloway-Loring soil association (Krinard and Johnson 1988) that developed from wind-blown silt, or loess. Within these terrace sites, Calhoun soils occur on the flats and depressional areas, Calloway soils are found on low ridges, and Loring soils occur on slightly higher ridges. Well over half of the study area consists of Calhoun soils, with lesser proportions of Loring and Calloway soils. The soils are generally poorly to somewhat poorly drained, but some of the higher ridges are moderately well-drained. Permeability is slow across most of the area. These soils have low-to-medium natural fertility that has been reduced through many years of use for crop production. Texture in the upper soil horizon at both sites is silt loam. Soil pH is very strongly to medium acid and ranges from 4.5 to 6.0 across both sites. Calloway and Loring soils both contain fragipans at depths of 20 to 30 in. that limit effective rooting depth and hinder tree growth.

The loessial soils of the Macon Ridge are somewhat unproductive for the growth of hardwood species, when compared to well-drained alluvial soils or the loessial hills on the east side of the Mississippi River. Broadfoot (1976) reported an average site index of 83 ft at 50 years for water oak on Calloway soils, but did not provide similar information for Calhoun or Loring soils. Based on the method described by Baker and Broadfoot (1979), we estimated that site index for water oak averaged 86 ft at 50 years across the entire study area, but ranged as high as 90 ft on the higher ridges.

Treatments

In the fall of 1986, the plantations were divided into 12 treatment plots, nine on the larger tract and three on the smaller tract. Each treatment plot was 150 ft by about 400-450 ft (45 rows) and covered an area of about 1.4 to 1.5 acres. Three O.l-acre square measurement subplots were systematically established within each of the 12 treatment

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plots; data were pooled across the three subplots within each treatment plot. Diameter-at-breast-height (d.b.h.) and crown class were assessed on all trees within each subplot. Stocking percent was estimated from trees per acre and quadratic mean diameter, according to the stocking equation developed by Goelz (1995).

Thinning treatments were originally scheduled for the winter of 1986-87, but wet soil conditions prevented harvesting activities. The plantations were not measured again prior to thinning. Consequently, pre-treatment measurements were actually taken 1 year prior to thinning.

Four replications of three levels of thinning were applied in a randomized block design to the 12 treatment plots (experimental units) during the winter of 1987-88 at age 28 years: (1) no thinning, (2) light thinning to 180 dominant and codominant trees per acre, and (3) heavy thinning to 90 dominant and codominant trees per acre. Low thinning was used to remove trees primarily from the lower crown classes. Logs were removed from the stand and utilized as fuelwood.

RESULTS AND DISCUSSION

Residual Stand Conditions

One year prior to thinning, the plantation as a whole averaged 356 trees and 86 ft^2 of basal area per acre, with a quadratic mean diameter of 6.7 in. (Krinard and Johnson 1988). Stocking averaged 87 percent across the entire study area. No statistical differences were detected among the three treatments in any of the stand parameters 1 year prior to thinning.

Light thinning reduced stand density to 188 trees and 52 ff of basal area per acre: heavy thinning reduced stand density to 103 trees and 34 ft^2 of basal area per acre. These residual densities were slightly greater than the target densities of 180 and 90 dominant and codominant trees per acre for the light and heavy thinning treatments, respectively. Expressed as percentages, light thinning removed 47 percent of the trees and 40 percent of the basal area from the plantation, whereas heavy thinning removed 71 percent of the trees and 60 percent of the basal area. Light thinning reduced stocking to 52 percent; heavy thinning reduced stocking to 33 percent. The intensity of both thinning treatments turned out to be quite severe.

Although low thinning was used to remove the smaller, less-vigorous trees, primarily from the lower crown classes, no significant differences in quadratic mean diameter could be detected among the three treatments immediately following thinning. Quadratic mean diameter ranged from 7.1 in. in the lightly thinned stand to 7.8 in. in the heavily thinned stand. Quadratic mean diameter in the unthinned stand was 7.3 in.

Stand Development Following Thinning

Prior to thinning, the plantation was a dense stand composed of small-diameter trees with short boles. The presence of many dead trees scattered throughout the stand and the presence of numerous epicormic branches along the boles of many of the living trees were indicators that the stand was not healthy and was approaching stagnation. Bottomland red oaks, when grown in even-aged mixtures with sweetgum (*Liquidambar styraciflua* L.), are generally able to eventually gain a competitive advantage over the sweetgum, dominate the stand, and develop into large trees with long, clear boles (Clatterbuck 1987, Clatterbuck and Hodges 1988, Johnson and Krinard 1988). However, oaks do not generally compete well with other oaks when grown in pure stands (Aust and others 1985), such as these two water oak plantations. Under these circumstances, it is difficult for individual oaks to gain a competitive advantage over neighboring oaks. Consequently, pure oak stands have a tendency to stagnate quickly after several years of intense competition among individual trees.

Stand development over the 7-year period following thinning was characterized by high mortality in the unthinned stand and by steady recovery in the thinned stands. The number of trees per acre in the unthinned stand steadily declined from 319 at the time of study installation to 260 in 7 years (table 1). This decrease is equivalent to 18 percent mortality over the 7-year period. In contrast, mortality in the thinned stands was substantially less, about 7 percent and 5 percent 7 years after light and heavy thinning, respectively. Mortality in the unthinned stand occurred primarily in the smaller, less-vigorous, lower-crown-class trees. As expected, we found significant differences among treatments in the number of trees per acre 7 years after thinning.

Table l-Stand conditions 7 yr after thinning in a 28-yr-old water oak plantation. Means followed by the same letter are not significantly different at the 0.05 level of probability

Treatment	Trees	Basal area	Stocking
	No./acre	*Sq ft/acre*	*Percent*
Unthinned	260 a	109 a	102a
Light thinning	175b	75 b	69 b
Heavy thinning	98 c	52 c	47c

Light and heavy thinning greatly reduced stand basal areas to 52 and 34 ff per acre, respectively, immediately following thinning. However, basal area increased steadily to 75 and 52 ft^2 per acre during the 7 years following thinning in the lightly and heavily thinned stands, respectively (table 1). Basal area in the unthinned stand increased from 92 to 109 ft^2 per acre over the same period. Neither thinning treatment significantly affected stand-level basal area growth rates, which averaged 3.3, 2.6, and 2.4 ft^2 per acre per year in the lightly thinned, heavily thinned, and unthinned stands, respectively. Although the thinned stands are recovering, their rates of basal area growth are insufficient to produce densities that approach that of the unthinned stand. Consequently, large significant differences in stand basal area across treatments still exist 7 years after thinning (table 1).

We observed a similar trend for changes in stocking among the three treatments 7 years after thinning (table 1). Light thinning originally reduced stocking to 52 percent, a value consistent with the recommended residual stocking level after thinning, as proposed by Putnam and others (1960), in stands of similar size and density. On the other hand, heavy thinning originally reduced stocking to 33 percent, a value well below recommended residual density following thinning (Goelz 1995, Putnam and others 1960). Seven years after thinning, stocking in the lightly thinned stand rose to 69 percent, a level approaching adequate stocking to promote satisfactory stand-level growth and recovery from thinning disturbance. However, stocking in the heavily thinned stand increased to only 47 percent, a level still below recommended stand density (Goelz 1995, Putnam and others 1960). Even 7 years after thinning, the heavily thinned stand is still severely understocked. Stocking in the unthinned stand increased from 91 percent at the time of study installation to 102 percent over the 7-year period.

Stand Structure

Prior to thinning, the diameter distribution pooled across the water oak plantation resembled a bell-shaped curve in which the most abundant diameter class was 6 in. (fig. 1). Seven years after study installation, the diameter distributions of the unthinned stand and the lightly thinned stand were very similar; both peaked in the 8-in. class. In contrast, heavy thinning removed most of the trees in the lower diameter classes and caused a shift in peak abundance to the IO-in. class. Because the shape of the diameter-distribution curve of a pure, even-aged stand generally flattens and peak abundance shifts to the right as the stand develops and matures, heavy thinning effectively increased the rate of stand development in this water oak plantation.

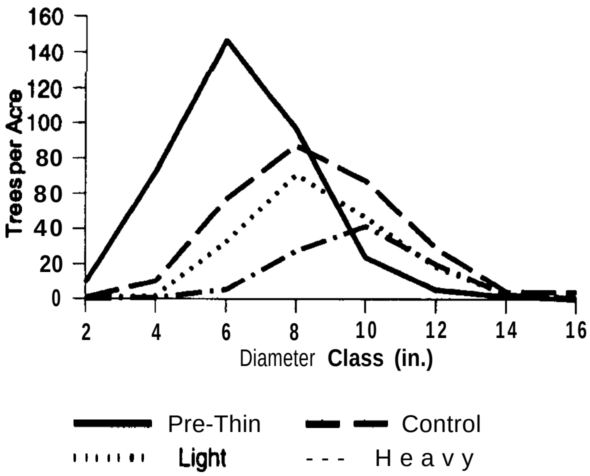

Figure I-Pooled diameter distribution 1 year prior to thinning and the diameter distributions produced by each treatment 7 years after thinning in a 28-year-old water oak plantation.

Prior to thinning, 74 percent of the trees in the water oak plantation were classed as either dominant or codominant (fig. 2), a proportion indicative of a young stand in the early phases of the canopy stratification stage of stand development. However, in addition to a large reduction in the total number of trees due to mortality in the unthinned stand over the last 7 years, we also observed a significant shift in the crown class distribution of the unthinned stand as many trees moved down one or more classes. Many of the dominant trees became codominant; many of the codominant trees became intermediate or suppressed. Seven years after study installation, the proportion of upper-crown-class trees in the unthinned stand dropped dramatically from 74 percent to only 47 percent, indicative of a stressed stand experiencing severe competition and intense canopy stratification. Crowns of individual trees in the unthinned stand are deteriorating, losing dominance, and suffering diminished photosynthetic capacity, a situation leading to reduced tree growth, increased mortality, and reduced stand productivity. In contrast, both thinning treatments removed trees primarily from the lower crown classes and produced stands that have been able to maintain high proportions of upper-crown-class trees: 65 percent in the lightly thinned stand and 79 percent in the heavily thinned stand (fig. 2). Crown subordination of some trees has occurred in the lightly thinned stand, but was not widespread. The proportion of upper-crown-class trees in the heavily thinned stand 7 years after thinning is still higher than in the pre-treatment stand. Both thinning treatments maintained or enhanced the vigor of most residual trees, as evidenced by these high proportions of upper-crown-class trees.

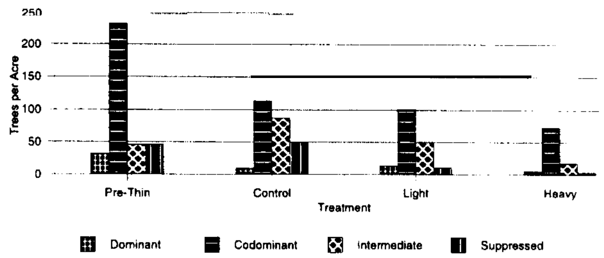

Figure P-Pooled crown class distribution 1 year prior to thinning and the crown class distributions produced by each treatment 7 years after thinning in a 28-year-old water oak plantation.

Diameter Growth

Heavy thinning produced a significant increase in quadratic mean diameter, but quadratic mean diameters in the lightly thinned and unthinned stands were nearly equal 7 years after thinning (fig. 3). Prior to this most recent measurement, we were unable to detect significant differences among treatments in quadratic mean diameter, even though it was generally greater in the heavily thinned stand. As is apparent in figure 3, quadratic mean diameter of the heavily thinned stand has been increasing at a more rapid rate than in either the lightly thinned or unthinned stands since the second or third year after thinning, and averaged 9.9 in. at the end of the seventh year. We expect this difference to continue to increase in the future.

Cumulative diameter growth of individual trees may provide the most accurate assessment of the effects of the thinning treatments (fig. 4). Neither thinning treatment significantly affected cumulative diameter growth during the first 2 years after thinning, with growth averaging 0.44 in. across all treatments. However, a response to thinning was detected after the third year, when cumulative diameter growth of residual trees in the heavily thinned stand (1 .OO in.) was significantly greater than in the unthinned stand (0.58 in.).

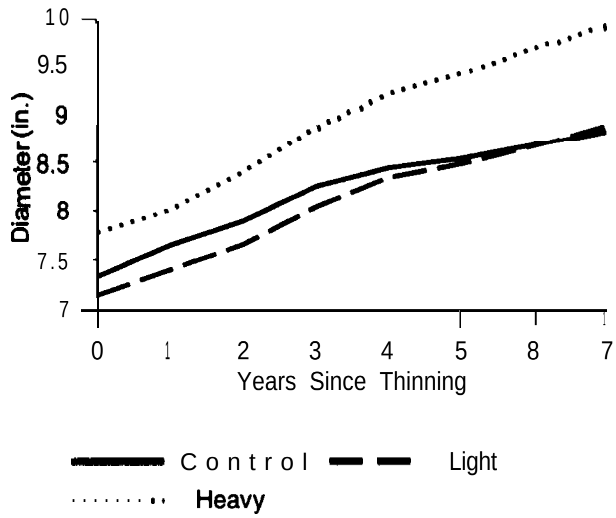

Figure 3—Changes in quadratic mean diameter, by treatment, following thinning in a 28-year-old water oak plantation.

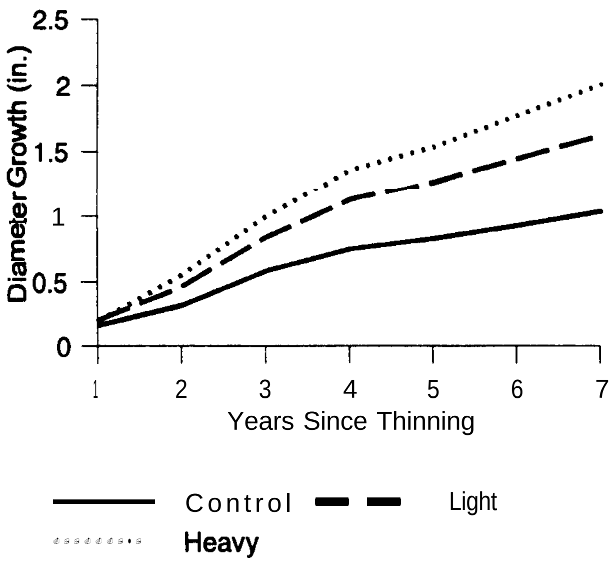

Figure 4—Cumulative diameter growth of residual trees, by treatment, following thinning in a 28-year-old water oak plantation.

This trend has continued since then, with ever-widening differences between the thinned and unthinned treatments.

By the end of the seventh year after thinning, surviving trees in the unthinned stand had grown an average of only 1.04 in. in diameter. This poor growth is indicative of a low-vigor stand in which additional mortality of small trees is expected in the near future. In contrast, residual trees in the lightly thinned stand grew an average of 1.63 in. in 7 years; those in the heavily thinned stand grew an average of 2.02 in., growth rates classified as "medium" for water oak by Putnam and others (1960). Seven-year cumulative diameter growth did not differ significantly between the two levels of thinning, but both produced cumulative diameter growth significantly greater than that observed in the unthinned stand. We anticipate that these differences in diameter growth rate will continue to widen over the next several years.

Both levels of thinning increased diameter growth of trees in all crown classes. The effect was most pronounced in the codominant and intermediate classes, but even dominant trees responded well to thinning. In fact, light thinning increased diameter growth of dominants by 32 percent and codominants by 51 percent. Heavy thinning increased diameter growth of dominants by 42 percent and codominants by 86 percent.

CONCLUSIONS

Trees in the unthinned stand are not currently growing in diameter at an acceptable rate for water oak. Expressed on a 1 O-year basis, these trees are growing at the rate of 1.5 in. per decade. More than half of the trees are in subordinate crown classes and will likely continue to decline in growth, vigor, and quality if left unmanaged. Mortality will continue to be high over the next several years. Stand density is simply too high to promote the development of vigorous, high-quality trees.

Light thinning increased the average diameter growth rate of residual trees to an acceptable level of 2.3 in. per decade. Stand-level basal area growth appears to be sufficient to promote recovery of the stand to a fully stocked condition in a reasonable period of time. At its present rate of development, this stand will achieve 100 percent stocking when quadratic mean diameter reaches about 11 to 12 in., in approximately 9 to 10 years. Another low thinning will be necessary at that time. Among the treatments evaluated in this study, light thinning promoted the most desirable combination of individual-tree diameter growth and stand-level basal area growth.

Heavy thinning increased the average diameter growth rate of residual trees to 2.9 in. per decade, a value nearly double that of trees in the unthinned stand. However, heavy thinning reduced stocking to the point that stand-level basal area growth is inadequate to allow full recovery of the stand in the near future. It will not achieve 100 percent stocking until quadratic mean diameter averages 15 to 16 in., in approximately 20 years. Although this level of thinning greatly increased diameter growth of residual trees, it created a severely understocked stand that cannot fully occupy the site for many years to come.

Without conducting a much earlier precommercial thinning in these two water oak plantations, average initial spacing (5 x 9 ft) was too narrow to allow satisfactory development of individual trees for sawtimber management. The narrow spacing led to the onset of intense competition among neighboring trees at an early age. Trees severely competed with one another for soil moisture, nutrients, light, and growing space for many years prior to thinning. As a result, surviving trees in the stand at the time of thinning were small, low-vigor trees with deteriorating crowns, poor bole quality, and less-than-satisfactory diameter growth rates. We believe that the diameter-growth response to thinning observed in this study was diminished largely as a consequence of this narrow initial spacing that led to the long period of intense competition prior to thinning. To alleviate these problems, we currently recommend that initial spacing in bottomland red oak plantations range from 8 x 9 ft to 12 x 12 ft, depending on anticipated survival of planted trees and expected availability of markets for small-diameter trees.

The relatively poor site also impaired the ability of residual trees to respond adequately to thinning. Poor drainage, low-to-medium fertility, past land use, and the presence of fragipans on portions of the study site combined to restrict growth of trees in these plantations. A fragipan greatly hinders tree growth because it results in a perched high water table during winter and spring, but limits the effective rooting depth and leads to severe water deficits during summer. This situation, coupled with the poor drainage and slow permeability of the soil above the fragipan, creates a harsh site that is very wet in the winter and spring months and very dry in the summer and fall months. Even though thinning alleviates some of the competitive factors previously mentioned, the inherent low productivity of the site itself limits the ability of residual trees to respond to the thinning.

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DEVELOPMENT OF MIXED CHERRYBARK OAK-SWEETGUM PLANTATIONS PLANTED AT DIFFERENT SPACINGS IN EAST-CENTRAL MISSISSIPPI AFTER 17 YEARS[1]

Brian R. Lockhart, Andrew W. Ezell, John D. Hodges, and Wayne K. Clatterbuck[2]

Abstract-Interest in mixed-species bottomland hardwood plantations has increased in recent years. Benefits from mixed-species plantations include increased diversity, wildlife habitat, aesthetics, and log-quality of crop trees. But few studies exist to compare results from mixed-species bottomland hardwood plantations against mixed natural stands. Results from mixed cherrybark oak (*Quercus* pagoda)-sweetgum (*Liquidambar styraciflua*) plantations planted at different spacings and with different densities of sweetgum indicate that stand stratification patterns in plantations are similar to those found in natural cherrybark oak-sweetgum stands. At age 8, sweetgum trees were taller in height and larger in diameter, but by age 17 cherrybark oak trees were at least of similar size as neighboring sweetgum. These cherrybark oak trees are expected to eventually pass sweetgum in both height and diameter.

INTRODUCTION

Planting mixtures of tree species has only recently been viewed as an alternative to single-species artificial regeneration efforts in bottomland hardwoods (Goelz 1995a). These mixed-species planting efforts generally fall under one of three objectives. First, mixtures are planted for wildlife habitat diversity. Oaks (*Quercus* spp.) and other hard mast species including sweet pecan (*Carya illinoeninsis*) are either planted or direct seeded with the presumption that the future overstory will contain a mixture of these species. A second objective for mixed-species regeneration efforts on flood-prone sites involves the deliberate attempt to regenerate oaks. Notable among these efforts are planting trials of eastern cottonwood (*Populus deltoides*) and Nuttall oak (*Q. nuttallii*) by the USDA Forest Service Center for Bottomland Hardwoods Research and industrial partners. In short, eastern cottonwood is planted on a 12 foot by 12 foot spacing. Two or three years later, Nuttall oak is planted between every other row. The theory is that Nuttall oak, and most bottomland oaks in general, will benefit from the partial shade environment provided by eastern cottonwood (Gardiner and Hodges 1998). The third objective for planting species mixtures on bottomland sites is to simulate natural stands using current knowledge of stand development patterns. Theoretically, using known stand development patterns as a management guideline should result in the development of a more-desirable crop tree, whether it be for timber and/or wildlife habitat objectives. Clatterbuck and Hodges (1986) found that the distance of competing sweetgum (*Liquidambar styraciflua*) had a pronounced effect on the development of individual cherrybark oak (Q. pagoda) trees. Depending on the spacing of neighboring sweetgum, cherrybark oak development patterns were labeled as being unrestricted, restricted, or overtopped. With these latter development patterns in mind, a series of mixed cherrybark oak-sweetgum plantations of different spacing and proportions of sweetgum were established to determine if development patterns in natural cherrybark oak-sweetgum mixtures would occur in a plantation setting. Seventeen-years results are reported.

MATERIALS AND METHODS

Location/Site Description

The study site is located in Oktibbeha County on the Noxubee National Wildlife Refuge in east-central Mississippi. Soils are Stough very fine sandy loam which is considered marginal for cherrybark oak (range of site index, base age 50, is 75-90 feet) due to the presence of a fragipan. Prior to planting, the site was used for grazing and hay production.

Planting Design

Three planting arrangements were used on two sites located approximately 300 feet apart. The first spacing arrangement involved planting mixtures of cherrybark oak and sweetgum on an eight foot by eight foot spacing (8x8). This spacing was the normal plantation spacing for trees in the early 1980's. The first row in this design was planted in sweetgum. Cherrybark oak and sweetgum seedlings were alternated on the second row, and the third row was planted to sweetgum. This planting arrangement resulted in each individual cherrybark oak seedling, which was considered plot center, being surrounded by eight sweetgum seedlings. A total of 35 cherrybark oak and 118 sweetgum seedlings were planted in seven rows (three rows were alternating cherrybark oak and sweetgum), excluding buffer trees.

The second spacing arrangement involved planting mixtures of cherrybark oak and sweetgum on a five foot by five foot spacing (5x5) using the same row design as the 8x8. The closer spacing of cherrybark oak and sweetgum would result in earlier inter-specific competition (competition between species). A total of 45 cherrybark oak and 168 sweetgum seedlings were planted in 11 rows (five rows were alternating cherrybark oak and sweetgum).

The third spacing arrangement involved planting mixtures of cherrybark oak and sweetgum on a five foot by five foot spacing (5x5D) similar to the second spacing arrangement. The one difference is that two rows of sweetgum were planted on each side of the alternating cherrybark oak and

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sweetgum row for a total of 14 sweetgum seedlings surrounding each cherrybark oak seedling. The reason for two rows of sweetgum was, if cherrybark oak could overtop sweetgum early in this closer spacing, then the second row of sweetgum would provide additional inter-specific competition for the cherrybark oak with supposed better bole quality development in the long run. A total of 27 cherrybark oak and 182 sweetgum seedlings were planted in 11 rows (three rows were alternating cherrybark oak and sweetgum). All three spacing arrangements were replicated on a second site (Site 2).

Plantation Establishment

Prior to planting, each site was disked. Seedlings were then planted on Site 1 in March 1982 and January/February 1983 for Site 2. Cherrybark oak seedlings on Site 1 were 2-O stock while 1-O stock was used on Site 2. The 2-O stock was produced in a nursery on the Mississippi State University campus. For both sites 1-O sweetgum and cherrybark oak stock was purchased from a private nursery. Thirty-four percent of the cherrybark oak perished on Site 1 following the 1982 growing season. These seedlings were replaced with 1-O cherrybark oak stock at the time Site 2 was planted. After plantation establishment, each site was mowed during their first two growing seasons.

Measurements

Since this test was designed as a demonstration and not as a scientific study, only periodic measurements have been conducted since plantation establishment. Height and diameter measurements were conducted on Site 1 in 1989 and on both sites in 1991 and 1998. Height measurements in 1989 and 1991 were conducted using a height pole while the 1998 measurements were conducted with a laser-height instrument. Diameter (dbh, 4.5 feet above ground) was measured each time using a standard diameter tape.

Analyses

Survival was calculated as the number of seedlings surviving during each measurement period, including those cherrybark oak seedlings that were replanted on Site 1 in 1983. Height and dbh of the sweetgum trees within each cherrybark oak plot were averaged and compared with their associated cherrybark oak tree using a t-test. An alpha level of 0.05 was used to determine statistical significance.

RESULTS AND DISCUSSION

Survival

Overall survival for the two plantations was 64 and 96 percent for the cherrybark oak and sweetgum, respectively. Greater survival for cherrybark oak occurred on Site 1 as compared to Site 2 due possibly to the use of larger seedlings (2-O versus 1-O) and the replanting of 36 spots (34 percent) on Site 1 following first-year seedling mortality (table 1). No changes in survival have occurred on Site 1 since the 1989 measurements. Lower survival on Site 2, especially for cherrybark oak, may be indicative of differences in soils. Discussions with those involved in the establishment of this plantation indicated that soils on Site 2 were more difficult to dig compared to Site 1, even with the use of a portable post-hole digger, indicating a possible shallower soil to the inherent fragipan. Changes in survival on Site 2 have occurred between measurement years, particularly among the cherrybark oak trees in the 5x5 and 5x5D spacings. These changes in survival may also be a

Table l-Survival (percent) of mixed-species plantations of cherrybark and sweetgum by site and spacing

Spacing	Species	n	1989	1991	1998
		Site 1			
8x8	Cherrybark oak	35	89	89	89
	Sweetgum	138	100	100	100
5x5	Cherrybark oak	45	89	89	89
	Sweetgum	168	100	100	100
5x5D	Cherrybark oak	27	78	78	78
	Sweetgum	182	99	99	99
		Site 2			
8x8	Cherrybarkoak	35	—[a]	77	71
	Sweetgum	137	—	98	98
5x5	Cherrybarkoak	45	—	29	11
	Sweetgum	168	—	91	88
5x5D	Cherrybark oak	27	—	93	59
	Sweetgum	182	—	95	93

[a] No data (no measurements were conducted on Site 2 in 1989).

result of density-dependent mortality interacting with differences in soil as sweetgum is overtopping cherrybark oak on this possibly poorer site.

Height

A difference of eight to eleven feet in cherrybark oak height occurred within a spacing arrangement between the two sites by end of the 1998 growing season (table 2). Such a difference would not be expected based on age alone given that Site 2 trees are only one-two years younger than Site 1. This difference is more likely the result of soil differences previously mentioned. Little difference existed in height for sweetgum between the two sites except for the 5x5D spacing. In this case, sweetgum trees on Site 1 averaged about six feet greater in height. Sweetgum, with a more well-developed taproot than oaks (Kormanik 1990), appears less sensitive to the possible shallower soil on Site 2. Another explanation for the similar heights between sites for sweetgum is that greater inter-specific competition exists on Site 1 with the cherrybark oak having a detrimental effect on the height growth of sweetgum.

Within spacings, cherrybark oak and sweetgum trees were taller in height in the 8x8 spacing as compared to the 5x5 and 5x5D spacings for both sites (table 2). Although spacing usually does not affect height except at the extremes of density (Smith and others 1997), in this species mixture, the 5x5 and 5x5D spacing appears to result in greater competition between the trees with a subsequent detrimental effect on height growth.

Patterns of height development indicated that, in the 1989 measurement on Site 1, sweetgum trees were significantly taller than associated cherrybark oak trees (table 2). This difference was expected given the rapid juvenile height growth pattern of sweetgum (Kormanik 1990). After the 1991 measurements, the heights of cherrybark oak on Site 1 in

Table 2-Height (ft) of mixed-species plantations of cherrybark and sweetgum by site and spacing

Spacing	Species	1989	1991	1998
		Site 1		
8x8	Cherrybark oak	15.4a	22.8a	42.7
	Sweetgum	8.9b	27.4b	40.8
5x5	Cherrybark oak	13.0a	19.2	36.1a
	Sweetgum	14.6b	20.0	28.6b
5x5D	Cherrybark oak	1.1a	16.6a	33.8
	Sweetgum	13.2b	18.5b	30.3
		Site 2		
8x8	Cherrybark oak	—[a]	13.2a	33.9a
	Sweetgum	—	19.5b	42.6b
5x5	Cherrybark oak	—	17.7	25.1
	Sweetgum	—	19.6	28.8
5x5D	Cherrybark oak	—	17.6	23.7
	Sweetgum	—	18.5	24.9

Means followed by different letters within a site, spacing, and year are different at $p \geq 0.05$.
[a] No data (no measurements were conducted on Site 2 in 1989).

the 5x5 spacing were similar to sweetgum. Sweetgum was still significantly taller than cherrybark oak on the 8x8 spacing on both sites and the 5x5D spacing on Site 1. No differences in height existed on the remaining two spacings on Site 2. By 1998 the heights of cherrybark oak and sweetgum were statistically the same on 8x8 and 5x5D spacings on Site 1. Cherrybark oak was actually taller than sweetgum on the 5x5 spacing. No changes have occurred in height patterns between cherrybark oak and sweetgum from 1991 to 1998 on Site 2 with sweetgum still being significantly taller on the 8x8 spacing and no differences with the other two spacings. It should be noted though that considerable mortality on Site 2 resulted in fewer cherrybark oak trees by 1998 (e.g., n=5 for the 5x5 spacing). Analyses of the replanted cherrybark oak seedlings on Site 1 showed similar patterns of height development on the 8x8 and 5x5D spacings. Replanted seedlings on the 5x5 were not different than the sweetgum following the 1998 measurements although sweetgum was taller in the previous two measurements.

The ascendance of cherrybark oak to a similar height as sweetgum by age 17, as demonstrated on Site 1, followed natural stratification patterns. Clatterbuck and Hodges (1988) found that the spacing of sweetgum trees had a profound effect on the development of individual cherrybark oak trees. When sweetgum trees averaged about six to 18 feet from a cherrybark oak tree then the cherrybark oak exhibited a restricted pattern of development. The cherrybark oak would, early in life, have a lower height than neighboring sweetgum. But as long as the cherrybark oak was not overtopped, i.e., it was receiving some direct sunlight from above, then the cherrybark oak would eventually catch up and then, by about age 23-25, surpass the sweetgum. Clatterbuck (1985) suggested several reasons for this:

(1) crown architecture - sweetgum exhibits an excurrent crown form while cherrybark oak exhibits a semi-excurrent crown form when competing with sweetgum but changes to a decurrent, spreading, form after emergence into the overstory,
(2) crown abrasion - sweetgum twigs are smaller and more brittle at a given age as compared to cherrybark oak twigs thus, during wind events (especially squall lines associated with frontal storms), the terminal buds and twigs of sweetgum tend to break when scraped against twigs of neighboring cherrybark oak stems,
(3) high initial sweetgum density - a high initial sweetgum density may delay intra-specific (within species) crown differentiation thus leading to stagnation (Johnson 1968), and
(4) phenology - bud break in cherrybark oak, though occurring several days later than in adjacent sweetgum, occurs basipetally (from the top of the crown towards the bottom) while bud break in sweetgum occurs acropetally (begins at the base of the crown and proceeds to the top) (Young 1980).

Of particular importance may be the crown abrasion aspects of inter-specific competition. It was noted in the field that in those cases where cherrybark oak trees were of similar height or taller than neighboring sweetgum that the sweetgum limbs were broken. Subsequent crown development was from lateral buds opposite from the cherrybark oak, i.e., the sweetgum crown tended to grow away from the cherrybark oak crown as the cherrybark oak crown expanded outward.

Clatterbuck and Hodges (1988) also found that when the average spacing between cherrybark oak and sweetgum was less than six feet, then the cherrybark oak would usually become suppressed and eventually perish. Such was not found in this mixed-species plantation demonstration, especially on Site 1. Although cherrybark oak trees in the 5x5 and 5x5D spacings were shorter as compared to those on the 8x8 spacing, survival and development was excellent on Site 1. On Site 2 no differences existed in height between cherrybark oak and sweetgum on the 5x5 and 5x5D spacings. But considerable mortality had occurred since plantation established. This mortality was probably the result of competition between the cherrybark oak and neighboring sweetgum. Cherrybark oak trees that had perished over the last several years were in an overtopped canopy position before death.

Diameter

Diameter growth patterns were similar to height patterns for cherrybark oak and sweetgum on each site and each spacing with two exceptions (table 3). On Site 1, no differences in diameter existed between cherrybark oak and sweetgum on the 5x5 spacing in 1989. On Site 2, sweetgum maintained larger diameters than cherrybark oak on the 5x5 spacing in 1991 and 1998. Otherwise, at age seven (1989) sweetgum had larger diameters but by 1998 cherrybark oak had either caught up to the sweetgum or had surpassed sweetgum in diameter (Site 1 only).

Table 3-Diameter-at-breast-height (dbh, inches) of mixed-species plantations of cherrybark and sweetgum by site and spacing

Spacing	Species	1989	1991	1998
		Site 1		
8x8	Cherrybark oak	1.82a	2.77a	5.49
	Sweetgum	2.35b	3.44b	5.14
5x5	Cherrybark oak	1.30	2.05	.Ila
	Sweetgum	1.40	2.05	2.82b
5x5D	Cherrybark oak	0.98a	1.65a	3.69
	Sweetgum	1.30b	2.01 b	3.11
		Site 2		
8x8	Cherrybark oak	—[a]	1.32a	3.16a
	Sweetgum	—	2.65b	5.89b
5x5	Cherrybark oak	—	1.52a	2.40a
	Sweetgum	—	2.18b	4.73b
5x5D	Cherrybark oak	—	1.90	3.24
	Sweetgum	—	1.92	3.95

Means followed by different letters within a site, spacing, and year are different at $p \geq 0.05$.
[a] No data (no measurements were conducted on Site 2 in 1989).

CONCLUSIONS

Similar patterns of development appear to exist in plantation mixtures of cherrybark oak-sweetgum as found in natural stands, both in height and diameter. Early in stand development sweetgum trees were larger than associated cherrybark oak trees. By age 17 cherrybark oak trees have caught up to, and in one spacing on one site surpassed, sweetgum in both height and diameter. Based on development in natural stands, the cherrybark oak trees, especially on Site 1, will be taller and larger in diameter than sweetgum by age 23-25. Data indicate that these stratification patterns may even occur a few years earlier in plantations as compared to natural stands.

While this plantation was installed as a demonstration area and not as a replicated scientific study, several interesting questions arise for future considerations. First, assuming Site 2 is a lower quality site, it appears that patterns of stand development in mixed-species bottomland hardwood plantations are dependent on site quality. Wider spacings may be necessary between cherrybark oak and sweetgum on lower quality sites to increase oak survival and development. A second question involves the development of pure stands relative to mixed stands. Such a comparison could not be made in this study due to a lack of pure plantations of cherrybark oak and sweetgum planted at the same time. Future studies should include pure stands to test stand development, growth, and bole quality issues. Such an effort is currently underway in green ash, water oak, and Nuttall oak mixtures (Goelz 1995b).

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COMPOSITION AND DIVERSITY OF GROUND FLORA THREE YEARS FOLLOWING CLEARCUTTING AND SELECTION CUTTING IN A BOTTOMLAND HARDWOOD ECOSYSTEM'

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Abstract-Timber harvesting has occurred in bottomland hardwood ecosystems for over two centuries. Only in the last twenty years though has there been quantitative data on ecological functions of these areas after harvesting. Understanding the ecology of bottomland hardwood ecosystems is important in assessing the impacts of harvesting operations. As part of an integrated study on the impacts of harvesting in a bottomland hardwood ecosystem located near the Mississippi River we sampled ground flora composition and calculated diversity, evenness, richness, density and community similarity following clearcutting and selection harvesting. Unharvested controls were also included in the sampling. Permanent ground flora assessment plots were installed following the Winter 1995/1996 harvesting activities. Sampling was scheduled for three different time intervals during the 1996, 1997, and 1998 growing seasons (May, July. and September); although one sampling period was lost in each year due to flooding. There were 67 species of woody and herbaceous plants recorded after the 1996 sampling period, 82 species in 1997, and 88 species in 1998. Dominant herbaceous species included *Acalypha rhomboidea* Raf., *Eupatorium* spp., *Solidago* spp.. *Polygonum* spp., and vines such as *Vitis* spp., *Brunnichia ovata* (Walt.) Shinners, *Rubus* spp. and *Smilax* spp. Ground flora density increased in both the clearcut and selection treatments as compared to the controls three growing seasons after treatment while species diversity increased slightly over the same period. Flood depth, timing, and duration played a role in determining species composition and diversity during each growing season regardless of treatment.

INTRODUCTION

Understanding the structure and functions of bottomland hardwood ecosystems in the Mississippi Alluvial Plain has become an important issue in recent years (Hodges 1994). Bottomland hardwoods provide many important functions such as fish and wildlife habitat, water quality maintenance, flood attenuation, recreation, and timber products (Guidice and Ratti 1995). Wildlife habitat functions also include browse, cover, and nesting sites for numerous species of insects, birds, fish, amphibians, reptiles and mammals (Wigley and Lancia 1998). Alteration of ground flora strata may have significant impacts on composition and diversity of wildlife and plant species (Bonham 1989). Management practices effect some species more than others, therefore a knowledge of composition and life histories of specific species is important (Noss 1983). Disturbance of ground flora using silvicultural treatments and the degree of impact on floral and faunal communities in bottomland hardwood ecosystems are not well known (Lockaby and Stanturf 1996). Most studies conducted in bottomland hardwoods have focused on tree species composition and regeneration of commercially valuable species (Baker and Hodges 1997, Carter and others 1990, Wiseman 1982). Other studies have been conducted addressing old-field succession in abandoned agriculture fields in the Mississippi Alluvial Plain (Bazzaz 1975, Bonck and Penfound 1945, Hopkins and Wilson 1974). Few studies have focused on the effects of harvesting on ground flora diversity and early succession in bottomlands. Therefore, the objective of this study was to evaluate ground flora composition and diversity over time following harvesting in a bottomland hardwood ecosystem.

METHODS

The study site was located on Pittman Island, Issaquena County, Mississippi on land owned by Anderson-Tully Company. The area was located inside the levee system of the Mississippi River (batture lands). Tree species composition of this site was mixed bottomland hardwoods consisting of sugarberry (*Celtis laevigata* Willd.), green ash (*Fraxinus pennsylvanica* Marsh.), and American elm (*Ulmus americana* L.). Other species included sycamore (*Platanus occidentalis* L.), sweet pecan (*Carya illinoensis* (Wang.) K. Koch), bitter pecan (*C. aquatica* (Michx. f.) Nutt.), Nuttall oak (*Quercus nuttallii* Palmer), water oak (*Q. nigra* L.), overcup oak (*Q. lyrata* Walt.), boxelder (*Acer negundo* L.), red maple (*A. rubrum* L.), common persimmon (*Diospyros virginiana* L.), and honey locust (*Gleditsia triacanthos* L.). Distribution of these species was based on physiographic conditions such as ridge/swale topography (Hodges and Switzer 1979).

Pre-harvest permanent plots were installed during the summer of 1995 using a systematic plot design. Treatment plots were 20 hectares (ha) in size and each treatment (clearcut, selection and control) was replicated three times. Within each treatment sixteen O.lO-ha circular plots were systematically installed. Eight of these plots were used to evaluate ground flora composition and diversity using two 1 x 1 meter square plots located in two cardinal directions, five meters from plot center.

The study site was harvested during the winter of 1995-96. After harvesting, clearcuts were re-entered and all remaining stems > 5 cm diameter at breast height (1.4 m above ground) were felled to establish a complete clearcut. Selection treatments were harvested according to Anderson-Tully guidelines with approximately 50 percent of the basal area removed in single-tree and group selection openings. Species favored to keep during marking of the stands were green ash, sweet pecan, Nuttall oak, and well-formed sugarberry.

Three sampling periods of ground flora were to be conducted, May, July and September of each year during this study. However, only two sampling periods were used

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each year due to inundation of the site during the growing season. All plants within each 1 x 1 m plot were identified to species and classified as a forb, composite, legume, grass, sedge, fungi, vine, or woody stem. Stem counts were also taken for each species and percent cover was determined within each plot for individual species.

Calculations included Shannon-Weaver diversity indices (Shannon and Weaver 1949) which included species evenness and richness. Species evenness was defined as the distribution of abundance among different species. Richness was simply the number of species occurring within a community (Hunter 1990). Species richness and evenness are variables used in calculating species diversity within a community. Density (total number of individuals/treatment) was also calculated. Sorenson's Community Similarity equation was used to compare species composition between treatments (Mueller-Dombois and Ellenburg 1974). Importance values (sum of relative frequency, relative density, and relative dominance) was also calculated for each species within each treatment. Analysis-of-variance was used to determine if significant differences occurred between treatments ($P \leq .05$ level). Repeated measures analysis was also used to determine differences between samples over time. Duncan's Multiple Range Test was used for mean separation (Little and Hills 1974). Nomenclature of tree species followed Duncan and Duncan (1988). Nomenclature of herbaceous plants followed Smith (1988, 1994), Godfrey and Wooten (1981), and Radford and others (1968).

RESULTS

Composition

A total of 43 families and 67 species of herbaceous and woody plants were recorded following the 1996 samples (May and July). Percent composition was 49 percent forbs, 35 percent woody and herbaceous vines, and 16 percent were woody stems. Grasses and sedges were < 1 percent following the first growing season. The 1997 samples (July and September) resulted in 42 families and 86 species being recorded. Percent composition was 51 percent forbs, 36 percent woody and herbaceous vines, and 12 percent woody stems. Grasses and sedges made up only 1 percent of species recorded. The 1998 samples (July and September) resulted in 48 families and 88 species being recorded. Composition was 48 percent forbs, 41 percent woody and herbaceous vines, 8 percent woody stems and 3 percent grasses and sedges. For a complete species list refer to Appendix 1.

May 1996

Species diversity was highest in harvested treatments following the May 1996 sampling (table 1; F = 10.05, P = 0.01, df = 8). Selection treatments and clearcuts were similar in diversity. There was no difference in species evenness (F = 3.02, P = 0.12, df = 8) or richness among all treatments (F = 2.84, P = 0.14, df = 8). No difference also occurred in density between all treatments (table 1). Community similarity for May 1996 was highest between the clearcut/selection treatments followed by control/selection treatments and clearcuffcontrol treatments (table 2).

Species displaying the highest importance values were opportunistic annuals and perennials that quickly invaded the site after disturbance. These included wild parsley (*Trepocarpus aethusae* Nutt.) and stinging nettle (*Urtica chamaedryoides* Pursh.). Wild parsley had the highest importance value in selection and control treatments while stinging nettle was highest in the clearcut treatments

Table I-Diversity, evenness, richness and density by treatment for the 1996, 1997, and 1998 sampling periods on Pittman Island, Issaquena County, Mississippi

	Treatments		
Sampling period	Clearcut	Selection cut	Control
May 1996			
Diversity	2.70a[a]	2.74a	2.34b
Evenness	.81	.81	.74
Richness	28	30	24
Density	488	571	648
July 1996			
Diversity	2.02	2.31	1.95
Evenness	.80a	.76a	.69b
Richness	13b	21a	17a
Density	99b	244a	259a
July 1997			
Diversity	2.60	2.63	2.62
Evenness	.70	.71	.79
Richness	41a	41a	28b
Density	1018a	1057a	553b
Sept. 1997			
Diversity	2.70	2.67	2.68
Evenness	.51ab	.70b	.79a
Richness	42a	46a	30b
Density	854a	1003a	484b
July 1998			
Diversity	2.39a	2.75a	1.65b
Evenness	.67ab	.74a	.51b
Richness	36a	41a	26b
Density	1275	1308	1381
Sept. 1998			
Diversity	2.43ab	2.75a	1.80b
Evenness	.68	.74	.55
Richness	37a	42a	26b
Density	1333	1395	1254

[a] If no letters are present within a row then no difference existed between treatments ($P \leq 0.05$).

Table P-Sorenson's Community Similarity Index by treatment combination for the 1996, 1997, and 1998 sampling periods on Pittman Island, Issaquena County, Mississippi

	Treatment combinations		
Sampling period	Clearcut/ selection	Clearcuff control	Control/ selection
1996			
May	0.71	0.42	0.59
July	.46	.38	.66
1997			
July	.50	.28	.41
Sept.	.52	.36	.43
1998			
July	.47	.19	.42
Sept.	.46	.23	.45

Table 3—Importance values (sum of relative frequency, relative density, and relative dominance) for dominant ground flora by treatment for the 1996, 1997, and 1998 sampling periods on Pittman Island, Issaquena County, Mississippi

Species and sampling period	Treatments		
	Clearcut	Selection cut	Uncut control
May 1996			
Urtica chamaedryoides	106	**109**	76
Trepocarpus aethusae	73	**111**	149
Celtis laevigata	58	88	99
July 1996			
Celtis laevigata	54	120	135
Brunnichia ovata	67	84	111
Rubus trivialis	80	99	96
July 1997			
Celtis laevigata	58	88	**99**
Brunnichia ova ta	38	60	61
Polygonum pensylvanicum	42	44	20
September 1997			
Amaranthus rudis	88	80	88
Polygonum pensylvanicum	74	73	74
Rubus trivialis	69	120	134
July 1998			
Rubus trivialis	77	84	**111**
Amaranthus rudis	70	108	57
Brunnichia ovata	58	88	99
September 1998			
Rubus trivia/is	**90**	**99**	**95**
Amaranthus rudis	86	21	**0**
Brunnichia ovata	38	60	61

(table 3). Wild parsley occurred in controls where there were openings created by blow-down of single or multiple trees within or surrounding a measurement plot.

July 1996

Following the July 1996 sample there was no difference in species diversity between treatments (table 1; F = 2.61, P = 0.15, df = 8). A difference was found in species evenness (F = 3.79, P = 0.09, df = 8) with the harvested treatments having greater evenness than controls. Species richness was higher in selection treatments compared to clearcut treatments (F = 9.05, P = 0.02, df = 8) while density was greater in the selections and controls compared to clearcut treatments (table 1; F= 32.57, P = 0.0006, df = 8). Community similarity between treatments was higher for control/selection treatments followed by clearcut/selection and clearcut/control treatments, respectively (table 2). Species displaying high importance values after the May 1996 sample were insignificant following the July 1996 sample. These species were replaced by sugarberry, buckwheat vine (*Brunnichia ovata* (Walt.) Shinners), and blackberry (*Rubus trivia/is* Michx.) (table 3). Prior to the July sample the site was inundated for approximately four weeks.

July 1997

No significant difference in species diversity or evenness was found following the July 1997 sample (F = 0.03, P = 0.97, df = 8; F = 3.46, P = 0.10, df = 8, respectively). Control treatments were lower in species richness compared to harvested treatments (table 1; F = 7.81, P = 0.02, df = 8) following the July 1997 sample. Density in control treatments was also lower compared to the harvested treatments (F = 9.64, P = 0.01, df = 8). Clearcut/selection treatments were most similar in species composition after the July 1997 sample, followed by control/selection treatments and clearcuffcontrol treatments (table 2).

Species displaying the highest importance values after the July 1997 sample were sugarberry, smartweed (*Polygonum pensylvanicum* L.), blackberry, and pigweed (*Amaranthus rudis* Saur) (table 3). Again, there was a change in species of high importance values from the previous year. Pigweed and smartweed are common wetland plants that are found on moist soils and, due to the intensity of flooding prior to sampling, the soil was saturated.

September 1997

No difference in diversity was found following the September 1997 sample among all treatments (table 1). Species evenness was highest in control treatments and selection treatments were significantly lower than controls (F = 4.01, P = 0.08, df = 8). Species richness and density were greater in the clearcut and selection treatments compared to controls (table 1; F = 8.99, P = 0.02, df = 8; F = 9.25, P = 0.01, df = 8, respectively). Community similarity favored clearcut/selection treatments followed by control/selection and clearcut/control treatments being the least similar in species composition (table 2).

Species displaying the highest importance values after the September 1997 sample were similar to those in the July sample. Pigweed had the highest importance value followed by smartweed, blackberry, and buckwheat vine (table 3).

July 1998

Control treatments were different from selection treatments in species diversity following the July 1998 sample (table 1; F = 7.73, P = 0.02, df = 8). Species evenness was also highest in selection treatments compared to controls (F = 6.00, P = 0.04, df = 8) following the July 1998 sample. As with the previous two sampling periods species richness was greater in the harvested treatments (F = 9.25, P = 0.01, df = 8). No difference was found in density between all treatments after the July sample (table 1). Community similarity favored clearcut/selection treatments and selection/control treatments (table 3).

Species displaying the highest importance values were sugarberry, buckwheat vine, and pigweed. Sugarberry was highest in control treatments; buckwheat vine was of importance across all treatments and pigweed dominated in clearcuts (table 3).

September 1998

Selection treatments had greater species diversity than controls following the September 1998 sample while clearcut treatments were similar to both selections and controls (table 1; F = 4.51, P = 0.06, df = 8). No significant difference was found in species evenness after the September 1998 sample (table 1; F = 2.62, P = 0.15, df = 8). Control treatments were significantly different from selection treatments in species richness (table 1; F = 9.25, P = 0.01, df = 8) while there was no difference in density among all treatments. Community similarities were similar between clearcut/selection treatments and control/selection treatments while clearcut/control treatments were the least similar (table 2). Sugarberry displayed the highest values in control treatments followed by buckwheat vine in selections and pigweed in clearcuts (table 3).

Repeated Measures Analyses

Clearcut treatments-A significant difference was found in species diversity between the July 1996 sample and July 1998 sample (F = 3.56, P = 0.03, df = 5); all other periods were similar in diversity. Diversity values dropped following the first sample (May) in 1996 due to inundation of the study site for approximately four weeks. There was no treatment effect or treatment/time interaction. There was a time effect on diversity in clearcut treatments.

Analysis of species evenness over time found that the September 1997 sample was different from the July 1996 sample (F = 2.43, P = 0.09, df = 5) where distribution of species shifted from clearcuts in July 1996 to controls being more evenly distributed following September 1997 samples. Distribution of species during the September 1997 sample was probably influenced by flooding. Flood depth during the spring of 1997 was higher than in previous years, therefore making recovery of plants slow. Distribution was of few species scattered throughout the study site and consisted of late annuals and perennials.

There was a treatment and time effect on species richness in clearcut treatments. The May 1996 sample was different from the July 1998 sample, and the July 1996 sample was different from the May 1996 sample (F = 46.55, P = 0.0001, df = 5).

A significant difference was found in density across all time periods (F = 6.57, P = 0.004, df = 5). July and September 1998 samples were similar in density (table l), the May and July 1996 had lower densities compared to the 1998 and 1997 samples in clearcut treatments.

Selection treatments-Species diversity following the July 1996 sample was different from the July 1997 sample (F = 4.53, P = 0.01, df = 5). There was no difference between other sampling periods. Similar results were found in clearcut treatments with July 1996 being different from other periods, probably due to inundation during the growing season. The September 1997 sample was different in species evenness from the May 1996 sample (F = 2.43, P = 0.10, df = 5) while other sampling periods were similar in species evenness.

A significant difference was found in species richness between the September 1998 and the September 1997 sample, also May 1996 was different from July 1997 and July 1996 was different from May 1996 samples (F = 46.55, P = 0.0001, df = 5). The September 1997 sample had the highest species richness followed by the September 1998 sample.

Density in selection treatments followed the same pattern as in clearcut treatments. The July 1997 sample was different from the September 1998 sample, the May 1996 sample was different from the September 1997 sample and the July 1996 sample was different from the May 1996 sample (table 1; F = 6.57, P = 0.004, df = 5). The highest density occurred following the September 1998 sample in selection treatments (table 1). This may have occurred due to less intensity of flooding early in the 1998 growing season.

Control treatments-A significant difference was found between the September 1998 sample **and the July 1996** sample in species diversity (table 1; F = 3.90, P = 0.02, df = 5). A difference was found in species evenness between the July 1998 and the September 1998 sample, September 1998 was also different from the July 1996 sample (F = 5.23, P = 0.009, df = 5).

A difference was also found in species richness between the May 1996 sample and the July 1996 sample (F = 2.04, P = 0.14, df = 5). These two sampling periods were separated by a flood during June 1996. Ground flora had not completely recovered while sampling was done. The May 1996 sample was significantly different from the July 1998 sample in density while the July 1996 sample was different from the July and September 1998 sample (table 1; F = 5.09, P = 0.001, df = 5).

DISCUSSION

Maintaining diversity in vegetation communities is an important aspect of bottomland hardwood ecosystems (Harris and Gosselink 1990). Having a variety of vegetation communities on a site is important for sustainable resources such as wildlife habitat, timber production and water quality (Harris and Skoog 1980). Growing season flooding accompanied by timber harvesting may affect the diversity and composition of species in a bottomland hardwood ecosystem.

The results from this study do not show a specific pattern in species diversity, evenness, and richness three years following harvesting on this site: These variables were influenced by both harvesting practices (a factor tested) and flooding during the growing season (a factor not tested). Flood depth, duration and frequency are factors which determine plant and animal species found in bottomland hardwood ecosystems (Harris and Gosselink 1990). Any type of major disturbance such as flooding or timber harvesting will revert a stand back to an earlier successional stage, subsequently changing species composition (Hanna 1981). Studies have suggested that forests in many regions have species compositions and age structures which are largely a result of previous disturbances (Agee and Huff 1980, Franklin and Waring 1979, Oliver and Stephens 1977). Natural succession in bottomland hardwoods is also influenced by differences in elevation and rate of deposition (Hodges and Switzer 1979).

An increase in resources, such as light and nutrient availability, following a major disturbance result in a temporary increase in species diversity and density of the ground flora. Francis (1984) looked at regrowth of an Il- year-old clearcut in the Mississippi River floodplain and found that herbaceous species densities and above-ground biomass were higher in one-year-old clearcuts, but declined after four years. A similar study in east Texas (Nixon and others 1981) also found that density declined after three growing seasons following complete harvesting. The number of species (richness) increased during the same time period.

A similar pattern is not apparent three years after harvesting in this study. Densities have increased after the third growing season on Pittman Island following harvesting compared to the two previous growing seasons. The major factor affecting diversity and composition in this study was growing season flooding during each year of sampling. Ground flora was set back during the spring making recovery of the herbaceous and woody plants difficult; depending on flood depth and duration. Diversity is high in the early stages of development in clearcut and selection treatments and should advance into a higher seral stage as the tree canopy becomes re-established.

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Appendix I--Species list of ground flora for the 1996, 1997, and 1998 sampling periods on Pittman Island, Issaquena County, Mississippi

Family	Scientific name	Common name
ACANTHACEAE	*Dicliptera brachiata* (Pursh.) Spreng.	Dicliptera
	Justicia ovata (Walt.) Lindau var. *lanceolata* (Chapm.) R.W. Long	Water willow
ACERACEAE	*Acer rubrum* L. var. *rubrum*	Red maple
AMARANTHACEAE	*Amaranthus albus* L.	Pigweed
	A. rudis Saur.	Pigweed
ANACARDIACEAE	*Toxicodendron radicans* (L.) Kuntz.	Poison-ivy
APOCYNACEAE	*Trachelospermum difforme* (Walt.) Gray	Climbing dogbane
AQUIFOLIACEAE	*Ilex decidua* Walt. var. *decidua*	Possomhaw, decidous holly
ARISTOLOCHIACEAE	*Aristolochia serpentaria* L.	Virginia snakeroot
ASCLEPIADACEAE	*Gonolobus gonocarpus* (Walt.) Perry	Angle-pod
BIGNONIACEAE	*Bignonia capreloata* L.	Crossvine
	Campsis radicans (L.) Seem.	Trumpet creeper
BORAGINACEAE	*Heliotropium indicum* L.	Indian heliotrope
	H. procumbens P. Mill.	Heliotrope
CHENOPODIACEAE	*Chenopodium album* L. var. *album*	Pigweed
COMMELINACEAE	*Commelina virginica* L,	Dayflower
COMPOSITAE	*Eupatorium coelestinum* L.	Boneset
	E. rugosum Houtt.	Boneset
	Heterotheca subaxillaris (Lam.) Britt. & Rusby	Golden aster
	Iva annua L.	Marsh elder
	Senecio glabellus Poir.	Butter-weed
	Solidago canadensis L.	Goldenrod
	Vernonia gigantea (Walt.) Trel. ex Bran. & cov.	Giant ironweed
	Xanthium strumarium L.	Vocklebur
CONVOLVALACEAE	*Ipomea lacunosa* L.	Morning glory
	I. pandurata (L.) Mey.	Morning glory
CORNACEAE	*Cornus drummondii* Meyer	Swamp dogwood
CRUCIFERAE	*Capsella bursa-pastoris* (L.) Medic.	Shepard's purse
	Cardamine hirsuta L.	Cress
CUCURBITACEAE	*Cayaponia quinqueloba* (Raf.) Shinners	Manso
	Cucumis melo L. var. *dudaim* Naud.	Cucumber, melon
	Melothria pendula L.	Creeping cucumber
CYPERACEAE	*Carex cherokeensis* Schwein.	Cherokee sedge
	C. crus-corvi Shuttlw. ex Kuntze	Sedge
DIOSCOREACEAE	*Dioscorea oppositifolia* L.	Yam
EBENACEAE	*Diospyros virginiana* L.	Common persimmon
EUPHORBIACEAE	*Acalypha rhomboidea* Raf.	Three-seeded mercury
	Croton glandulosus L. var. *septentrionalis* Muell. Arg.	Wolly croton
	Phyllanthus caroliniensis Walt.	Leaf-flower
FAGACEAE	*Quercus nigra* L.	Water oak
	Q.? nuttallii Palmer	Nuttall oak
FUMARIACEAE	*Corydalis flavula* (Raf.) DC.	Pale corydalis
GRAMINEAE	*Digitaria filiformis* (L.) Koel. var. *filiformis*	Crabgrass
	Echinochloa crusgalli (L.) Beauv.	Barnyard grass
	Leersia virginica Willd.	Cutgrass
	Leptochloa filiformis (Lam.) Beauv.	Sprangletop
	Setaria glauca (L.) Beauv.	Foxtail grass
	Sorghum halepense (L.) Pers.	Johnson grass
	Panicum capillare L. var. *capillare*	Panic grass
	P. laxiflorum Lam.	Panic grass
JUGLANDACEAE	*Carya illinoensis* (Wang.)K. Koch	Sweet pecan, pecan hickory
LABIATAE	*Perilla frutescens* (L.) Britt.	Beef-steak plant
	Teucrium canadense L. var. *canadense*	Wood sage

Family	Scientific name	Common name
LEGUMINOSAE	*Desmanthus illinoensis* (Michx.) MacM. ex Rob. & Fern.	Prairie mimosa
	Gleditsia triacanthos L.	Honey locust
	Sesbania macrocarpa Muhl.	Hemp sesbania
	Vicia sativa L.	Common vetch
LILIACEAE	*Smilax bona-nox* L.	Greenbriar
	S. rotundifolia L.	
	S. tamnoides L. var. *hispida* (Muhl.) Fern.	
LOGANIACEAE	*Gelsemium sempervirens* (L.) Jaume St. Hill	Yellow jessimine
MENISPERMACEAE	*Cocculus carolinus* (L.) DC.	Carolina moonseed
MOLLUGINACEAE	*Mollugo verticillatta* L.	Carpet-weed
MORACEAE	*Maclura pomifera* (Raf.) Schneid.	Osage-orange
	Morus rubra L.	Red mulberry
OXALIDACEAE	*Oxalis dillenii* Jacq.	Wood sorrell
PASSIFLORACEAE	*Passiflora lutea* L.	Yellow passion flower
PHYTOLACCACEAE	*Phytolacca americana* L.	Pokeweed
POLYGONACEAE	*Brunnichia ovata* (Walt.) Shinners	Buckwheat vine
	Polygonum pennsylvanicum L. var. *pennsylvanicum*	Smartweed
	P. punctatum Ell.	Smartweed
	P. virginianum L.	Jumpweed
RHAMNACEAE	*Berchemia scandens* (Hill) K. Koch	Rattan vine
ROSACEAE	*Rubus flagellaris* Willd.	Dewberry
	R. trivia/is Michx.	Blackberry
RUBIACEAE	*Spermacoce glabra* Michx.	Smooth buttonweed
SALICACEAE	*Populus deltoides* Marsh. subsp. *deltoides*	Eastern cottonwood
	Salix nigra Marsh.	Black willow
SAPINDACEAE	*Cardiospermum halicababum* L.	Ballon vine
SOLANACEAE	*Physalis angulata* L.	Ground cherry
	P. pubescens L.	Ground cherry
	P. virginiana P. Mill.	Ground cherry
	Solanum carolinense L.	Horse nettle
ULMACEAE	*Celtis laevigata* Willd.	Sugarberry
	Ulmus americana L.	American elm
UMBELLIFERAE	*Trepocarpus* aethusae Nutt.	Parsely
	Sanicula canadensis L.	Black snakeroot
URTICACEAE	*Boehmeria cylindrica* (L.) Sw.	False nettle
	Utica chamaedryoides L.	Stinging nettle/strawberry nettle
VALERIANACEAE	*Valerianella radiata* (L.) Dufr.	Corn salad
VIOLACEAE	*Viola sororia* Willd. var. *sororia*	Violet
VITACEAE	*Ampelopsis arborea* (L.) Koehne	Pepper vine
	A. cordata Michx.	False grape
	Parthenocissus quinquefolia (L.) Planchon	Virginia creeper
	Vitis aestivalis Michx.	Summer grape
	V. mustangensis Buckl.	Grape
	V. palmata Vahl	Grape
	V. rotundifolia Michx.	Muscadine

* Species names follow Smith 1994 and Radford and others 1968.

LITTER DECOMPOSITION WITHIN DISTURBED COASTAL PLAIN RIPARIAN FORESTS[1]

Laura A. Giese, W. Michael Aust, Carl C. Trettin, and Randy K. Kolka[2]

Abstract-Decomposition rates of leaf litter from two thermally disturbed riparian areas at different stages of succession and a mature bottomland hardwood stand were compared. Decomposition rates were determined for one year among and between the sites for each litter type. Litter type and inherent quality appears to be more of an overriding factor influencing decomposition rates, than forest age. The influence of litter quality was evident in the decomposition rates of the different litter composites used in this study. In all four sites the litter composite from the mature riparian forest decomposed significantly more than the litter composites from the younger riparian forests. The fairly rapid decomposition of red maple which was one of the main components in the mature riparian forest litter composite likely influenced the greater decomposition rate. The litter composites from the younger riparian forests were similar and both included more resistant litter types, specifically waxmyrtle and alder. Decomposition rates did not differ between the individual successional stages.

INTRODUCTION

Decomposition of organic matter is an essential ecosystem process whereby nutrients become available for assimilation by plants and other organisms. Typically, leaf litter comprises 70 percent of the total aboveground litter contributed to the forest floor on an annual basis. Forest productivity can be reduced if decomposition is too slow because the nutrients are removed from active circulation. Conversely, litter decomposition and subsequent nutrient release can occur faster than plants and soil are able to retain them and the nutrients are leached out of the rooting zone.

Rates of litter decomposition vary with forest type and generally increase as the quantity of litter fall increases. An inverse relationship exists between litter fall biomass and nutrient content and the biomass and nutrient content of the forest floor. In riparian forests decomposition is related to flooding frequency, depth, and duration, although consistent relationships have not been established. For instance litter decomposition has been found to be more rapid in the wettest sites of an alluvial swamp (Brinson 1977) to greater in dry sites adjacent to flooded areas of the Corkscrew Swamp (Duever and others 1984). Litter decomposition in aerobic areas with adequate moisture is probably greater than continually dry sites (Mitsch and Gosselink 1993). Peterson and Rolfe (1982) found leaf litter decomposition to be greater in a floodplain forest than the adjacent upland. Permanently anaerobic riparian forests probably have the slowest litter decomposition rates (Brinson and others 1981).

Physical and chemical properties of litter vary by species. The soil microclimate and chemistry induced by litter will influence the type and activity level of soil microflora. Often, nutrient rich litter decomposes more rapidly than nutrient poor litter in the same forest environment. Sweetgum (*Liquidambar styraciflua* L.) decomposes more slowly than red maple (*Acer rubrum* L.), black gum (*Nyssa sylvatica* L.) and red ash (*Fraxinus pennsylvanica* Marsh.) in a floodplain forest along Lower Three Runs Creek located at the Savannah River Site (Shure and others 1986). Day (1982) found highest decomposition among mixed litter from a cypress site and maple-gum site than a cedar or mixed-hardwood site.

The overall rate of decomposition is largely determined by temperature and moisture. Temperature is a primary component because it influences microbial activity. Successional stage will influence density of groundcover and canopy cover subsequently affecting the temperature and moisture regime in the forest. In riparian forests there are contradictory results on the effect of hydroperiod on litter decomposition (Lockaby and others 1996; van der Walk and others 1991; Day 1983).

Baker (1998) examined decomposition processes on three floodplain sites in the southeastern United States -- Cache River-Arkansas, Coosawhatchie River-South Carolina, and latt Creek-Louisiana. He placed litter from the latt Creek floodplain in all three sites and found litter decomposition in the latt Creek site to be greater than the other two sites. This suggests the possibility of site-specific microbial communities. The uniqueness of this study is the ability to exchange litter types from forests of different successional stages within close proximity to each other (3 to 7 miles).

SITES

The study sites are located in the riparian forests adjacent to three braided, blackwater streams of the Savannah River Site (SRS), National Environmental Research Park in South Carolina. Pen Branch and Fourmile Branch are third order tributaries of the Savannah River that received thermal, elevated discharge from nuclear production processes occurring from 1954 to 1989, and 1955 to 1985, respectively. This disturbance resulted in the loss of vegetation and possibly removal of soil organic matter. The third stream system, Meyer's Branch, represents a minimally disturbed reference site. The age of the riparian areas adjacent to Pen Branch, Fourmile Branch, and Meyer's Branch at the time of the study are 7-years, 1 l-years, and approximately 75 years, respectively. The riparian area along Pen Branch has received two treatments. One area is considered a control and has been allowed to regenerate naturally (PBC). An adjoining area received site preparations

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of herbicide application followed by burning and then planted with bottomland hardwood species (PBD).

Species Composition

The riparian areas on either side of the main stream channels range in width from 8 to 95 meters. Early successional species of willow (*Salix* spp. L.), waxmyrtle (*Myrica cerifera* L.), smooth alder (*Alnus serrulata* (Ait.) Willd.) and buttonbush (*Cephalanthus occidentalis* L.) dominate the natural regeneration riparian forest of Pen Branch. The planted section of Pen Branch is dominated by herbaceous vegetation and blackberry (*Rubus* spp.) with some buttonbush and alder. The woody component of the Fourmile riparian area is also dominated by willow with the addition of red maple, alder, waxmyrtle and loblolly pine (*Pinus taeda* L.). Meyer's Branch represents a mature bottomland forest with a mixed species composition including bald cypress (Taxodium *distichum* L.), tupelo, red maple, Virginia willow *(/tea virginica* L.), and arrowwood *(Viburnum dentatum* L.) as the dominant species.

Soil Descriptions

Soil descriptions were obtained independent of the Soil Survey of Savannah River Plant (Azola 1997). The soils in the riparian area of Pen Branch include Typic Endoaquepts, Typic Fluvaquents, and Thapto-Histic Fluvaquents. In Pen Branch micro-topography has slightly influenced soil development. Adjacent upland soils were characterized as Entisols and Ultisols.

In the Fourmile Branch riparian area soils are generally Thapto-Histic Fluvaquents which have a buried A or histic horizon. Characterization of soil profiles was not significantly influenced by micro-topography. Adjacent upland soils are Ultisols on the west side of the main channel (Typic Endoaquults, Aquic Hapludults) and Entisols on the east side of the main channel (Typic and Aquic Quartzipsamments).

Most of the soils in the Meyer's Branch riparian area have an organic layer at least 18 cm deep and the Typic Medisaprists had several organic layers extending to an average of 102 cm. Other riparian soil types include Humaqueptic Endoaquepts and Fluvaquents. Micro-topography effects on the morphology of the soils were slight. The upland soils are very sandy (Grossarenic Hapludults, and Arenic Endoaquults).

PROCEDURES

Fresh leaf litter was collected from each riparian forest community, except the planted area of Pen Branch, from the 1996 growing season. Approximately 5 g (dry wt.) of representative litter was placed in 2-mm mesh nylon bags with a drawstring closure. One-hundred eight(108)bags were filled with litter for each riparian forest community type and placed in the field September 13 and 14, 1997. Nine bags of litter from each riparian forest were placed in three groupings within a site for a total of 27 bags per site for each riparian community type. A control consisted of craft sticks made from Maine birch. An empty bag was also placed within each group to determine possible weight change in the bag itself. A temperature data logger set to obtain readings every four hours was placed within each grouping.

Three bags(one from each grouping within a site) were collected after 7, 13, 20, 27, 42, 72, 141, 217 and 356 days. Three bags per litter type were placed in the field and then immediately retrieved to assess transportation loss. All of the collected bags were dried at 60 °C for at least one week and bag plus litter were weighed. Because of sediment deposition the litter was removed from the bags, weighed and ground to pass a 20-mesh sieve in a Wiley mill. The empty bag was also weighed to address the amount of sediment deposition. The ground litter samples were ashed at 380 °C for 24 hours to apply ash mass correction factors. A correction factor for the organic matter within the sediment was applied to bags collected at 141, 217, & 356 days. Soil samples were obtained adjacent to the litter bag groupings and ashed at 380 °C for 24 hours to determine the amount of organic matter in the deposited sediment.

Unanticipated flooding depth and duration waterlogged many of the temperature data loggers resulting in the loss of data for the majority of the year.

Statistical analysis consisted of analysis of variance (ANOVA) comparisons between the four riparian forests and between litter types within each riparian forest. The SAS (1988) general linear model procedure was used and significant differences were sorted by the least significant difference (LSD) multiple comparison procedure. An alpha=0.05 was used to determine significance between treatments.

RESULTS AND DISCUSSION

Comparison Between Sites

Comparison of litter decomposition between the four riparian forests demonstrates that litter decomposition rates does not appear to be influenced by forest age. Decomposition of 7 year-old Pen Branch control (PBC) litter was not significant between sites (p=0.0715) (fig. IA). However, LSD at an alpha=0.05 indicates that decomposition of Pen Branch litter decomposed significantly more in the Fourmile Branch riparian forest than either PBC or PBD riparian forests. The discrepancy in alpha level significance may be due to the data being slightly unbalanced. The depth and duration of winter/spring flooding in the Fourmile riparian forest possibly influenced the difference in litter decomposition.

The decomposition of litter from the 11 year-old Fourmile Branch riparian forest was not significantly different (p=.3072) between the four sites (fig. 1 B). Litter from the mature riparian forest (Meyers Branch) showed a significant difference in decomposition between sites (p=0.0035) (fig. 1C). The Meyers Branch litter decomposed significantly more in Fourmile Branch and the Pen Branch control riparian forests than Pen Branch planted (PBD).

Decomposition of the control showed a pattern similar to the Pen Branch litter (fig. 1 D). The ANOVA indicated no significant difference between sites (p=0.0827), however, LSD at an alpha=0.05 indicated that decomposition of the control was significantly more in Fourmile than Pen Branch control (PBC).

Fourmile Branch and Pen Branch riparian forest litter both decomposed approximately 25 percent after one year which is much lower than the 85 percent annual decomposition of mixed floodplain species found by Shure and others (1986).

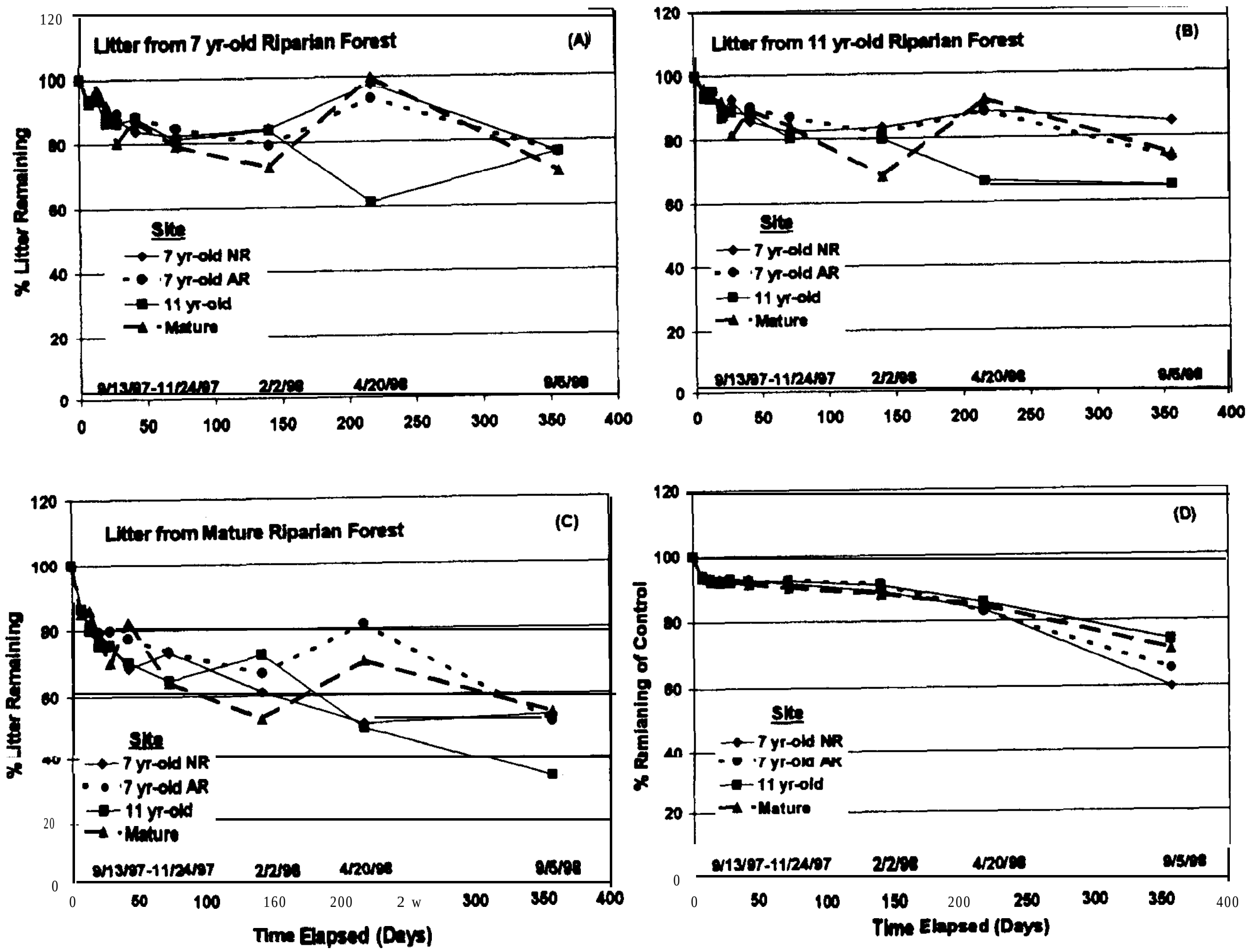

Figure l-Comparisons of riparian forest succession on litter decomposition rates. (A) litter from a 7-yr-old riparian forest, (B) litter from a 1 l-yr-old riparian forest, (C) litter from a mature riparian forest, and (D) a control. All values are expressed on an ash-free basis.

Comparison of Litter Type Within Each Riparian Forest

The quality and chemical composition of litter from individual tree species influences their decomposition. This was evident in the decomposition rates of the different litter composites used in this study. In the Pen Branch control (PBC) riparian forest the Meyers Branch litter decomposed significantly more than the Fourmile litter, and the indigenous PBC litter (fig. 2A). A similar decomposition pattern was exhibited in the planted Pen Branch riparian forest (fig. 2B).

The Meyers Branch litter also decomposed significantly more than Pen Branch litter, and indigenous Fourmile litter in the Fourmile Branch riparian forest (fig. 2C). Furthermore in the mature Meyers Branch riparian forest the indigenous Meyers Branch litter decomposed significantly more than the Pen Branch and Fourmile Branch litter (fig. 2D).

In all four sites the Meyers Branch litter decomposed significantly more than the other litter types. After one year approximately 50 percent was remaining. The fairly rapid decomposition of red maple (Shure and others 1986) which was one of the main components in the Meyers Branch litter likely influenced the greater decomposition of Meyers Branch litter. Although transportation losses were accounted for and the decomposition bag mesh size was small, the small size of bald cypress needles may have influenced the decomposition rate by either falling out or rapid decomposition themselves.

The litter composites from the younger riparian forests, Pen Branch and Fourmile Branch, were similar and both included more resistant litter types, specifically waxmyrtle and alder. The control decomposed less than the leaf litter in all four sites and values were indicative of twig decomposition rates.

Temperature and Hydrologic/Sediment Deposition Effects on Litter Decomposition

The limited temperature data revealed some patterns between the four sites, however, there was no significant difference in the comparison of monthly means. Lacking a forest canopy the temperature in the planted portion of Pen Branch (PBD) was higher than the other three sites. The mature riparian forest (MB)with a full canopy was several °C lower than the other three sites.

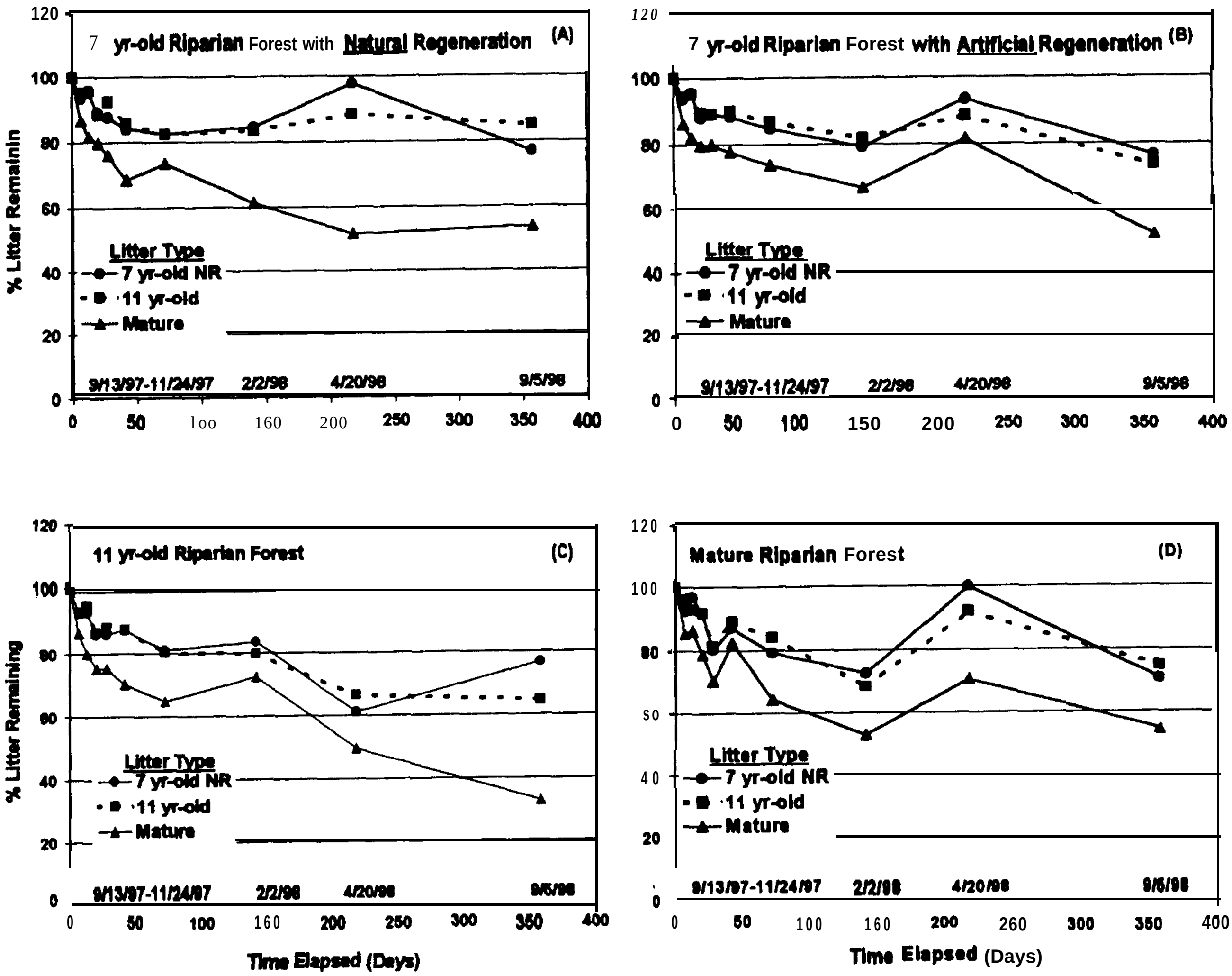

Figure 2-Comparisons between litter type within each riparian forest. (A) 7-yr-old riparian forest with natural regeneration, (B) 7-yr-old riparian forest with artificial regeneration, (C) 1 1-yr-old riparian forest, and (D) mature riparian forest. All values are expressed on an ash-free basis.

Extremely high amounts of rainfall occurred during the winter and spring months of 1998. Water levels rose on the Savannah River subsequently backing up Fourmile Branch causing extensive flooding. The Fourmile Branch riparian forest remained inundated approximately from February through March potentially affecting decomposition rates. Pen Branch and Meyers Branch did not receive the same intensive flooding duration, however, depth was phenomenal.

Sediment deposition was very prevalent in Meyers Branch which receives fairly frequent, brief flood events (fig. 3). The natural regeneration riparian forest of Pen Branch (PBC) was also subject to excess sediment deposition. The other two sites were also affected by sediment deposition, but not to the extent of the Meyers Branch riparian forest and PBC. The sediment contributed organic matter to the decomposition bags altering the final values. Although an attempt was made to correct for the amount of organic matter in the sediment, the percent remaining may be underestimated.

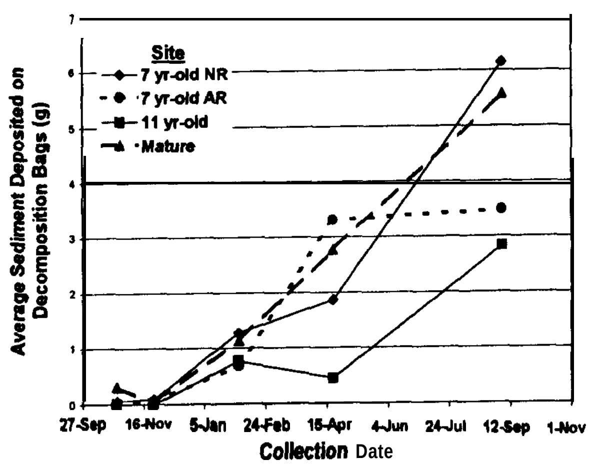

Figure 3-Average sediment deposited on decomposition bags in four riparian forests located at the Savannah River Site, SC; 7-yr-old Pen Branch with natural regeneration/control, 7-yr-old Pen Branch with artificial regeneration, 1 l-yr-old Fourmile Branch, and mature Meyers Branch.

Litter type and inherent quality (physical and chemical makeup) is more of an overriding factor influencing decomposition rates, than forest age. The individual litter types had similar decomposition patterns between the four riparian forests, but within each riparian forest the litter types had differing decomposition rates. This has management implications for restoring disturbed sites. The rapid incorporation of organic matter and subsequent nutrient release may affect restoration success.

ACKNOWLEDGMENTS

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DELAYED TREE MORTALITY FOLLOWING HURRICANE ANDREW IN SOUTHERN LOUISIANA'

Bobby D. Keeland and Lance E. Gorham[2]

Poster Summary

Hurricane Andrew passed through the Atchafalaya Basin of Southern Louisiana in August 1992 with winds in excess of 225 kph. During the summer of 1993 we established permanent study plots at 18 bottomland hardwood locations spread across the basin (south of Interstate-IO, between Baton Rouge and Lafayette). At each location we established two or three 0.05 ha study plots (total of 50 plots) and mapped the species, location and damage of each stem larger than 2.5 cm diameter-at-breast-height. Viability of each tree was evaluated during the summers of 1993 and 1994. A second part of the study, conducted near two of the same locations, involved the recording of species and viability for a total of 120 uprooted trees during 1994, 1996 and 1998.
Damage was not uniform across the basin or among species. Minor damage in the form of defoliation, branch loss, and bent or leaning stems was evident on trees of all species throughout the impacted area. Major damage in the form of snapped or uprooted stems was more common for some species and for all species in the right front quadrant of the hurricane. Species that tended to sustain the least damage included red maple, box elder, sugarberry, pumpkin ash, water elm, and baldcypress. Even the oaks (n=42), which are generally severely damaged by hurricane force winds, received little damage as a result of Hurricane Andrew. Some species, such as swamp cottonwood, black willow, sandbar willow, and Chinese tallow sustained major damage more frequently than other species.

The majority of trees, including those severely damaged, were alive and sprouting prolifically in 1993. One year after the hurricane overall mortality was only 1.5 percent. Although survival of most species was similarly high during the second year after the hurricane, mortality rates of some tree species increased dramatically. For example, swamp cottonwood mortality increased from 6.3 to 61 .1 percent (n=79), while sandbar willow mortality increased from 4.6 to 57.1 percent (n=22). Greater than half of the individual trees of these species were either snapped or up-rooted. The majority of trees that died by 1993 were still standing with no apparent cause of death. Mortality associated with major damage (snapped stems or up-rooting) was much more prevalent in 1994. In the second portion of the study swamp cottonwood was found to constitute only 3 percent of the stem density, yet accounted for 65 percent of the uprooted trees (n=78). All uprooted swamp cottonwood trees died within two years of the hurricane. In contrast, stem sprouts on many uprooted individuals of sycamore, swamp red maple, green ash, American elm, and sugarberry were still alive in 1998, six years after the hurricane.

Hurricanes have been called stand replacing events and the recovery process has been deemed uncertain. Most studies, however, have reported low mortality following hurricanes. In our study the only species with high mortality were early successional and these same species may constitute the majority of seedlings invading into the newly opened areas. This could result in very little change in species composition as a result of Hurricane Andrew. One possible change in species composition, however, may result from the highly invasive nature of Chinese tallow. Because of its rapid growth rate, precocity, high fecundity, lack of pests, and tolerance to different soil types, light levels, drought, and flooding this species may expand much more rapidly than it would in an undisturbed forest. The overall effect could be a reduction in species diversity as many areas may become mono-specific Chinese tallow stands. Long-term studies of hurricane impacted areas are needed to test this hypothesis.

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Hardwood Regeneration

Moderator:

PHIL CANNON
Alabama A&M University

EFFECTS OF TEMPERATURE AND MOISTURE CONTENT ON THE STORABILITY OF HARDWOOD SEEDS'

Kristina F. Connor and Franklin T. Bonner[2]

Abstract-Experimental results have been inconclusive about low temperature storage of recalcitrant seeds from temperate zone trees. Experiments were conducted on four species of oak • chinkapin (Quercus *muehlenbergii* Engelm.), water (Quercus *nigra* L.), Shumard *(Quercus shumardii* Buckl.), and northern red *(Quercus rubra* L.). Storage temperatures were -1.5 °C and 3 °C, and lengths of storage were 1, 2, and 3 years. Seeds, stored both hydrated and dried, had moisture contents ranging from 23 to 45 percent. Chinkapin acorns did not survive past 1 year in storage, and few northern red acorns were viable after 3 years. Both water oak and Shumard acorns survived at high and low moisture contents; however, Shumard acorns lost 2/3 of their viability by year 3 with best survival rates at -1.5 °C, while water oak survival was over 75 percent after three years storage at 3 "C. Presprouting occurred in all species. Additional investigations have begun on white oak *(Quercus alba* L.), swamp chestnut oak *(Quercus michauxii* L.), and red buckeye *(Aesculus pavia* L.). Differences are known to exist in the degree of recalcitrance in seeds, and these studies will determine if some recalcitrant seeds are more amenable to storage than others.

INTRODUCTION

Low temperature storage of hardwood tree seeds has been studied for the last 30 years. During this period, it has been determined that seeds can be divided into at least two storage classes — orthodox and recalcitrant (Roberts 1973). Orthodox seeds can be dried to a moisture content (MC) less than 12 percent and stored for long periods of time at low or sub-freezing temperatures; recalcitrant seeds are sensitive to moisture loss, making storage for any useful period extremely difficult. Some north American genera containing species with recalcitrant seeds are *Castanea* (Pritchard and Manger 1990) and some *Acer*, *Aesculus,* and *Quercus* (Bonner 1990).

The physiological basis of recalcitrant behavior is not fully understood. Several hypotheses have been proposed suggesting that seed deterioration during storage may be due to (1) deleterious changes in lipid composition (Flood and Sinclair 1981, Pierce and Abdel Samad 1980), (2) physical disruption of the seed membranes (Seewaldt and others 1981, Simon 1974), or (3) an increasingly aberrant metabolism during hydrated storage (Pammenter and others 1994) and as water is lost (Berjak and Pammenter 1997).

Acorns of the red oaks and of *Quercus robur* have reportedly been stored at -1 °C or -2 °C for periods up to 5 years in Europe (Suszka and Tylkowski 1980, 1982) . Experiments here have been less successful, suggesting a varying degree of dormancy between European and United States species. We are reporting the results from a 3-year storage study of chinkapin *(Quercus muehlenbergii* Engelm.), water *(Quercus nigra* L.), Shumard *(Quercus shumardii* Buckl.), and northern red oak *(Quercus rubra* L.) acorns: and preliminary results of a storage experiment on species with seeds even more sensitive to desiccation, namely red buckeye *(Aesculus pavia* L.), white oak *(Quercus alba* L.), and swamp chestnut oak *(Quercus michauxii* L.).

PROCEDURES

Shumard, water, and chinkapin oak acorns were collected locally in Oktibbeha and Winston Counties, Mississippi. The northern red oak acorns were from Georgia, the swamp chestnut oak from Texas, and the white oak from North Carolina. All seeds were cleaned by floatation, soaked overnight, and then stored at 3-4 °C until the start of the experiment. Original MC's for each drying regime were determined by drying 4 to 5 samples of acorns at 105 °C for 16 to 17 hours. In preparation for germination tests, acorns were cut in half, and the seed coat peeled from the half containing the embryo. Buckeye seeds were germinated intact. Germinations were conducted on moist Kimpak at an alternating temperature regime of 20 °C for 16 hours in the dark and 30 °C for 8 hours with light. The red oaks received 60 days of moist stratification prior to testing. Since sprouting in storage can be a common problem, counts were made at the start of each germination test of the number of seeds in a sample which had sprouted during storage and stratification. Experiments were conducted as follows:

Experiment I-High and low moisture levels for Shumard, water, chinkapin, and northern red oak acorns were imposed by either soaking in tap water for 16 hours or by drying on a lab bench for 16 hours. Lots of 100 to 150 acorns were stored in 4-mil polyethylene bags either in a refrigerator set at 3 °C or in a modified chest freezer set at -1.5 °C. Temperature in the latter fluctuated from -1 to -3 "C. Original percent germination was determined for all species and was tested again as follows: 1, 2, and 3 years for water and northern red oak: 2 and 3 years for Shumard oak; and 1 and 2 years for chinkapin oak. Seeds were germinated as six replications per sampling period.

Experiment P-This experiment was conducted on tree species with highly recalcitrant seeds. Two separate lots of swamp chestnut oak acorns were received from Texas; the first lot was stored fresh or after drying on the lab bench for 2 days. Buckeye and the second lot of swamp chestnut oak acorns were stored either fresh or after drying for 3 or 6 days on the lab bench: the large size of these seeds and limited amounts received restricted quantity stored to 25 per bag. White oak acorns were stored 50 per bag at the fresh MC only. Seeds were stored at either 4 °C in a Lab-Line Ambi-

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Hi-Low Chamber or at -2 °C in a modified chest freezer. Original percent germination was determined, and all species were tested again at 75 and 90 days. Seeds were germinated as two replications per sampling period. Seeds dried prior to storage were rehydrated overnight in tap water prior to germination testing. Tests at 120 days and 6 months are planned.

RESULTS

Experiment I-High MC's ranged from 33 percent (Shumard) to 46 percent (northern red) and lows from 23 percent (water oak) to 35 percent (northern red); original viability averaged over 90 percent for all species (table 1). Chinkapin oak did not survive for more than 1 year in storage; by this time, sprouting was prevalent, especially in the high temperature treatment (3 "C), and germination had been reduced by at least 30 percent for all treatments (fig. 1). Storage at the low temperature treatment, -1.5 °C, yielded the best results; MC at this temperature did not have a significant effect on storability. Northern red oak also did not store well beyond 1 year. Storage at -1.5 °C kept germination high and sprouting at a minimum (fig. 1); however, unlike chinkapin oak, the acorns stored at -1.5 °C and high MC yielded significantly better germination results than those dried prior to storage. By the second year, however (fig. 2), germination had dropped below 35 percent, even in the best storage treatment (-1.5 "C/high MC); and by year 3, survival in all treatments was minimal (fig. 3). The best 2-year storage treatment for Shumard oak was also -1.5 "C/high MC (fig. 2). However, like chinkapin oak, germination had fallen well over 30 percent from the original value, and by year 3 (fig. 3), viability had dropped to less than 30 percent for all treatments. Water oak was unique in that storage at -1.5 °C was not superior to that at 3 °C; and, unlike any of the other species, one treatment, 3 "C/high MC, had excellent survival after 3 years (figs. l-3).

Experiment 2—MC's of fresh seeds vs. those dried for 2 to 6 days varied by as little as 4.5 percent or as much as 17.5 percent within a species (table 2); original viability of treated seeds averaged 80 percent or more. *Quercus michauxii* acorns did not store well at 4 °C, but, through 90 days have survived at rates above 50 percent when stored at -2 °C (fig. 4). In contrast, red buckeye seeds (fresh and day 3 treatments) had excellent survival at both 4 °C and -2 °C (fig. 5); seeds dried for 6 days, however, had low viability. Sprouting in both these species is negligible. White oak acorns stored at -2 °C lost over 60 percent viability after 90 days, and sprouting averaged 6.3 percent. Those stored at 4 °C have a survival rate considerably higher, 68.2 percent after 90 days; but sprouting at this temperature has been extremely high, averaging 33 percent after 75 days and 73 percent after 90 days, thus negating any storage advantage offered by this treatment.

Table I-Original average moisture contents and germination of acorns at the start of storage experiment 1

Species	Moisture content High	Moisture content Low	Initial germination
	Percent		
Northern red oak	*45.5*	*35.0*	*99.0*
Chinkapin oak	39.7	*30.7*	*91.3*
Shumard oak	*32.8*	*25.0*	*99.4*
Water oak	29.1	*23.2*	*96.3*

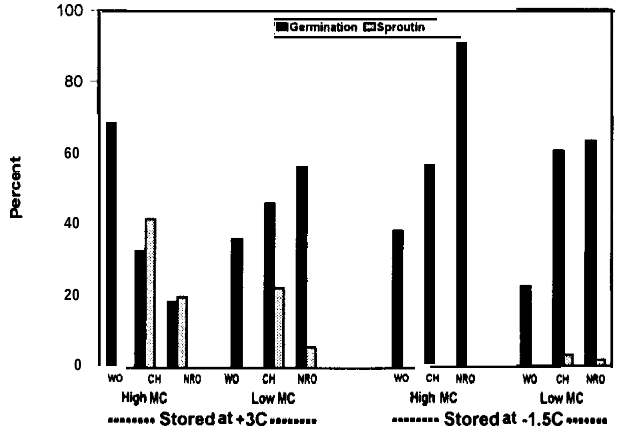

Figure l-Germination and sprouting percentages of high and low moisture content water oak (WO), chinkapin oak (CH), and northern red oak (NRO) acorns stored for 1 year at 3 °C and -1.5 "C. Moisture contents are presented in table 1.

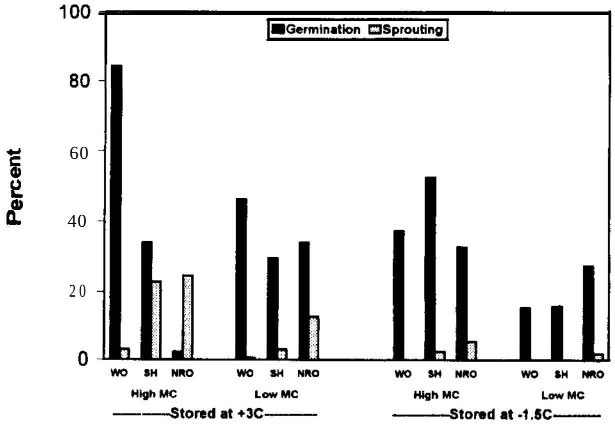

Figure 2-Germination and sprouting percentages of high moisture and low moisture content water oak (WO), Shumard oak (SH), and northern red oak (NRO) acorns stored for 2 years at 3°C and -1.5 °C. Moisture contents are presented in table 1.

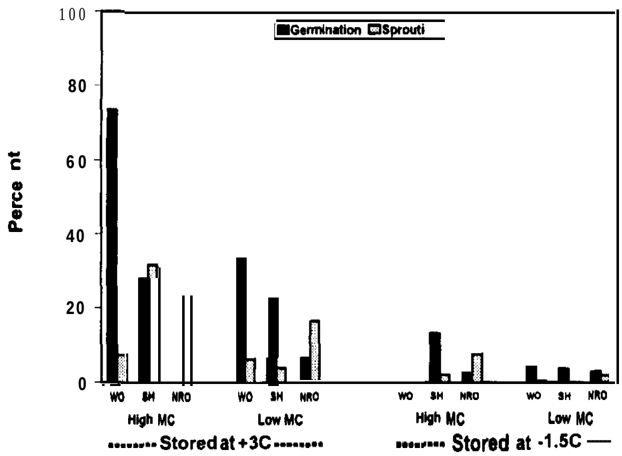

Figure 3-Germination and sprouting percentages of high moisture and low moisture content water oak (WO), Shumard oak (SH), and northern red oak (NRO) acorns stored for 3 years at 3 °C and -1.5 °C. Moisture contents are presented in table 1.

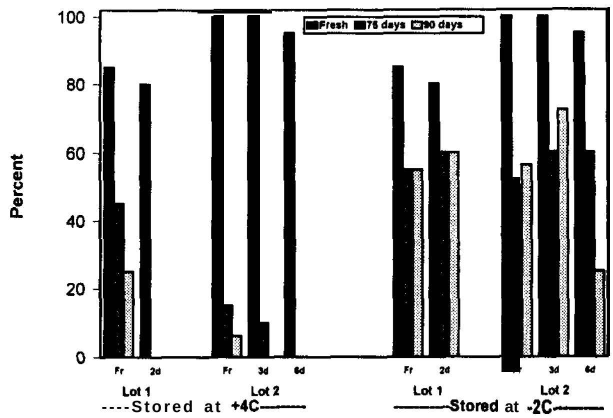

Figure 4-Germination of two lots of swamp chestnut oak stored at 4 °C and -2 °C for 0 (fresh), 75, and 90 days. The acorns were stored at fresh (Fr) moisture content or after drying for 2 days (2d), 3 days (3d), or 6 days (6d). Moisture contents are presented in table 2.

Table 2—Original average moisture contents and germination of acorns at the start of storage experiment 2

Species	Days drying	Initial germination	Initial moisture content
		----- *Percent* ------	
White oak	0	82.0	45.1
Red buckeye	0	82.5	62.6
	3	90.0	54.4
	6	80.0	44.0
Swamp chestnut 1	0	85.0	51.1
	2	80.0	46.6
Swamp chestnut 2	0	100	48.1
	3	100	45.9
	6	95.0	42.6

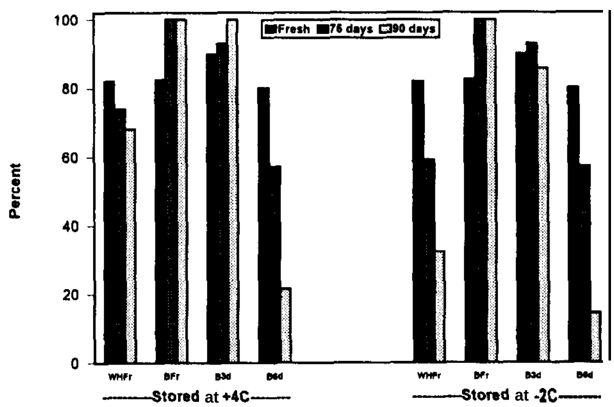

Figure 5-Germination of white oak (WHFr) and red buckeye stored at 4 °C and -2 °C for 0 (fresh), 75, and 90 days. Buckeye seeds were stored at fresh (Bfr) moisture content or after drying for periods of 3 days (B3d) or 6 days (B6d). Moisture contents are presented in table 2.

DISCUSSION

No one temperature/MC combination was best for storage of all oak species, In experiment 1, chinkapin acorn viability was highest and sprouting lowest when stored at the combination of -1.5 °C/low MC. The low storage temperature was also best for acorns of northern red oak and for 2-year storage of Shumard oak. However, unlike chinkapin, the acorns of these species stored at high MC had a higher rate of survival than those dried prior to storage; and after 3 years of storage, Shumard acorns stored at 3 °C had a higher rate of survival than those stored at -1.5 "C. Viability for all three species dropped significantly from the original viability count after only 1 to 2 years in storage. Water oak, unlike the other three oaks, retained a high viability after 3 years of storage and stored best at the 3 "C/high MC combination. This supports the idea that the most dormant red oaks store best. It should be noted that water oak had less sprouting than the other species (figs. l-3). Sprouting apparently does little harm over a short storage period, such as 1 year, but over longer periods it may hasten seed deterioration. Emerging radicles permit greater gas exchange between the embryo and the storage atmosphere, and the faster metabolism may be harmful. Primary roots from early sprouters soon die if storage is prolonged, and this dead tissue may promote the growth of damaging microorganisms.

The highly recalcitrant oak species in experiment 2 also differ in their storage preferences; to date, swamp chestnut oak acorns have good viability when stored at the -2 "C/high MC treatment: but white oak exhibited reduced viability when stored at -2 °C and, while viability is greater for white oak acorns kept at 4 °C, they sprout prolifically at this storage temperature. This species specificity for storage treatment further complicates the problem of extending storage of the recalcitrant-seeded oaks.

Red buckeye, unlike the oak species, has retained its viability at both 4 °C and -2 °C and at both the high and 3-day-drying MC. The drying regime can be harmful, though, as evidenced by the poor germination of the seeds dried for 6 days. Interestingly, these 6-day seeds have not rotted or shown other signs of deterioration; when cut open after the test, they are counted as 'good but ungerminated', suggesting that the drying regime may have an adverse effect on embryo hydration and elongation.

In summary, the storage of acorns beyond 3 years is not advised at this time; as is evident, some oaks do not store well beyond 1 year. It is also apparent that the best storage treatment for a species can change with the length of storage and that the best storage treatment is species specific. Other genera will be added to the experiment in the future, and the biochemistry and moisture dynamics of extended storage will be examined.

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EFFECTS OF THE FOREST FLOOR AND ACORN PLACEMENT ON ESTABLISHMENT AND EARLY DEVELOPMENT OF WATER OAK SEEDLINGS'

Yanfei Guo, Michael G. Shelton, and B.R. Lockhart[2]

Abstract-Effects of the forest floor (0, 10, 20, 30, 40, and 50 Mglha) and acorn placement (buried 1.5 cm below the soil surface, pressed into the soil surface, and placed within the forest floor) on establishment and early development of water oak (Quercus *nigra* L.) seedlings were tested in a 6 x 3 factorial study in southeastern Arkansas. Increasing forest floor weight increased the number of seedlings established, but placing acorns within the forest floor drastically reduced establishment. Increasing forest floor weight significantly increased seedling height and root-collar diameter. When a forest floor was present, seedlings were much larger than those without a forest floor. Seedling developmental stage was also influenced by forest floor weight and acorn placement. At the termination of the study, seedlings with forest floors of 10 and 20 Mg/ha had more growth flushes than those without a forest floor and those with the heaviest forest floor. Root-collar diameter was significantly related to the dry weight of herbaceous plants and forest floor weight (R^2 = 0.73). Results of the study show that the forest floor affects establishment of water oak seedlings directly by modifying the acorn's micro-environment, and indirectly by suppressing the growth of herbaceous vegetation.

INTRODUCTION

The forest floor consists of shed and dead plant materials in various decomposition stages on the soil surface, and it is a distinctive feature of forest ecosystems. Since it affects the micro-environment of seeds, the forest floor has a pronounced effect on germination and early establishment of many species. The forest floor usually suppresses the establishment of small-seeded species (Koroleff 1954), but the forest floor may favor establishment of large-seeded species, such as the oaks. For example, Barrett (1931) reported that establishment of chestnut oak (Quercus *prinus* L.) seedlings maximized at a litter depth of 2.5 cm. Forest litter also indirectly affects seedling establishment by suppressing competing herbaceous plants (Facelli 1994, Yeiser 1994, Shelton 1995). The influence of the forest floor may be mitigated by animals which bury acorns (Deen and Hodges 1991, Thorn and Tzilkowski 1991). Nyandiga and McPherson (1992) reported greater germination of emory oak (Q. *emoryi* Torr.) and Arizona white oak (Q. *arizonica* Sarg.) acorns buried at a depth of 7.5 cm or deeper than acorns placed on the soil surface and covered with litter. Johnson and Krinard (1985) also reported the best seedling establishment for acorns of Nuttall (Q. *nuttallii* Palmer) and water (Q. *nigra* L.) oaks planted at a depth of 5.0 cm in a Sharkey clay soil. However, burying acorns in soil does not always produce better germination and establishment. Lockhart and others (1995) found reduced germination of buried white oak (Q. *alba* L.) acorns when protected from predation. The mixed results of acorn placement on germination and establishment reveal a complex interaction of various environmental conditions, including predation from animals.

Water oak is a widespread and commercially important species that occurs on a wide range of soils (Vozzo 1990). Some evidence indicates that establishment of water oak is not as dependent on advanced reproduction as other oak species (Loewenstein and Golden 1995). Because of this, acorn germination and early seedling establishment may be important to the regeneration of water oak, which has relatively small acorns. Since the establishment of small-seeded species can be negatively affected by the forest floor, we designed a study to evaluate the effects of forest floor weight and acorn placement on establishment, early growth, and development of water oak seedlings in southeastern Arkansas.

METHODS

The study was conducted in the University Forest (91" 50' W and 33" 37' N) of the School of Forest Resources, University of Arkansas at Monticello in Drew County, Arkansas. The study site is in the West Gulf Coastal Plain, and the soil is a Sacul loam (clayey, mixed, thermic, Aquic Hapludults). The native vegetation of the site was mixed pines and hardwood. Annual precipitation averages 1337 mm with most occurring in the winter and early spring.

The study used a 6 x 3 factorial split-plot design with a completely randomized block layout. Forest floor was the whole unit, while acorn placement was the subunit. The six forest floor weights were: 0, 10, 20, 30, 40, and 50 Mg/ha. The three acorn placements were: (1) buried 1.5 cm below the soil surface and the designated forest floor added, (2) pressed into the soil surface to the acorns horizontal centerline and covered with the designated forest floor, and (3) placed on the fermentation layer of the forest floor and covered by litter layer. The fermentation layer was material that had undergone decomposition, while the litter layer was freshly deposited material. When there was no forest floor, acorn placement within the forest floor was not possible; the study was, therefore, incomplete. Four blocks were used, yielding a total of 24 main plots and 68 subplots. A main plot occupied 0.22 m^2, and a subplot 0.073 m^2 with dimensions of 26 x 28 cm. Forest floor materials were collected from a 75-year-old mixed, upland-oak stand by litter and fermentation layers to facilitate reconstruction. The forest floor in the stand averaged 12 Mg/ha with 31 percent in the

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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litter layer. Bulk materials were oven-dried at 50 °C. During bulk drying, a number of 100-g samples were collected and oven-dried at 105 °C to determine the residual moisture content of the bulk material, and adjustments were made during installation for corresponding treatment level weight.

The study was installed on January 12, 1994. The forest floor was reconstructed within wooden frames, establishing the same ratio of the litter and fermentation layers as observed in the stand where forest floor materials were collected. Water oak acorns were collected in Drew County, AR in November 1993 and float-tested before storing in a refrigerator at 4 °C until used in the present study. Six acorns were planted in each subplot. A removable screen covered each frame to keep out acorn predators.

Seedling ontogeny was evaluated weekly from May 21 to September 21, 1994 following the procedure of Hanson and others (1986). Developmental stages of seedlings were defined, and numerical values assigned to each stage for analysis purpose. At the termination of the study, height and root-collar diameter were measured. All aboveground herbaceous plants in each main plot were harvested and oven-dried at 105" C for 24 hours before weighing.

Height, root-collar diameter, and seedling development were analyzed by General Linear Models (GLM) of SAS (SAS Institute Inc. 1990). Means were separated by the Ryan-Einot-Gabriel-Welsch multiple range test at p = 0.05. When factors interacted significantly, a variable was created for each forest floor-acorn placement combination, and then these means were separated as if they were a one-way classification (Littell and others 1991). Because of the very low establishment of seedlings for acorn placement within the forest floor, that treatment was not included in the statistical analyses of seedling height, diameter, and developmental stage. Regression was also used to determine the effect of herbaceous plant dry weight and forest floor weight on seedling height and diameter.

RESULTS

The forest floor did not significantly affect the establishment of water oak seedlings (p = 0.53), while acorn placement strongly affected seedling establishment (p = 0.0001). In addition, the forest floor significantly interacted with acorn placement (p = 0.01). Forest floor placement resulted in the lowest seedling establishment of all placement treatments, averaging only 12 percent. In contrast, the average establishment was 85 percent for the soil surface-placement and 81 percent for the buried placement (fig. 1). The significant interaction between forest floor and acorn placement was due to the increased seedling establishment with the increasing forest floor weight for the forest-floor placement. When a forest floor of 50 Mg/ha was present, establishment was 37 percent compared to 0 percent with a forest floor of 10 Mg/ha. For acorns pressed into the soil surface, the lowest establishment occurred when no forest floor was present, but increasing the forest-floor weight from 0 to 50 Mg/ha had no substantial effect on establishment. Buried acorns also had the lowest establishment when no forest floor was present. Establishment of buried acorns peaked at 96 percent for a forest floor of 10 Mg/ha, although no statistical difference was detected among the forest-floor treatments.

Seedling height and root-collar diameter (fig. 2) were significantly affected by forest floor (p = 0.004 and 0.001, respectively), but acorn placement did not significantly affect either height or diameter (p = 0.15 and 0.11, respectively). The interaction between the forest floor and acorn placement was not significant (p = 0.42 and 0.23, respectively). Mean height and root-collar diameter were lowest when no forest floor was present, and they were greatest for forest floor weights of 10 and 20 Mg/ha (fig. 2).

The forest floor significantly affected the developmental stage of seedlings (p = 0.002) while the effect of acorn placement and the interaction was not significant (p = 0.32 and 0.39, respectively). At the termination of the study, seedlings with a forest floor present were at fourth flush appearing or beyond, while seedlings with no forest floor were at the lag period for the third flush. The most highly developed seedlings were for the 10 and 20 Mg/ha forest floors, where the mean seedling was in the lag period of the fourth flush. However, increasing forest floor weight above 20 Mg/ha retarded seedling development (fig. 3).

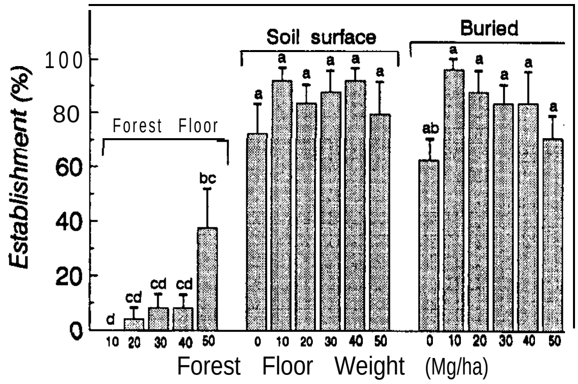

Figure l-Effects of forest floor weights and acorn placement on the establishment of water oak seedlings in southeastern Arkansas. Standard errors are represented by the vertical lines.

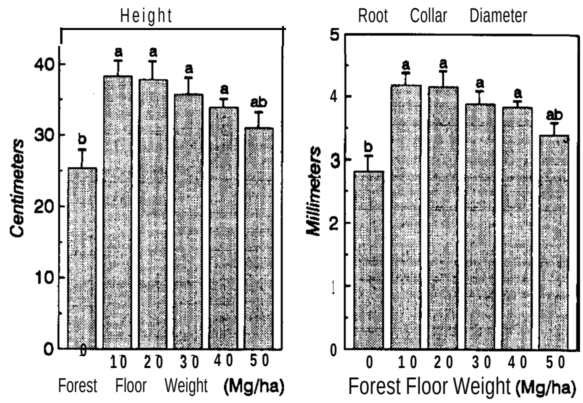

Figure 2-Effects of forest floor weights on the height and root-collar diameter of water oak seedlings at the termination of the study. Means are for the buried and soil surface placements only-the forest floor placement was not included due to low seedling establishment. Bars with the same letters are not significantly different (p = 0.05) and standard errors are represented by the vertical lines.

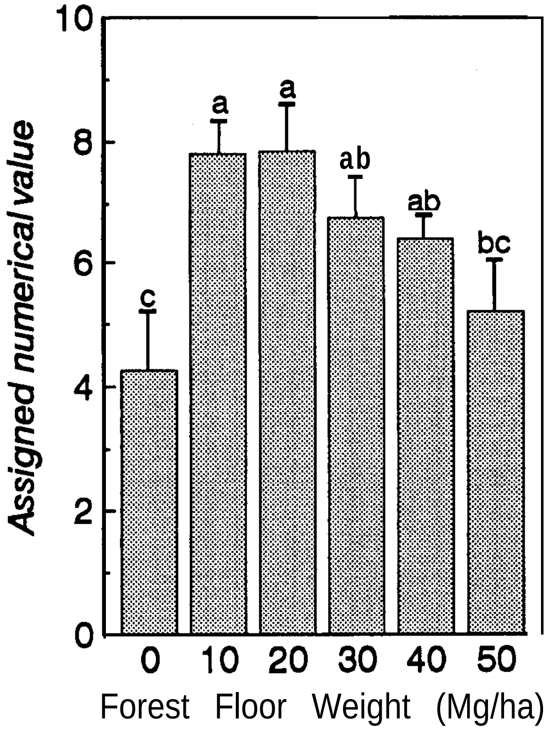

Figure 3-Effects of forest floor weights on the developmental stage of water oak seedlings at the termination of the study. Means are for the buried and soil-surface acorn placements only-the forest-floor placement was not included due to low seedling establishment. Bars with the same letters are not significantly different (p = 0.05). and standard errors are represented by the vertical lines. Assigned numbers represent the following stages: 4 = lag period third flush, 5 = fourth flush appearing, 6 = stem elongation fourth flush, 7 = leaf expansion fourth flush, 8 = lag period fourth flush, and 9 = fifth flush appearing.

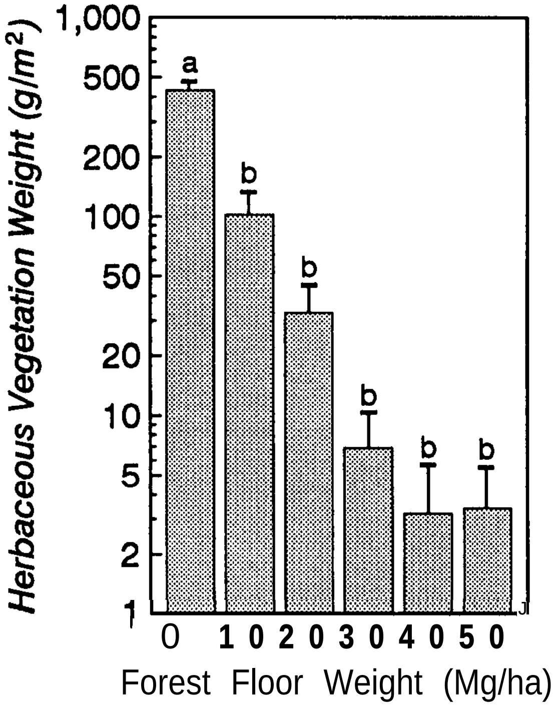

Figure 4-Effects of forest floor weights on the amount of herbaceous vegetation at the termination of the study. Bars with the same letters are not significantly different (p = 0.05), and standard errors are represented by the vertical lines. Note that the scale for herbaceous weight is logarithmic.

Herbaceous plants were strongly suppressed by the forest floor (p = 0.0001). When no forest floor was present, the dry weight of herbaceous vegetation averaged 430 g/m^2. The dry weight was reduced to about 7 g/m^2 for a forest floor of 30 Mg/ha (fig. 4).

Root-collar diameter (D in mm) was exponentially related with forest floor weight (F in Mglha) and the dry weight of herbaceous plants (H in g/m^2) as shown in the following equation:

$$\ln D = 1.60 - 0.00736\ F - 0.00131\ H \qquad (1)$$

This equation had a coefficient of determination (R^2) of 0.73. Both independent variables were significant (p = 0.0002 and 0.0001, respectively). Applying equation (l), the predicted root-collar diameter was 2.8 mm for a 0 Mg/ha forest floor with 430 g/m^2 of herbaceous plants. The predicted diameter increased to 4.0 mm when the forest floor was increased to 10 Mglha and herbaceous plants reduced to 100 g/m^2. Seedling height was not as closely related to forest floor amount and herbaceous plant weight as was root-collar diameter (R^2 = 0.42).

DISCUSSION

A wider range of the forest floor weights was tested in this study than forest floors typically found under field conditions, especially the 40 and 50 Mg/ha treatments. This was done to determine the effects of extreme forest floor conditions on acorn germination and seedling establishment. During forest succession on uplands in the Upper Coastal Plain, Switzer and others (1979) found that forest floor weights maximized at a mean of 21 Mg/ha in 65-year-old pine stands and then declined to 14 Mg/ha as hardwoods became dominant. These average forest floors were close to the 10 to 20 Mglha treatments of our study. Switzer and others (1979) also noted that considerable forest floor variation may occur due to local variation in topography, drainage, and site features that tend to accumulate litter.

Results of this study indicate that it is very important for acorns to be in contact with mineral soil for high rates of seedling establishment for water oak. Pressing water oak acorns into the soil surface or burying acorns increased seedling establishment, height, root-collar diameter, and developmental stage. A forest floor of 10 or 20 Mg/ha also improved the establishment, growth, and development of seedlings. For the buried and soil-surface placements, seedling establishment increased from 67 percent without a forest floor to 94 percent with a forest floor of 10 Mg/ha. The forest floor apparently improved the moisture relatiohships for acorns buried in the soil or on the soil surface. The research site for this study was a small forest opening, and exposure to full sunlight was extensive. Soil moisture may have been limiting during the germination of acorns and the subsequent growth of seedlings. In studying the effects of soil surface topography and litter cover on musk thistle (Carduus *nutans* L.), Hamrick and Lee (1987) indicated that optimum germination, survival, and growth occurred in treatments that reduced evaporation. Johnson and Krinard (1985) also pointed out that better germination and establishment of Nuttall oak was partially due to improved soil moisture for buried acorns.

Acorn placement within the forest floor drastically reduced seedling establishment, which averaged only 12 percent. However, seedling establishment for acorns placed within the forest floor tended to increase for the heavier weights. Establishment was 37 percent for a forest floor of 50 Mg/ha. Water oak acorns or their radicles apparently have a low ability to absorb moisture from forest floor material. Acorns either died due to desiccation while dormant, or the radicles died while attempting to penetrate the fermentation layer and reach the soil. The heavier forest floors apparently provided protection to moderate desiccation and increased seedling establishment.

The acorn size and germination characteristics may affect the establishment of seedlings from acorns placed within the forest floor. Within a species, acorn size has been found to be positively related to the establishment and growth of seedlings for blue oak (Q. *douglasii* Hook. & Am.) by Tecklin and McCreary (1991), and for blue oak, valley oak (Q. *lobata* Nee), and coast live oak (Q. *agrifolia* Nee) by Matsuda and McBride (1986). Lockhart and others (1995) found that white oak acorns, placed within similar forest floors as those of this study, germinated and established equally well as the acorns in contact with the soil surface. Burying white oak acorns, however, reduced germination. White oak acorns are very large and germinate soon after falling to the ground (Rogers 1990). The large acorns may provide more energy to support radicle growth into the soil. In addition, radicles reaching the soil may prevent the desiccation of white oak acorns during the winter. We have also noted that the radicles of white oak are very robust when compared to the radicles of water oak, which may have difficulty penetrating the physical barrier presented by the forest floor.

The forest floor strongly affected the establishment and growth of herbaceous vegetation in the study area. Increasing forest-floor weight from 0 to 30 Mg/ha reduced the amount of herbaceous vegetation by over 60 fold. Clearly, this herbaceous vegetation competed with water oak seedlings for moisture, resulting in smaller seedlings when no forest floor was present. A similar improvement in the growth of planted and natural loblolly pine (*Pinus taeda* L.) seedlings has also been attributed to the suppression of competing herbaceous vegetation by the forest floor (Yeiser 1994, Shelton 1995). In contrast to this beneficial effect, forest floors over 20 Mg/ha reduced the height, root-collar diameter, and developmental stage of seedlings in the present study. Although the causal mechanism is not clear from our results, a heavy forest floor may reduce growth by adversely affecting aeration or temperature within the acorn's micro-environment. For example, the insulating effect of the forest floor may have slowed soil warming during the spring, thereby retarding acorn germination. Under field conditions, the forest floor may also indirectly benefit oak establishment by protecting acorns from predation. For example, Myster and Pichett (1993) reported that forest litter reduced seed predation by animals for six tree species, including northern red oak (Q. *rubra* L.).

Results of this study allow us to make the following conclusions. First, water oak acorns need to be in contact with mineral soil for high rates of seedling establishment. Acorns that were pressed into the soil surface to their centerline yielded very similar results to acorns that were buried at a depth of 1.5 cm. Acorns that were placed within the forest floor had low seedling establishment, apparently due to desiccation during dormancy or germination. Second, forest- floor weights over 20 Mg/ha suppressed the growth and development of water oak seedlings developing from acorns in contact with the mineral soil, possibly by adversely affecting aeration or temperature. Third, the forest floor strongly suppressed the amount of herbaceous vegetation, thereby reducing competition levels for water oak seedlings. Fourth, optimum establishment, growth, and development of water oak seedlings occurred at moderate forest floor weights (10 to 20 Mg/ha), which are close to the average conditions found in hardwood stands in the southeastern United States.

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ARTIFICIAL REGENERATION OF MULTIPLE HARDWOOD SPECIES TO DEVELOP SPECIFIC FOREST COMMUNITIES[1]

Paul P. Kormanik, Taryn L. Kormanik, Shi-Jean S. Sung, Stanley J. Zarnoch, and Charles Possee[2]

Abstract-A five-species mixed hardwood plantation consisting of *Liqudambar styraciflua, Quercus michauxii, Q. pagoda, Fraxinus pennsylvanica,* and *Carya aquatica* has been established at the National Environmental Research Park, New Ellenton. SC. All were grown under uniform conditions with the same nursery fertility protocol. Individual trees for outplanting were chosen from approximately the best 50 percent of the nursery crop for each species based upon a combination of first-order lateral root characteristics, heights, and root collar diameters. All trees were free-to-grow at the end of the fifth growing season. Fiflh year survival runs between 83 and 100 percent. Sweetgum and green ash are the largest with heights of 3.77 and 3.71 m and diameters of 4.53 and 3.08 cm, respectively. Sweetgum stem volume exceeds the others by 2-14 times. All species are represented in the main crown canopy and the high vigor of most trees suggests this mixture can be maintained.

INTRODUCTION

The hardwood forests of the Southern U.S. are not naturally composed of single, predominant species. The diversity of tree species within these stands is one of the qualities that makes them so valuable for multiple use stand management. The characteristic species of the various hardwood forest types dictates the sustainability, stability, and level of appropriate human activity tolerated within each stand.

The emphasis on artificial regeneration in the Southeastern U.S. has been with single-species conifer plantations. Successful wide-scale hardwood plantings have been difficult to achieve. Three primary factors may be responsible for this low rate of success. First, overstory competition is quite deleterious to seedlings because it delays recovery from transplant shock. The degree to which overtopping shade prevents seedlings from thriving is frequently underestimated. Second, seemingly minor soil variations within the planting site may significantly impact hardwood root establishment. Last, until recently, obtaining competitive, high quality hardwood planting stock in the Southern U.S. has been difficult (Williams and Hanks 1994). Standards for growing and grading planting stock were not available. Furthermore, reliable nursery production is also severely impacted by periodicity in hardwood seed production. Mother trees of specific species with desired characteristics cannot be relied upon to produce adequate annual seed crops.

While many of the best hardwood sites have been planted to pines since the 1950's, some proportion of these pine stands now being harvested may need to be reforested to mixed hardwood stands to achieve desired biological diversity and to provide increased flexibility to forest managers. Recently, nursery protocols were reported that permit reliable hardwood seedling production and that define grading criteria for identifying a seedling's future competitive potential (Kormanik and others 1994 a,b).

The objective of this research is to evaluate stand development when five species, produced under a uniform nursery protocol and graded according to specific standards for each species, are outplanted on a common site. The overall goal is to artificially establish a biologically diverse, mixed hardwood stand.

METHODS

Mother trees for five species were selected from an area managed by the USDA Forest Service in the National Environmental Research Park (Savannah River Natural Resource Management and Research Institute, New Ellenton, SC). The species were cherrybark oak (CB, Quercus *pagoda* Raf.), swamp chestnut oak (SC, Q. *michauxii Nutt.),* green ash (GA, *Fraxinus pennsylvanica* Marsh.), sweetgum *(SG, Liquidambar styraciflua* L.), and water hickory (WH, *Carya aquatica* Nutt.). Seeds were collected in the fall of 1992. Depending upon species and availability of seed, anywhere from 12 to 20 mother trees were selected and netted prior to seed fall. The seeds for each species were composited prior to sowing and sent to the Georgia Forestry Commission's Flint River Nursery.

All species were grown according to the nursery soil fertility protocol reported earlier (Kormanik and others 1994b). The soil was first fumigated with methyl bromide, then amended to the fertility levels desired for hardwood seedling production. At this location, based upon a standard double acid soil extraction, the levels of Ca, K, P, Mg, Cu, Zn, and B were adjusted to 500, 80, 80, 50, 2, 6, and 1.2 PPM, respectively. A total of 1322 kg per ha of ammonium nitrate was applied during the growing season. The first two application rates were 17 kg per ha, the third was 56 kg per ha, the next six were 168 kg per ha and the final two were 112 kg per ha. These nitrogen topdressings were applied uniformly throughout the nursery beds, regardless of species. The first nitrogen applications began in mid-May and continued every 10 to 14 days until mid-September.

The target bed density for all the species was 54 to 57 seedlings per m^2. The beds were sown continuously with a single species until all seeds were sown. A gap of 2 to 4 m was created between seeds of differing tree species sown.

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The seedlings were irrigated intermittently during the entire growing season to supplement shortfalls in rain.

In early February 1994, all seedlings were undercut to provide a 25- to 30-cm long tap root. Prior to lifting, samples of seedlings from each species were obtained to identify ranges in seedling heights, stem caliper, and number of first-order-lateral roots (FOLR). From these data, visual criteria were developed to select the best 50 percent of the crop for each species for outplanting.

The planting site was a 2.5ha area within a sweetgum fiber plantation study site. The entire study area was previously in pine and had been recently harvested and cleared of logging debris. Planting rows were laid out in a general north-south direction. Two hundred seedlings from each of the five species were randomly assigned planting locations at a 3.3 m x 3.3 m spacing. Because variations in soil profile characteristics were apparently far in excess of what one would assume based upon the soil maps available for that location (National Cooperative Soil Survey 1990), a second soil mapping of the planting site was subsequently completed to clarify observed soil differences.

The plantation was fertilized with diammonium phosphate (395 kg per ha) early in the second growing season. Early in the third (1996) growing season, ammonium nitrate was applied at 395 kg per ha. Competing vegetation including the annual weeds that were stimulated when the fertilizer was disked into the soil was controlled both with herbicides and mechanical means. Growth and survival data were obtained annually in early winter following leaf abscission.

The objective of this study was to determine the feasibility of developing a hardwood stand composed of five species. There was no interest in testing hypotheses related to growth and survival among the individual species. Hence, no formal statistical tests were performed.

RESULTS AND DISCUSSION

After 5 years, it appears that a sufficient number of competitive seedlings were available for each of the five species to warrant confidence that a desirable association of hardwood species has been established to satisfy any number of management options. Although the plantation is developing satisfactorily, soil conditions may lack the uniformity needed to adequately assess the effect of initial seedling grading. Significant variation in soil properties that impact root penetration precluded direct comparisons of loblolly pine (*Pinus taeda* L.) seedlings graded by FOLR characteristics (Kormanik and others 1998). However, within specific soil conditions, seedlings that had initially higher numbers of FOLR grew significantly better than those with fewer FOLR. A similar situation may be developing in this hardwood stand.

Edaphic Effects

The planting site was a small portion (less than 10 percent) of a larger sweetgum fiber plantation study site which was classified as a Rembert sandy loam in 1993. However, during outplanting it became obvious that the soil was not Rembert but rather a mosaic of several soil series. After the seedlings were outplanted, the soils in this study area were mapped and reclassified to a finer scale more suitable for this research study. Five clearly defined soil series were revealed in this soil complex (fig. 1). The soils were characterized by shallow residual plow layers, presence of

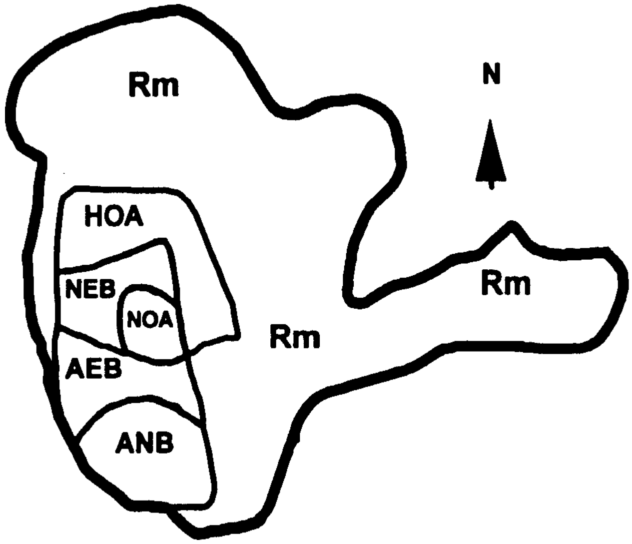

Figure I-Five soil series identified on a 2.5-ha mixed hardwood planting area originally classified as a single soil series on a 25 ha area on the Crackerneck Wildlife Management area at the Savannah River Research Park, New Ellenton, South Carolina. Rembert sandy loam (Rm), Hornsville fine sandy loam (HoA), Neese loamy sand (NoR), Ailey sand (AeB), Albany loamy sand (AnB).

plinthic horizons, (in some cases lying immediately under the shallow plow layer), and heavy mottling, which is indicative of poor drainage. Not all of these characteristics were uniformly present throughout the planting site. Variations in soil characteristics in this area are due to geological history and past agricultural practices. None of the mixed hardwood plantings overlapped into any of the soil classified as Rembert. The variation in soil characteristics had a significant impact on the development of individual seedlings at specific planting locations in spite of planting the best 50 percent of the seedlings from each species. Edaphic factors may impact forest plantations at specific locations far more than we realize.

Mortality

The initial 3 years were characterized by relatively normal rainfall patterns throughout the growing season and no mortality occurred among any of the five species. Severe droughts occurred during the fourth and fifth growing seasons, particularly between June 1 and mid-September. The drought was so severe that scheduled fertilizations were not applied early in the growing season because the soil was too hard to disk.

Survival data was obtained each year. Mortality was observed toward the end of the fourth growing season and occurred sporadically throughout the fifth growing season (table 1). Based upon the occurrence of excessively small, low vigor buds in certain trees of all species at the end of the fifth season, additional mortality of about 10 to 15 percent can be anticipated, especially if a severe drought occurs in the sixth growing season. Excluding those trees with low vigor buds, most other individuals of all species appear thrifty enough to withstand a moderate to severe drought during the sixth growing season. Soil horizons which restrict root penetration (i.e., plow pans, plinthic horizons, etc.)

Table l-Heights, stem caliper, survival, and mean stem volume of five hardwood species in mixed species plantation in Crackerneck Wildlife Management Area at the Savannah River Research Park, Aiken SC

	1993		1996		1997		1998			
	Nursery		Third		Fourth		Fifth		Vol	
Species	Height	RCD	Height	D.b.h.	Height	D.b.h.	Height	D.b.h.	D^2H	Survival
	m	*cm*	*m*	*cm*	*m*	*cm*	*m*	*cm*	*cm^3*	*Percent*
Cherrybark oak	0.61	0.70	0.94	0.10	1.68	0.69	2.28	1.67	1341	84
Green ash	.93	1.43	1.95	1.16	3.07	2.00	3.71	3.08	4182	100
Swamp chestnut oak	.92	1.31	1.32	.36	2.02	1.17	2.59	2.44	2089	92
Sweetgum	1.18	1.21	1.85	1.22	3.08	2.90	3.77	4.53	9411	83
Water hickory	.61	1.20	1.08	.13	1.81	.79	2.19	1.35	649	95

seem to be associated with mortality, especially when these formations are close to the soil surface. Adequate survival is expected for all species and it is anticipated that this five-species association will thrive in the future.

Growth

Initial stem caliper and heights of the species at the nursery varied somewhat. Water hickory and CB were the shortest and CB had the smallest stem caliper (table 1). The relative rankings in height and diameters were comparable through the fifth growing season, and the wide variability among individual trees of all species can be attributed in part to edaphic conditions.

The impact of two consecutive drought seasons is depicted in fig. 2, where mean stem measurements are shown along with the largest and smallest individuals representative of each species. The ranking of species is relatively consistent regardless of whether mean height and diameter are compared or the largest or smallest individuals are compared. All species have individuals represented in the main crown canopy providing further evidence that a mixture of hardwood species can be maintained.

Sweetgum-Although **sweetgum** had the poorest survival rate (83 percent), it had by far the best average stem volume (table 1). At the end of the fifth growing season, it had more than twice the average stem volume of the other species (table 1). Visually, sweetgum appears to be the most vigorous of the five species and individual saplings have produced seed during both the fourth and fifth growing seasons. When found in adjacent positions in or between rows, the crowns of the sweetgum are frequently in contact and, to some degree, capable of shading competing understory plants. The larger dominant individual sweetgum is more uniformly present throughout the plantation. This may be indicative of broad site adaptability characteristic of this species. No deer *(Odocoileus virginianus)* browse has been observed on any sweetgum.

Green ash-No mortality was observed with GA. Overall, this tree species had the most uniform height and stem diameters of the five species even though it had been browsed heavily by deer during the initial two years (fig. 2). Green ash ranked second in average stem volume (table l), but many trees became chlorotic and suffered premature

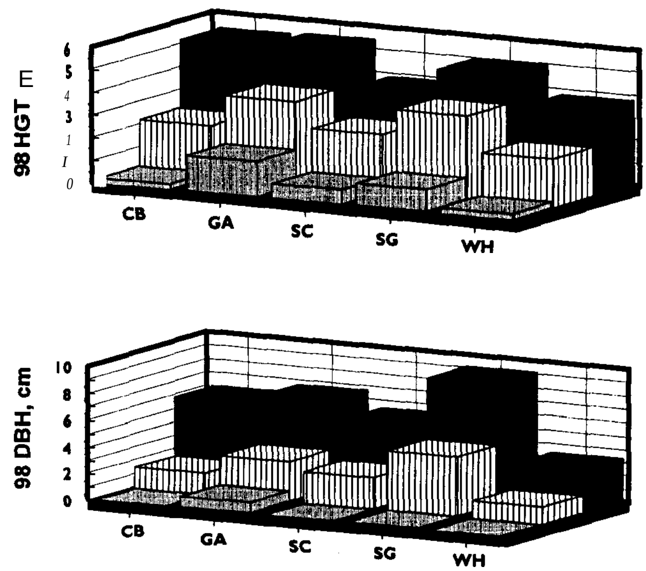

Figure P-Mean stem heights and diameters (vertical striped) along with the largest (black) and smallest (grey) individuals for each species after 5 years in a mixed species planting. Cherrybark oak (CB), green ash (GA), swamp chestnut oak (SC), sweetgum (SG), and water hickory (WH).

defoliation as a result of the severe fifth-year drought. This chlorosis was evident on branch tips of the current year's growth. Interestingly, six individual GA also produced a limited seed crop in year 5. Adequate numbers of trees exhibited sufficient vigor such that their presence in the mixture appears promising.

Cherrybark oak-Although numerically ranking fourth in both height and stem caliper at the end of the fifth growing season, CB had many of the tallest, as well as the smallest, individuals in the study (fig. 2). The best 10 percent of the CB rivaled the best SG and GA in size and vigor, and their continued presence in a future stand appears to be assured. No significant deer browse has been observed on this species.

Swamp chestnut oak-Swamp chestnut oak is among the most highly prized mast species on southern bottomlands. Even though survival has been outstanding, the soil conditions on this study site are not well suited for optimal development of this species (fig. 2). Swamp chestnut oak ranked third in survival as well as in average stem volume (table 1). Sufficient competitive individual SC are scattered throughout the planting to ensure a viable future presence in the stand. No significant deer browse has been observed on this species.

Water hickory--Water hickory was an unknown variable when this study was initiated. It is well known that nursery production of other hickory species has been unsatisfactory, and no information regarding techniques for growing WH could be found (Williams and Hanks 1994). Fortunately, this species developed better in the nursery than did other hickories and suitable planting stock was obtained. Although average heights after 5 years were comparable to CB, and perhaps SC, fewer WH dominated the canopy at specific planting locations (fig. 2). This was the only species defoliated by the tent caterpillar (*Malacosoma disstria*) in both the fourth and fifth year. The defoliation was very severe during the fifth growing season with well over one-half of the WH affected by mid-September. Currently, a number of competitive WH are present in this study. It is anticipated that this species will be represented as the stand matures. Little has been reported on artificial regeneration of this species (Francis 1990), but the effects of slow early growth and shade intolerance may be overcome by early provision of free growing space.

CONCLUSION

A complex mosaic of soils with plow layers, plinthic horizons, and other impediments to root growth have significantly affected this hardwood plantation. That being stated, the acceptable growth by the majority of individuals from all species suggests that grading and outplanting only the best 50 percent of a specific nursery crop may be quite effective. Although drought for 2 consecutive years resulted in some mortality, it has not materially affected the future development of this five-species association. This hardwood mixture appears to be thriving because adequate growing space and sunlight have been assured. The benefit of controlling competition has, to some degree, been reduced by the extreme variability in soil drainage and impediment layers affecting root development.

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A COMPARISON OF LARGE-SCALE REFORESTATION TECHNIQUES COMMONLY USED ON ABANDONED FIELDS IN THE LOWER MISSISSIPPI ALLUVIAL VALLEY[1]

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Abstract-Reforesting abandoned land in the lower Mississippi alluvial valley has attracted heightened attention. Currently, federal cost share programs, such as the Wetland Reserve Program and the Conservation Reserve Program, are enticing landowners to consider reforesting lands that are marginally productive for agriculture. This study examined four reforestation techniques commonly used in the area. These techniques were applied operationally. following methods used under federal reforestation programs. Four techniques were implemented on 8.1-ha blocks in a completely randomized design with three replications. The entire study site was prepared by disking following soybean harvest in the fall of 1994. The techniques tested were: (1) direct seeding Nuttall oak (*Quercus nuttallii* Palmer) acorns (2) planting 1-O bareroot Nuttall oak seedlings (3) establishing a nurse crop of eastern cottonwood (*Populus deltoides* Marsh.) and then underplanting 1-O bareroot Nuttall oak seedlings (4) control (natural succession). All techniques were implemented by April 1995, except the underplanted oaks, which were planted following two growing seasons for the cottonwood (oak underplanted in March 1997). Results of this study are reported for 3 years of survival and growth of the seed germinants and seedlings, for cottonwood survival and growth, and interplanted oak survival and growth following 1 year. Natural invasion onto the site is also discussed. Comparisons are made among the four reforestation techniques, with ideas for incorporating this information into the administration of federal cost share reforestation programs.

INTRODUCTION

Large-scale reforestation of former agricultural lands in the lower Mississippi alluvial valley (LMAV) continues to attract interest. Lands that were cleared in the 1960's primarily for soybean production are undergoing a use shift again, this time back to trees. The decision by many landowners to reforest these lands has been aided, in part, by the increased availability of reforestation programs, such as the Wetland Reserve Program (WRP). This program provides the landowner with a one-time easement payment, technical expertise, and cost-share to cover part or all of the reforestation costs. Applying the information amassed for large-scale reforestation of hardwoods on former agricultural lands has been challenging. There are perhaps several reasons for this. Technology transfer outlets, such as written reports and other publications, may not be the most suitable methods of disseminating this information. Additionally, the target audience is diverse, and many of the practitioners are unknown.

Research continues on expanding our current reforestation knowledge base from a small to a larger scale. The basic techniques for introducing desirable hardwood species on former agricultural land have been worked out. However, much of the preliminary work has been done on a much smaller scale. Currently, large-scale reforestation is occurring on thousands of ha in the LMAV. Much of this work has been done under the Wetland Reserve Program, and seedling and acorn survival rates have been low. One objective of this study was to test four commonly used reforestation techniques and to monitor both growth and survival so that operational techniques can be adjusted accordingly.

In many reforestation projects in the LMAV, emphasis has been placed on hard-mast producing species such as the oaks. Typical reforestation on recently abandoned fields involves the establishment of one to three overstory species, usually oaks. Sowing of acorns is a conventional method for establishing new stands of oak even though failures often occur. Researchers have indicated that planting 1-O bareroot nursery stock or direct seeding acorns can work well for most bottomland hardwood species planted on a variety of sites in the LMAV (Allen 1990, Baker and Blackmon 1973, Johnson 1983, Johnson and Krinard 1985, Krinard and Kennedy 1987).

This project was designed to test one alternative reforestation technique which combines a faster growing species, cottonwood (*Populus* deltoids Marsh.) and a slower growing species, Nuttall oak (Quercus *nuttallii* Palmer), and to contrast this technique with more traditional approaches of planting bareroot seedlings or direct seeding of acorns of Nuttall oak. The control treatment for this study is to do nothing and allow natural field succession to occur.

Compared to other reforestation techniques, one advantage of using the cottonwood nurse crop may be the creation of a more favorable microclimate for oak growth and survival. Obviously, we cannot test this until later in the study. The early growth of cottonwood allows for the rapid establishment of a forest canopy. The advantage of this canopy is that it may lend itself to accelerating natural succession by attracting birds and small mammals that are vectors for dispersal of heavy seed.

The major disadvantage of pure cottonwood plantations to wildlife may be the paucity of hard mast. Although some may also feel that cultivation works against restoration goals, it has been found that wildlife importance values for all wildlife food plants in several cottonwood plantations studied peaked in the fourth, fifth and sixth growing seasons

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(Wesley and others 1981). The planting scheme under study here will provide for hard mast, and cultivation cessation after establishment will hopefully serve to promote plant establishment that would benefit wildlife and restoration in the later growing seasons.

In addition to providing wildlife habitat, the high survival rates and rapid growth of cottonwood will enable harvest in 10 years, generating income in a relatively short time period. Stanturf and others (1998) conducted a financial analysis for a private landowner of a cottonwood plantation and found that the cottonwood provided a cash flow over the rotation, with a positive internal rate of return. Data collected from the current study will allow for future costs analysis with the additional returns of the oak together with the cottonwood.

OVERVIEW AND METHODS

Four reforestation techniques have been installed on former agricultural land located in Sharkey County, Mississippi. The site is 2.5 km east of the community of Anguilla, approximately 1 km south of State Highway 14, and immediately north of the Delta National Forest. This land was transferred to the USDI Fish & Wildlife Service from the Farmers Home Administration in 1993, and is administered by personnel at the Yazoo National Wildlife Complex.

A recent soil survey of the tract conducted by the Natural Resources Conservation Service(NRCS) indicated that the soil is of the Sharkey series, a heavy clay with shrink-swell properties, described as a very fine, montmorillonitic, nonacid, thermic Vertic Haplaquepts (Personal communication. Floyd Wood. 1995. Soil biologist, NRCS, 100 Capitol St., Jackson, MS 39269). The Sharkey series consists of poorly drained, clayey soils formed in fine textured sediment in slack water areas along the Mississippi River. The shrink-swell nature typical of clays with montmorillinitic mineralogies results in 2-10 cm wide cracks up to 1.5 m deep that form under dry conditions, and close upon wetting. The hydrologic and edaphic conditions of our study site typify most of the abandoned agricultural land available for and undergoing reforestation in this region.

The experimental design follows a randomized complete block design with three replicates located in different portions of the tract. Treatment plots are approximately rectangular in shape and 8.1 ha in size. Treatment plots were established in October 1994 (Blocks II and Ill) and February 1995 (Block I). The assignment of treatments to plots was done using a random numbers table, and is summarized in table 1.

Agricultural production on the study site ended in fall 1994. The entire study site was double disked (including the natural succession treatment) following soybean removal. Acorns were collected in the Delta National Forest, placed in water and non-viable acorns that floated were discarded. Acorns were then stored in ventilated polyethylene bag at 1.7 "C. The Fish & Wildlife Service conducted the planting/sowing using their standard equipment and techniques. In May 1995, acorns were machine sown at 1 .1 m X 3.7 m spacing, with one acorn placed at each planting spot. Oak seedlings (1-O stock) were obtained from Fratesi Nursery, Leland, MS (seed source Delta National Forest). Seedlings were machine planted in March 1995 at 3.7 m X 3.7 m spacing.

Table I-Treatment plot assignment in each block

Treatment plot	Block I[a]	Block II	Block III
1	PLN	SOW	NUR
2	NAT	NAT	SOW
3	NUR	PLN	NAT
4	SOW	NUR	PLN

[a] PLN = Plant bare-root Nuttall oak seedlings (1-O stock), NAT = natural old field succession, NUR = cottonwood/Nuttall oak intercrop, SOW = direct seeded Nuttall oak acorns.

Four cottonwood clones (ST-66, ST-72, ST-76, and S7C-1) were established using plantation establishment procedures practiced by Crown Vantage, Inc. in spring 1995 (table 2). Cottonwood cuttings were hand-planted in pure blocks at 3.7 m X 3.7 m spacing in March 1995. Each cottonwood clone area (2 ha per clone per block) was split, with one-half of the area (1 ha) receiving weed control by disking in 1995 only, and the other half receiving the same weed control in 1995 and 1996.

In March 1997, the underplanted Nuttall oak seedlings were planted underneath the cottonwood, in every other row (3.7 m X 7.4 m spacing). Additional seedlings were also planted in 0.4-ha blocks in the open fields adjacent to each cottonwood plot. Survival, height, and diameter data were collected in 1997, following one growing season.

Four permanent measurement plots were installed in each treatment plot in fall 1995. For the direct seeded and planted treatments, measurement plots were rectangular, approximately 0.2 ha in size. Sample measurement plots for cottonwood clones were also 0.2 ha and placed, by clone, in the 1995 and the 1995-96 disked areas. All cottonwood, planted and direct seeded spots were flagged in each treatment measurement plot. The control areas were sampled by installing 64 circular plots (6.45-m radius). This sample area equals 0.85 of the total ha sampled for each control treatment plot, which is comparable to the total area sampled in the direct seeded and planted measurement plots (0.2 ha X 4 quadrants). Height and diameter data have been collected for all woody stems in all treatments following the third growing season (1997).

Statistical analysis followed a Model I ANOVA. The SAS statistical package (SAS Institute, Inc. 1990) was used for data analysis, incorporating Duncan's New Multiple Range test for mean comparisons. All significant differences are reported at $a \leq 0.05$.

RESULTS

Seedling and Acorn Germinant Plots

The seedling height and diameter growth increased significantly over 3 years (table 3). Seedling survival was 64 percent after 3 years, averaging 489 trees per ha.

Table 2—Schedule of operations for cottonwood/Nuttall treatment

Dates	Activity
October 1994	Two-pass site preparation disking Row establishment and liquid nitrogen applied in trenches @ 112 kg N ha^{-1}
March 1995	Plant cottonwood
March 1995	Spray herbicide in band over dormant cuttings (oxyfuorfen @ 0.26 kg ha" + glyphosate @ 1.4 kg ha")
May 1995	One-pass disking, followed 2 weeks later by second pass at right angle to first
June & July 1995	Basal application of oxyfluorofen @ 0.7 kg ha"
August 1995	One-pass disking, followed 2 weeks later by second pass at right angle to first
Summer 1995	Insect control for cottonwood leaf beetles (carbanyl @ 0.92 kg ha^{-1})
June 1996	Insect control for cottonwood leaf beetles (carbanyl @ 0.92 kg ha^{-1})
June & July 1996	One-pass disking
March 1997	Plant Nuttall oak seedlings at offset position from cottonwood
Winter 2004	Cottonwood pulpwood harvest

Table S-Seedling and acorn germinant height, diameter, and survival comparisons among growing seasons

	Year		
Variable	1997[a]	1996	1995
Seedling height (cm)	73.8a	52.9b	1.3c
Seedling diameter (mm)	10.7a	6.2b	.Ic
Seedling survival (percent)	64.2a	59.6a	62.8a
Germinant height (cm)	27.4a	18.4b	.5c
Germinant diameter (mm)	3.4a	2.5b	.Ic
Germinant survival (percent)	16.0ab	10.6b	17.6a

[a] Different letters within rows indicate significant differences among means: average n = 1135 for seedlings: average n = 530 for germinants.

Acorn germinant survival was 16 percent, which was not significantly different from the 1995 or 1996 survival percentages (table 3). The 1995 acorn germinant survival was greater than that of 1996, and 1996 survival was less than 1997 survival. The most likely explanation for these discrepancies was sampling error. Acorn germinants averaged 225 stems per ha after 3 years. Height and diameter of germinants increased consistently over the three growing seasons.

Control Plots

In 1996, in a total of 0.85 ha sampled in each control plot, seven trees were found in Block 1 (five green ash *Fraxinus pennsylvanica* Marsh., two cedar elms *Ulmus crassifolia* Nutt.), five in Block 2 (four green ash, one cedar elm) and five in Block 3 (one green ash, four cedar elms). More volunteer trees were found in 1997 (table 4). In 1997, the average number of trees per ha was 195, 25 and 20 per block. The high number of swamp dogwoods (*Cornus foemina* Mill.) found in Block 1 heavily weighted this average.

Cottonwood Plots

After three growing seasons, the clones displayed differences in growth, with ST-66 > S7C-1 > ST-75 > ST-72 for both height and diameter (table 5). Height and diameters were greater for those cottonwood clones that received 1 year of weed control compared to those that were disked in 1995 and 1996 (table 6). The results for survival among clones by weed control regime are given in table 7.

Cottonwood-Red Oak: Underplanted and Open-Grown Oaks

Following one field growing season, the underplanted oaks were significantly taller (48.2 cm for underplanted, 43.9 cm for open grown) and had greater average diameters (8.1 mm for underplanted, 7.7 mm for open grown) compared to those grown in the adjacent open fields. Survival for underplanted oaks averaged 57 percent after one growing season, while open-grown oaks had a 43 percent survival rate.

Table 4-Number and species of volunteer trees found on control plots, total of 0.85 ha sampled for each block; Sharkey Research Site, 1997

	Block		
Taxa	I	II	III
Fraxinus Pennsylvania Green ash	11	14	2
Ulmus crassifolia Cedar elm	16	5	5
Cornus stricta Swamp dogwood	125	0	6
Diospyros Virginia Persimmon	7	0	0
Celtis laevigata Sugarberry	8	2	52
Gleditsia triacanthos Honeylocust	0	0	1

Table 5-Height, diameter, and total number of sprout comparisons among cottonwood clones for 1997 data

Clone type	Diameter[a]	Height	Sprouts
	cm	*m*	*Number*
ST-66	10.1a	9.49a	1.2c
S7C-1	9.0b	8.71b	1.3b
ST-75	8.7c	7.85c	1.5a
ST-72	8.1d	7.49d	1.4a

[a] Different letters within columns indicate significant differences among means; average n = 815.

Table 6—Height, diameter, total number of sprouts, and survival comparisons of means between 1 year (1995) and 2 years (199586) of weed control, by clone, following three growing seasons (1997 data)

Variable	Weed control	S7C-1[a]	ST-66	ST-72	ST-75
	Year(s)				
Height(m)	1995	6.9a	7.6a	5.9a	6.6a
	1995-96	5.8b	6.0b	5.5b	5.6b
Diameter (cm)	1995	7.1a	8.1a	6.1a	7.1a
	1995-96	5.8b	6.2b	5.6b	5.8b
Sprouts (no.)	1995	1.7a	1.6a	1.5a	1.7a
	1995-96	1.7a	1.5b	1.5a	1.6b
Survival (percent)	1995	97.6a	96.4b	88.6a	93.2a
	1995-96	94.4a	95.1a	82.2a	92.8a

[a] Different letters within columns, by clone, indicate significant differences between means.

Table 7-l 997 cottonwood clone survival among clones by weed control regime-l year (1995) or 2 years (1995-96) of weed control

Clone	1995 weed control[a]	1995-96 weed control
	Percent	
S7C-1	97.6a	94.4ab
ST-66	96.4ab	95.1a
ST-72	88.6c	82.2b
ST-75	93.2b	92.8ab

[a] Different letters within columns indicate significant differences among means.

DISCUSSION

After three growing seasons, results from these four reforestation techniques are beginning to shed some light on expected reforestation on this site. It is understandable that the cottonwood growth and survival are superior to that of the oaks. Not only is cottonwood the fastest growing tree species in North America, but also the care and attention given to its establishment are displayed in the results. Seedling survival was approximately as expected for a large-scale operation. At an average of 489 trees per ha, seedling establishment would be deemed above adequate under guidelines set by NRCS for federal tree establishment programs, especially WRP. Under WRP, 308 hard mast stems per ha after three growing seasons meets the success criteria. Therefore, the 225 trees per ha for the acorn germinants would fall short of this goal.

Seedling survival, compared to other similarly reforested sites, was average to below average. Allen (1990) evaluated oak plantations established by the USDI Fish & Wildlife Service personnel on refuges in west-central Mississippi. Seven out of ten stands Allen assessed had over 489 trees per ha. Krinard and Kennedy (1987) observed survival rates of hardwood seedlings planted on Sharkey clay soil from 69 to 97 percent after 2 years, and 57 to 98 percent after 4 years. They found that Nuttall oak seedling survival was 85 percent (2 years) and 80 percent (4 years). Wittwer (1991) observed 78 percent survival of planted bottomland oaks after 3 years. Savage and others (1989) reported 370 trees per ha and a 64 percent survival rate for both seedlings and germinants on reforested bottoms in Louisiana.

To date, obtaining adequate stocking of oaks on good to poor sites has been difficult with either natural or artificial regeneration. It has been suggested that the inherent sluggish growth habitat of oak is the principal cause of regeneration failures. This slow growth rate combined with intensive vegetative competition and frequent animal browsing has plagued forest managers in their attempts to regenerate oaks. Based on research trials and our knowledge of direct seeding on public and private lands in recent years, the overall likelihood of regeneration success with oaks in a given year is somewhat less with direct seeding than with planting (Bullard and others 1992).

Before acorns germinate, predation from mammals and birds constitutes the major cause of loss (Harmer 1994a, b; Korstian 1927). A pilot small mammal trapping study (600 trap nights) conducted on a single plot of the direct seeded and the cottonwood treatments in October 1995 indicated that very dense small mammal populations were present on the direct seeded treatment (202 animals captured 216 times) compared to the cottonwood (2 animals captured 2 times). *Sigmodon hispidus* was the most abundant of five species captured (Willis and others 1996). Therefore, rodent predation of acorns may have contributed to the lower survival rates and stocking in the direct seeded treatments, which had extensive weed cover compared to the bare soil conditions in the cottonwood treatments.

The expected survival of operationally direct seeded acorns has been reported at 35 percent (Johnson and Krinard 1985, Kennedy 1993). Theoretically, a large number of acorns should increase the possibility for some acorns to escape predation and germinate. Others have experienced this same problem and have addressed it by simply increasing the number of seeds sown. For example, Willoughby and others (1996) described results and recommendations from several studies designed to establish new woodlots by direct sowing. Their recommendation for acorns was to sown 10,000 per ha, with the aim of establishing 1,000 reasonably even-spaced vigorous trees by year 10. This figure allowed for losses from germination failure, predation, drought, herbicide damage, and weed competition. This planting density was also observed by the authors on State-run forests in Denmark, where the sowing and subsequent germination and growth of oak was so thick that it appeared almost like a shrub row.

The survival and stocking on these reforested sites must be viewed in the context of the landowners' objectives. If having a few widely spaced trees in fields dominated by herbaceous vegetation is the goal, it appears as if the current direct seeding or natural succession methods will work. However, if the objective is to restore these sites back to some level of a functional forested wetland, regardless of the function, more time and effort are needed to implement the techniques. The general knowledge of reforestation on old field sites exists; it now becomes a matter of using that information properly to get the desired results. Perhaps the biggest challenge is not working out the individual aspects of large-scale reforestation but putting all those pieces together in one scheme. We can only continue to match species to sites, use proper seed and seedling handling, strive for good quality planting stock, perform site preparation, and perhaps most importantly, have on-site supervision to help make the pieces fit.

Plantations of fast growing tree species in short rotation cycles are going to play a vital role in meeting the rising demand for woody biomass production. *Populus* has shown promising growth and productivity, can be harvested in short periods, and has combined well, thus far, with the red oak intercropping system. Twedt and Portwood (1997) noted that in addition to production-related benefits, planting early-successional species can (1) promote rapid colonization by migrant birds (2) enhance plant species diversity (3) provide a more rapid financial return to landowners, and (4) enhance the public's perception of reforestation efforts. The ongoing research into physiological response of oaks established beneath cottonwood, as well as the possible changes in the edaphic and microclimate environment under the cottonwoods, will aid in our prognosis of implementing such a system.

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CROP TOLERANCE OF NUTTALL, WATER, AND WILLOW OAKS TO PREEMERGENT APPLICATIONS OF DPX-6447: SECOND YEAR RESULTS[1]

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Abstract-Thousands of acres of agricultural crop lands are being planted with hardwood seedlings each year in the South. On such areas the competition from herbaceous plants and vines is intense and causes significant mortality in first-year plantings. Azafeniden is a herbicide which has potential for controlling a wide spectrum of herbaceous plants with no damage to tree seedlings. A total of ten treatments using three rates of azafeniden were applied over-the-top of recently planted Nuttall, water, and willow oak seedlings alone and in mixtures with sulfometuron methyl and metsulfuron methyl. All applications were replicated three times. Evaluations were completed throughout the first growing season for competition control and crop tolerance by the oaks. Evaluations in the second year were related to seedling survival and continued crop tolerance. Results demonstrated that azafeniden can be used safely as a preemergent application over these species of oaks. Tank mixtures with sulfometuron methyl improved competition control and did not damage seedlings. However, when metsulfuron methyl was added or applied alone, all three species of oak exhibited damage symptoms and suffered increased mortality. Rates of competition control varied among treatments with all applications yielding desirable results. This new herbicide has excellent potential for use in hardwood or pine plantations. Further testing should result in an expanded label for forestry applications.

INTRODUCTION

Oak seedlings are being planted on thousands of acres of abandoned agricultural land each year. Unfortunately, many of these seedlings die from a variety of reasons resulting in a loss of capital expenditure and future production. One of the principal causes of oak seedling mortality in these areas is competition from herbaceous vegetation. Cost-effective control of this herbaceous competition would be a highly desirable addition to management of these areas.

OBJECTIVES

The objectives of these studies were as follows:

(1) To evaluate the crop tolerance of various species of oaks to applications of azafeniden applied alone and in tank mixtures with sulfometuron methyl and metsulfuron methyl.

(2) To evaluate the effectiveness of azafeniden for herbaceous competition control in oak plantations.

MATERIALS AND METHODS

Treatments

A complete list of treatments can be found in Table 1. The same treatments were used in both 1997 and 1998 field trials.

Study Sites

In 1997, plots were established on a site south of Holly Bluff, MS. The area was being managed by the U.S. Corps of Engineers and had been in cotton production until October, 1996. The 1-O bareroot seedlings of Nuttall oak (*Quercus nuttallii*), water oak (Q. *nigra*), and willow oak (Q. *phellos*) had been planted in January, 1997. The soil was a Commerce silt loam with a pH of 5.7.

In 1998, plots were established on a site north of Pheba, MS which had been in soybean production until 1996. The 1-O bareroot seedlings of Nuttall oak and cherrybark oak (Q. *pagoda)* had been planted in January, 1998. The soil was an Urbo silty clay loam with a pH of 5.3.

Applications

All applications were completed in February (both years) while the trees were fully dormant. The treatments were applied in 6-foot wide bands over the top of the planted seedlings with the seedling serving as the center of the spray swath. Total spray volume was 20 gallons per acre (gpa). Applications were completed with a CO_2-powered backpack sprayer and hand-held wand equipped with a TK 2.5 Floodjet nozzle in 1997 and a T-boom using four, 8002 nozzles in 1998. The cotton stalks present on the 1997 site necessitated the use of a single nozzle configuration. Each treatment plot was 200 feet long, and each treatment was replicated three times in a randomized complete block design at both sites.

Evaluations

All plots contained 20 oak seedlings. The trees were evaluated in late April, early June, and early September following treatment application. During each plot evaluation, the treated area received an ocular estimate of percent coverages by grass and sedge, broadleaf forbs, and vines. Of particular interest was the percentage of clear ground (PCG) remaining in the plots at each evaluation time. Each seedling was assessed for any symptoms of phytotoxicity which could be attributed to application of the herbicide including necrosis, epinasty, fasciculation, discoloration, or stunting. The percentage estimate data was subjected to arc syne transformation and analyzed for statistical significance.

RESULTS

Crop Tolerance

Overall, azafeniden has no negative effect on any of the species in this study. It can be applied safely over the top of planted seedlings as a preemergent spray. Azafeniden can also be mixed with sulfometuron methyl (Oust) and applied over all species in this study safely, and combinations with hexazinone (Velpar) did not harm loblolly pine in a related study.

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Table I-List of treatments in azafeniden field trials, 1997-1998

Treatment number	Herbicide	Rate
		Oz *ai/acre*
1	DPX-6447	4
2	DPX-6447	8
3	DPX-6447	16
4	DPX-6447	4
	oust	1.125
5	DPX-6447	8
	oust	1.125
6	DPX-6447	4
	Escort	.3
7	DPX-6447	8
	Escort	.3
8	oust	1.125
9	Escort	.3
10	Untreated check	

However, when metsulfuron methyl was either mixed with azafeniden or applied alone, significant damage resulted on the water, willow, and Nuttall oaks. Foliar phytotoxic symptoms were noted on the cherrybark oak in 1998, but no long-lasting impacts on growth or survival resulted (table 2).

Competition Control

Results from the competition control evaluations are found in Tables 3 and 4. Overall, azafeniden provided control on a broad spectrum of herbaceous competition in both field trials. In 1997 trials, plots remained relatively clear until June with the addition of Oust improving the overall competition control as compared to other treatments. Comparing treatments 1-3, some rate response is evident for azafeniden applications, but increasing from 8 oz/A to 16 oz/A did not increase control proportionately. The Oust alone treatment (No. 8) performed very well also. Overall, the combinations of azafeniden and sulfometuron methyl or the sulfometuron methyl applied alone gave the best results for combined weed control and crop tolerance.

Results for the 1998 trials followed a similar pattern with one notable difference. The plots were invaded by dallisgrass which occupied virtually all open space in the entire operational planting area where the plots were located. The invasion restricted the ability to compare treatments at later evaluation times for percent clear ground.

Table P-Average percent crown damage to Nuttall oak, water oak, willow oak, and cherrybark oak[a] in treatment plots at each evaluation time

Treatment number	April	June	September
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0[b]	0	0
6	-[b]	93	90[c]
7	—	92	92[c]
8	0	10[d]	0
9	—[e]	50'	689
10	0	0	0

[a] Cherrybark oak exhibited phytoxic symptoms in Treatments 6, 7, and 9 but no long-lasting effect on survival resulted as did with the other species.
[b] No damage was noted, but trees in these plots were only beginning foliar emergence (much later than other treatments).
[c] Most stems showing residual damage with 34 percent mortality.
[d] Tip burn on upper leaves only.
[e] No damage noted, but trees had no foliage.
[f] All stems had damage and 50 percent were dead.
[g] All damaged with 68 percent mortality.

Table I-Average percent clear ground in 1997 azafeniden field trials

Treatment number	Evaluation time		
	April	June	September
	---------- Percent ----------		
1	37	47	23
2	50	50	22
3	57	47	27
4	90	57	27
5	95	48	23
6	91	68	28
7	73	50	25
8	93	77	23
9	40	35	30
IO	5	0	0

Table 4-Average percent clear ground in 1998 azafeniden field trials

Treatment number	Evaluation time		
	April	June	September
	Percent		
1	15	5	5
2	21	5	5
3	51	15	5
4	95	20	10
5	93	23	10
6	28	13	5
7	27	10	5
8	93	15	5
9	12	10	5
10	5	0	0

SUMMARY

Based on the observations from two years of field testing, the following points are most notable:

(1) Azafeniden is safe to be applied over the top of the hardwood species in this study.

(2) Azafeniden mixes well with sulfometuron methyl and provides excellent competition control and crop tolerance for these hardwood species.

(3) Applications of metsulfuron methyl are not considered advisable for use on Nuttall, water, or willow oak until further research can be completed.

(4) Azafeniden has excellent potential for use in hardwood management.

SEEDLING SURVIVAL AND NATURAL REGENERATION FOR A BOTTOMLAND HARDWOOD PLANTING ON 'SITES DIFFERING IN SITE PREPARATION'

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Abstract-In January 1998, three tracts in Hardin County, TX, were hand-planted with seven species of 1-O bareroot bottomland hardwood seedlings. The tracts, managed by The Nature Conservancy of Texas, were previously 20-year-old pine plantations. The tracts are located within the floodplain of Village Creek. An objective for this conversion is the restoration of a bottomland hardwood wetland in order to meet Clean Water Act requirements. A pre-harvest plant inventory was conducted for each tract. The tracts were clearcut during the Winter and Spring of 1997. Following harvest. each tract was subjected to a different site preparation technique. One tract was burned. Another tract was treated with herbicide to control Chinese tallow. The third tract was sheared, piled, burned and ripped. Planted seedling survival was greatest (72 percent) on the tract that was sheared, piled, burned and ripped. Hardwood natural regeneration was proportionally higher on the tract prepared by burning only. However, this tract appeared to have a greater potential for hardwood root collar sprouting following harvest of the pine overstory. Chinese tallow was a large portion of all natural woody regeneration on each tract.

INTRODUCTION

This paper presents first-year results of planted seedling survival and natural vegetation regeneration following the conversion of a pine plantation to a bottomland hardwood (BLH) forest. This conversion was implemented as wetland mitigation for pipeline construction as required by the Clean Water Act. For this project, successful mitigation requires establishment of at least 200 desirable seedlings per acre after 2 years. Restoration of structure and species richness to BLH forest is an additional long-term goal. A pre-harvest inventory was conducted to determine if an existing BLH seed source or advanced reproduction was sufficient to reforest the tracts. In the conversion process the three tracts were unexpectedly subjected to different site preparation techniques. Variation in site preparation afforded the opportunity to examine survival and recruitment with regard to site preparation technique. Off-site, existing BLH communities were inventoried to aid selection of species to be planted. Post-planting inventories were conducted to assess natural regeneration and to monitor seedling survival.

METHODS

Site Characteristics

Conversion was.performed on three tracts of 48, 14, and 8 acres in size which lie in the first-bottom of Village Creek on the Roy E. Larson Sandylands Preserve, Hardin County, Texas. Previously commercial loblolly and slash pine plantations, these tracts are now managed by The Nature Conservancy of Texas. The tracts are positioned on flats with sloughs occurring throughout. Soils on site are of the Mollville and Manco soils series. Manco soils are deep, somewhat poorly drained, and moderately permeable. The water table is typically within 2 feet of the surface for 1 to 3 months during the winter. Flooding typically occurs during the winter and spring. Mollville soils are deep, poorly drained, and slowly permeable. Mollville soils are typically ponded during the winter and spring and a perched water table may be present very near the surface for long periods. Observations of sediment deposits on leaves at 6 feet in height suggests all tracts are periodically inundated by floodwaters from Village Creek.

On all tracts, a pre-harvest inventory was conducted during the Summer and Fall, 1996. An objective of this inventory was to determine if portions of the tracts contained desirable BLH trees as a seed source or advanced reproduction that could be incorporated into the converted forest. Vegetation was inventoried using nested plots. Tenth acre plots were used to determine species composition of stems greater than 20 feet in height. Hundredth acre plots were used to determine composition of stems ranging from 3 to 20 feet. Loblolly or slash pine had the greatest pre-harvest basal area on each tract and were trailed by sweetgum, water oak, and other trees (scientific names appear in Appendix 1). Dominant trees, reported as relative density (stems/acre) are presented in Tables 1-3. The midstory on each tract was dominated by American hornbeam, sweetgum, American holly, and other understory species. No significant herbaceous layer existed on any tract prior to harvest.

Site Preparation

Commercial clearcuts were p&formed during Winter and Spring, 1997 on all tracts. Streamside Management Zones (SMZ's) of 50 to 75 feet were left intact, reducing planted acreage to 40 acres, 8 acres, and 3 acres respectively. Site preparation on the 48 acre tract included Shearing, raking, piling, burning, and ripping. An unsuccessful attempt was made to burn logging debris on the 14 acre tract. The 14 acre tract was broadcast sprayed in August 1997 with a tank mix containing 18 ounces Arsenal ™ (imazapyr) to 1 quart of Accord ™ (glyphosphate) per acre to control competition from Chinese tallow. The 8 acre tract was successfully burned and had no other site preparation. In SMZs, attempts were made to control the Chinese tallow trees using Pathway ™ (2,4 D/picloram) and Garlon 4 ™ (triclopyr) by injection and Garlon 4 ™ as an 11 percent basal spray. Post-planting spot control of Chinese tallow seedlings was attempted with Roundup ™ (glyphosphate) or Garlon 4 ™ applied with a backpack sprayer.

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Table l-Dominant pre- and post-harvest woody vegetation48 acre tract

Condition	Species	Relative density
		Percent
Pre-harvest	Loblolly pine	53
	Sweetgum	23.5
	Water oak	12
Post-harvest	Chinese tallow	85
	Sweetgum	8
	Planted seedlings	2.5

Relative density as stems per acre pre-harvest, woody stems per transect post-harvest.

Table 2-Dominant pre- and post-harvest woody vegetation-14 acre tract

Condition	Species	Relative density
		Percent
Pre-harvest	Sweetgum	33.5
	Water oak	27.5
	Chinese tallow	17
	Slash pine	12
Post-harvest	Chinese tallow	80
	Yaupon	6
	Water oak	3.5

Relative density as stems per acre pre-harvest, woody stems per transect post-harvest.

Table 3-Dominant pre- and post-harvest woody vegetation-8 acre tract

Condition	Species	Relative density
		Percent
Pre-harvest	Water oak	44.5
	Slash pine	28.5
	Sweetgum	14.7
Post-harvest	Chinese tallow	41.5
	Sweetgum	17
	Water oak	17

Relative density as stems per acre pre-harvest, woody stems per transect post-harvest.

Planting

Two recently undisturbed BLH sites adjacent to Village Creek were selected as reference stands and inventoried using tenth acre plots. Based on these inventories and regulatory guidance, species selected for planting and the relative amounts planted included: willow oak (21.6 percent), cherrybark oak (19.8 percent), swamp chestnut oak (19.4 percent), common persimmon (13.2 percent), water oak (12.8 percent), green ash (6.6 percent), and bald cypress (6.6 percent). Sweetgum was an important component in the reference stands but was not planted as sufficient seed source existed in stands adjacent to the tracts. Bareroot seedlings (1-O) were obtained from a commercial forest tree nursery and planted by a contract planting crew in January 1998. Seedlings were hand-planted on an 8 X 12 feet spacing (450 trees per acre). Some seedlings, notably persimmon, had larger roots which necessitated pruning to facilitate planting. Site conditions were moist, and temperature was mild. Seedlings were randomly mixed, placed in planting bags and given to the planters. On the ripped site, seedlings were planted adjacent to the rip.

Post-Harvest Inventory

Seedling density and survival were monitored using randomly located tenth acre plots. Fifteen tenth acre plots were established on the 48 acre tract, and two tenth acre plots per tract were established on both the 14 and 8 acre tracts. Initial density was recorded, and survival was recorded once per month, through October 1998. Initial density and final survival appear in Table 4. Pin flags were placed near each seedling to facilitate locating the seedlings. Seedling mortality was noted as lack of above ground green tissue or leaves. Some seedlings died back but later resprouted. Seedling mortality due to herbivory was not apparent.

Woody recruitment was sampled using a point-intercept method. On each tract, four transects were established from the edge to the interior on cardinal directions. Transects were positioned such that they did not overlap, and edge was minimized. Woody vegetation in contact with the transects was counted. Along the same transects, beginning with the edge, and at one chain or one-half chain intervals, 1 meter square sub-plots were established to measure

Table 4—Planted seedling density and first year survival

Tract	Stems/acre Initial	Stems/acre Final	Survival
Acres			*Percent*
48	480	350	72.9
14	360	220	61.1
8	430	170	40.0

Table !&Post-planting percent cover woody and herbaceous vegetation, all tracts

Species	Relative percent cover
Eupatorium	31.1
Openflower rosettegrass	10.8
Chinese tallow	10.2

Percent cover sampled 1 meter square subplots along transects.

species composition and percent area cover of species within the herbaceous layer. Percent bare ground and percent debris were also noted. Two or three 1 meter square sub-plots were measured at each station along the transect. If little variation in species or percent cover was found, only two sub-plots were used. If cover or species composition varied, three sub-plots were used. Both woody and herbaceous vegetation were recorded and identified to the species level when possible. This data appears in Table 5.

RESULTS AND DISCUSSION

In 1998, yearly precipitation was average. Precipitation for March through June was 12.78 inches below average, with only 10.7 inches of rain falling over these four months. Initial planted seedling density and survival differed by tract (table 4). The 48 acre tract had the highest initial density and highest survival. We believe site preparation may be the major factor differentiating tracts. More intensive site preparation on the 48 acre tract may have led to high densities and high survival. Ripping probably contributed to the quality of the planting. Soil around the rip was loosened, easing the effort of planting, lessening j-rooting, and allowing proper hole closure. Low densities on the 14 acre tract might be due to the difficulty of planting in logging debris. Seedling density on the 8 acre tract was good, possibly due to the absence of logging debris. However, seedling survival was low on the 8 acre tract, eventually falling below mitigation goals.

Recruitment of vegetation onto the site was rapid. After 1 year, more than 68 species had been identified within the three tracts. Shannon's diversity index, calculated using means from the 1 meter square sub-plot data, was similar among tracts, and had values ranging from 2.7 to 2.8. More than 50 percent of the post-harvest vegetation was represented by three genera: Eupatorium, openflower rosettegrass, and Chinese tallow (table 5). Most of the vegetation recruitment was herbaceous. Woody recruitment was dominated by water oak, sweetgum, and Chinese tallow. Winged elm, American holly, yaupon, and black gum, while present, represented less than 5 percent of woody recruitment on any tract. Chinese tallow recruitment represented the majority of woody recruitment, and will likely be a component of the mature forest, unless controlled (Bruce, Cameron, and Harcombe 1995).

Chinese tallow was a minor component of each tract prior to harvest. After harvest, Chinese tallow appears to have become the dominant woody plant on all three tracts (tables l-3). We believe this dominance may be due to existing seeds in the seed bed. Ten to fifty percent of Chinese tallow seeds remain viable after one year and viability for up to seven years has been reported (Bruce, Cameron, Harcombe, and Jubinsky 1997). Alternatively, Chinese tallow seeds float, and may have been carried in from off site during flood events (Jubinsky 1994). Chinese tallow may be sensitive to fire; low density of Chinese tallow on the 8 acre tract may be due to the site preparation fire (Robinson 1995). Natural regeneration of sweetgum and water oak, primarily coppice, was occurring on the 8 acre tract. This regeneration likely represents the future forest on the 8 acre. Herbicide injection or basal spray of mature trees seemed an effective method of Chinese tallow control in SMZs. Roundup ™ did not have an appreciable impact on young tallow, while Garlon 4 ™ appeared effective.

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APPENDIX I
Common and Scientific Names

Bald cypress	*Taxodium distichum* L.(Rich.)
Common persimmon	*Diospyros virginiana* L.
Green ash	*Fraxinus pennsylvanica* Marsh.
Cherrybark oak	*Quercus pagoda* Raf.
Swampchestnut oak	*Quercus michauxii* Nutt.
Water oak	*Quercus nigra* L.
Willow oak	*Quercus phellos* L.
Sweetgum	*Liquidambar styraciflua* L.
Chinese tallow	*Sapium sebiferum* (L.) Roxb.
Loblolly pine	*Pinus taeda* L.
Slash pine	*Pinus elliottii* Englem.
Yaupon	*Ilex vomitoria* Ait.
Eupatorium	*Eupatorium serotinum* Mich.
Eupatorium	*Eupatorium capillifolium* (Lam.) Small
Openflower rosettegrass	*Dichanthelium laxiflorum* (L.) Gould
Blackgum	Nyssa *sylvatica* Marsh.
American holly	*Ilex opaca* Aiton
Winged elm	*Ulmus alata* Mich.
American hornbeam	*Carpinus caroliniana* Walt.

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FROST HEAVING OF CONTAINER HARDWOOD SEEDLINGS PLANTED IN AN ABANDONED AGRICULTURAL FIELD IN SHARKEY COUNTY, MISSISSIPPI[1]

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Abstract-The use of container hardwood seedlings is an alternative to bareroot planting stock. In January 1996, 1,485 container seedlings of Nuttall oak (Quercus *nuttallii* Palmer), willow oak (Q. *phellos* L.), overcup oak (Q. *lyrata* Walter), and water oak (Q. *nigra* L.) were planted in Sharkey clay on an abandoned agricultural field situated in the Lower Mississippi River Alluvial Valley. Beginning with the passage of a cold front on January 31, daily minimum temperatures dipped as low as 6 °F. For 5 days, daily high temperatures did not climb above 32 °F. This cold period caused 33.7 percent of all seedlings to frost heave and an overall survival of 0.5 percent. Our observations suggest that container seedlings should not be planted on shrink-swell clay soils until after the threat of hard freezing has passed. Seedling root morphology combined with soil conditions at the time of planting may have contributed to the frost heaving.

INTRODUCTION

Bareroot seedlings have traditionally been used in hardwood reforestation. Bareroot seedlings are often preferred over direct seeding for reforestation because of better growth and higher survival rates on flood-prone sites (Allen 1990). However, bareroot seedlings usually have long, branched root systems that are easily damaged by desiccation and handling. Planting in the Lower Mississippi River Alluvial Valley (LMRAV) requires extra effort on the part of planters to ensure maximum survival of seedlings. Incomplete closure of planting holes may result in soil cracks during summer drought, which may expose and damage the roots of seedlings (Williams and others 1992).

Bottomland hardwood reforestation of abandoned agricultural fields in the LMRAV has not always been successful. Planted seedlings must overcome flooded and saturated soils early in the growing season and drought stress during the summer months. Repeated failures have left many landowners in the LMRAV looking for ways to increase seedling survival and growth rates on these harsh sites. Recently, researchers have turned to container seedlings as an alternative to bareroot planting stock. Container seedlings have been shown to have a greater total root length and better overall water relations than bareroot seedlings (Crunkilton and others 1992). These findings have suggested that container planting stock may offer a seedling better suited for tolerating flood and drought stress.

STUDY AREA

This study was conducted in a flood-control impoundment on Yazoo National Wildlife Refuge. Yazoo National Wildlife Refuge is located approximately 60 mi north of Vicksburg, MS, in the LMRAV. This site is adjacent to Delta National Forest and lies 5 mi east of Anguilla, MS. The site is on the floodplain of the Little Sunflower River, a tributary of the Yazoo River. Sharkey clay (very fine, montmorillonitic, nonacid, thermic, Vertic Haplaquepts) (SCS-USDA 1975) is the soil found on the research area. Seedlings are subjected to backwater flooding when waters from the Yazoo River rise in response to high water in the Mississippi River.

The impoundment is situated on an abandoned agricultural field that was cleared within the last 20 to 30 years. The site is typical of most land becoming available for reforestation. During the summer of 1995, the USDA Fish and Wildlife Service and the Natural Resource Conservation Service constructed the impoundment. Before construction began, the area was disked to simulate conditions in a recently abandoned field. Extreme care was taken to insure the soil in each block was not disturbed while levee construction took place.

PLANTING

Four species of container planting stock were used. Species included Nuttall oak (*Quercus nuttallii* Palmer), water oak (Q. *nigra* L.), overcup oak (*Q. lyrata* Walter), and willow oak (Q. *phellos* L.). The container planting stock was grown in 10-in.[3] plastic containers (Ray Leach "Cone-tainers" Nursery, 1500 N. Maple Street, Canby, Oregon 97103). The containers were filled with a commercial peat-perlite-vermiculite potting medium (Scotts Metro-Mix 366, Scotts-Sierra Horticultural Products Company, 14111 Scottslawn Rd., Marysville OH, 43041).

On January 20, 1996, 1,485 seedlings were planted. The seedlings were planted at 7 ft X 7 ft spacing using planting shovels. After planting, the height of each seedling was measured.

WEATHER DATA

Weather data was obtained from the U.S. Army Corps of Engineers weather station situated on the study site. On January 31, 1996, a series of cold fronts moved through the Southeast breaking many temperature records. Snow, sleet, and freezing precipitation accompanied their passage. Weather like this is seldom seen in the deep South. Temperatures remained below freezing for extended periods of time (fig. 1). The soil surface was frozen and soil temperatures at a depth of 12 in. fell as low as 38 °F.

FROST HEAVING

Two weeks after the freeze, on February 16, 1996, seedlings were checked to ascertain their condition. Observations of the seedlings revealed a large number of them had frost heaved to some degree. The seedlings were classified as (A) no damage, (B) partially frost heaved, or (C) completely frost heaved. Exactly 500 seedlings (33.7 percent) partially frost heaved (table 1). Only nine seedlings completely

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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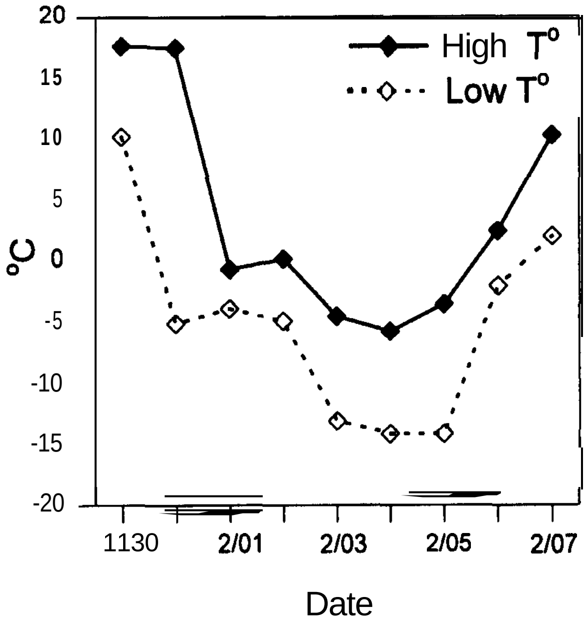

Figure I-Daily high and low temperatures as recorded from January 30 to February 7, 1996, in an abandoned agricultural field located on Yazoo National Wildlife Refuge, Sharkey County, Mississippi.

Table I-Results of survey accessing seedling conditions following a frost heaving event which occurred in a flood control impoundment located on Yazoo National Wildlife Refuge, Sharkey County, Mississippi, beginning on January 31, 1996

Seedling condition	Number of seedlings	Percent
No damage	976	65.7
Partially heaved	500	33.7
Completely heaved	9	.06

frost-heaved. All nine of the seedlings that were frost heaved exposed only the roots and left the potting medium unmoved in the soil. Of the heaved seedlings, the species observed to frost heave the most was water oak with 168 seedlings (33.0 percent). Overcup oak was next with 124 seedlings (24.4 percent), followed by willow oak and Nuttaii oak with 117 seedlings (23.0 percent) and 100 seedlings (19.6 percent), respectively (table 2). Subsequent examinations revealed only seven seedlings (0.5 percent) had survived to bud out the following spring.

DISCUSSION

On the morning the seedlings were planted, the soil was frozen at the surface. The stiff soil did not close properly and probably allowed frost heaving to occur. This problem was only aggravated further when temperatures began to rise and the soil began to thaw. Moist or saturated clay soils are extremely difficult for planting seedlings. Complete closure

Table 2-Frost heaving susceptibility as a result of a frost heaving event which occurred in a flood control impoundment located on Yazoo National Wildlife Refuge, Sharkey County, Mississippi, beginning on January 31, 1996

Species	Number heaved	Percent
Water oak	168	33.0
Overcup oak	124	24.4
Willow oak	117	23.0
Nuttali oak	100	19.6

of planting holes became almost impossible as the clay began to cling to planting shovels and boots. The moisture that made closing holes difficult increased the frost heaving capacity of the soil. Bare compact clay soils are one of the most difficult sites to establish trees in due to frost heaving in the more northern areas (McQuilken 1946). Disking late in the year further aggravated this situation by loosening up the soil. Disking destroyed the soil structure while removing vegetation that is needed to prevent frost heaving on a clay soil. McQuilken (1946) found 47 percent of unmulched trees frost heaved 1 in. or more. Vegetation slows the cooling of the soil and adds stability to its structure. Alternatives to disking should be considered. Mowing or ripping the site would ease planting for workers while leaving needed vegetative cover to prevent frost heaving. Ripping the soil would leave most of the vegetation intact while still breaking up any plowpan that could be present. Burning may even be an option. The fire would remove the vegetation found on the site but would leave the soil structure intact.

Finally, the combination of precipitation and freezing temperatures played an important role in the frost-heaving of seedlings. Research indicates the moisture condition most likely to produce frost-heaving is one where the soil voids are filled with water (Graber 1971). This condition was present on the study site and provided ample moisture for the formation of ice and ice crystals. Other researchers in the same impoundments noted some frost-heaving on bareroot seedlings and even direct-seeded acorns. in the case of the acorns, they had been pushed completely out of their holes by the shrink-swell action freezing had on the soil. The low survival of container seedlings on this site was caused by a combination of frost heaving and freezing temperatures. The seedlings that were heaved had the majority of their roots exposed to desiccating winds. Those seedlings that were not frost heaved were still in a saturated soil that was frozen to a significant depth, if not to a depth greater than that of the containers. This freezing action is what probably contributed the most to the low survival of seedlings.

in conclusion, large planting stock and adequate soil conditions are essential to successful planting. Data suggests soil conditions are important when planting seedlings in the LMRAV. Care should be taken when the soil has been disked. in some cases it may be advantageous to use some other form of site preparation. Planting stock of an adequate size should be used for reforestation on abandoned agricultural fields. Frost heaving will occur even with larger planting stock. However, survival from frost heaving is greater with larger planting stock (McQuilken 1946).

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USE OF IMAZAPYR INJECTION TO PROMOTE OAK REGENERATION AND WILDLIFE STAND IMPROVEMENT IN BOTTOMLAND HARDWOOD STANDS[1]

Andrew W. Ezell, Jonathan Lowery, Bruce Leopold, and Patrick J. Minogue[2]

Abstract-Naturally regenerating desirable species of oaks on high quality bottomland sites is a concern across the South. Earlier research has identified the amount of light as a critical factor in the development of oak seedlings. Undesirable midstory and understory stems were injected with aqueous solutions of imazapyr. Two concentrations (20 and 40 percent) of herbicide mixture were evaluated with all applications completed using one hack per three inches of stem diameter (dbh) and one milliliter of solution per hack in the oak regeneration study. A 25 percent solution was applied in an identical format for the wildlife stand improvement (WSI) study. In the oak regeneration study, oak seedlings were identified, tagged, and measured for use in treatment response evaluation. Overstory crop trees were monitored to evaluate any non-target herbicide impact. Injected stems were evaluated at the end of the first and second growing seasons following treatment application. Oak seedlings were evaluated for survival and growth at the end of the first growing season. Overall control of injected stems was excellent for all solutions. Absolutely no damage to overstory crop trees resulted from the injections. While oak seedling survival was higher in injected areas, flooding during the growing season impacted overall first-year results. No seedling mortality resulted from the injection and future evaluations are expected to demonstrate improved survival and growth. This application method has tremendous potential for management of hardwood stands. In the WSI study, wildlife browse production was evaluated at the end of the first and second growing seasons. Biologically and aesthetically, the procedure was extremely successful.

INTRODUCTION

Oaks are considered to be some of the most valuable species in bottomland forests from both a timber and wildlife perspective. Unfortunately, regenerating desirable species of oaks on these high quality sites has proven difficult in the past and is a strong concern for forest managers.

Lack of light on the forest floor is a detriment to oak regeneration and wildlife browse production. Typically, appreciable amounts of sunlight can penetrate the overstory in bottomland hardwood stands, but the established understory and midstory in these areas intercepts almost all of any available light before it can reach the ground. The purpose of these studies was to (1) evaluate the efficacy of imazapyr injection in controlling undesirable midstory and understory species of hardwoods, (2) evaluate any symptoms of damage to desirable overstory trees or seedlings, and (3) evaluate any change in wildlife habitat resulting from these injections.

MATERIALS AND METHODS

Treatments

Undesirable stems in the understory and midstory were injected with aqueous solutions of imazapyr. In the oak regeneration study, two concentrations (20 and 40 percent) of Chopper EC® were utilized whereas a 25 percent concentration of Arsenal AC was used in the wildlife stand improvement (WSI) study. In both studies, injections were completed on a basis of one hack per three inches of stem diameter (dbh) and one milliliter of solution per hack. In addition, untreated check plots were included in both studies.

Study Areas

In the oak regeneration study, circular plots were established and treated in both John W. Starr Memorial Forest and Noxubee National Wildlife Refuge in Winston, Co., MS. Each plot was one-fifth acre and all treatments were replicated five times on the Starr forest and three times on the Noxubee Refuge. On each study plot, three 1/1000-acre subplots were established to evaluate oak seedlings. Within these subplots on the Starr Forest 20 cherrybark oak seedlings were identified with a metal tag, plastic expansion ring, and pin flag, for the purpose of evaluating seedling survival and/or herbicide damage.

In the WSI study, four-acre treatment blocks were established on the Ward Bayou Wildlife Management Area near Pascagoula, MS. A total of three blocks were injected and one block was left untreated for a comparison.

In the oak regeneration study, the principal species injected were sweetgum, red maple, American hornbeam, winged elm, and shagbark hickory. In the WSI project, principal injection species were deciduous holly, American holly, drummond red maple, and American hornbeam. All injected stems were tagged, flagged, and recorded in order to facilitate subsequent measurements. More than 3,000 stems were injected in the two projects.

Injection was completed during February (dormant season) on the Starr Forest, May (early growing season) on the Noxubee Refuge and September (late growing season) on Ward Bayou. Timing of injection proved to be a critical element.

Evaluations

Desirable overstory stems (both studies) and oak seedlings received ocular evaluations throughout the first growing season following injection. Any symptoms of damage including foliage discoloration, necrosis, epinasty, or fasiculation would have been recorded during these evaluations.

At the end of the growing season injected stems were evaluated for percent crown reduction. This evaluation was

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an ocular estimate with 100 percent = dead tree and 0 percent = unaffected. Increments of 10 percent were utilized in the rating scale. At the same timing, tagged oak seedlings were evaluated for survival and growth.

To evaluate wildlife habitat, line-intercept sampling was completed pre- and post-treatment to evaluate browse production. Species were recorded and subsequently evaluated as to amount and desirability especially as browse producers.

After field evaluations were completed, the data were evaluated using analysis of variance and specific difference tests.

RESULTS

Crop Damage

No crop damage could be detected on any overstory stems or seedlings in either study. This is a notable fact that seedlings were often directly under or at the base of the injected stem. It also demonstrates the lack of any "back-flash" impact with this style of injection.' Hardwood managers are concerned with any potential damage to valuable crop trees, and these projects demonstrate the ability to control thousands of undesirable stems with no negative impact on desirable stems.

Control of Undesirable Stems

After one growing season in the oak regeneration study, a notable difference in percent crown reduction (PCR) could be attributed to the different injection timings. In the dormant season injections, control was excellent for all target species (table 1). The vast majority of stems were dead and crown reduction was essentially the same for red maple, sweetgum, and hickory. Although hornbeam had statistically lower crown reduction, 91 percent PCR was still biologically acceptable for stand management. Examination of the data revealed that PCR was greatly reduced in the 6-9 inch dbh group for hornbeam resulting in the overall lower average. There was no statistical difference between the 20 and 40 percent concentrations (table 1).

Table I-Mean percent crown reduction after one growing season following dormant season injection in the oak regeneration study

Species	20% Choppers	40% Chopper@	Untreated
	Treatment		
	- - - - - - - - - - - Percent - - - - - - - - - - -		
Red maple	98.0a[a] A[b]	99.3a A	11.4a B
Sweetgum	98.4a A	99.3a A	7.0a B
Hickory	98.3a A	98.1a A	8.4a B
Hornbeam	91.0b A	93.0a A	12.2a B
Average	95.3 A	96.9 A	9.8 B

[a] Values in a column followed by the same lower case letter do not vary at p = 05.
[b] Values in a row followed by the same upper case letter do not vary at p = 0.05.

In the early growing season injection plots, PCR was appreciably lower after one growing season (table 2). Generally, the PCR's were at least 20 percent lower as compared to the dormant season injections. The exception was sweetgum. Control varied among species and between treatments, with sweetgum and red maple exhibiting acceptable control from 20 percent solution injection. When 40 percent solutions were applied hornbeam, red maple, and sweetgum had more than 80 percent crown reduction. Examination of the data revealed that only sweetgum was consistently controlled at acceptable levels (≥80 percent) when stem diameters were greater than three inches dbh. Since the target species are essentially the same, the different response can be attributed to time of application.

Table P-Mean percent crown reduction after one growing season following early growing season injection in the oak regeneration study

Species	20% Chopper@	40% Chopper@	Untreated
	Treatment		
	- - - - - - - - - - - Percent - - - - - - - - - - -		
Sweetgum	86.8a[a] A[b]	96.4a B	3.8a C
Red maple	79.9a A	86.4a A	4.3a B
Hornbeam	74.6ab A	89.0a A	2.6a B
Winged elm	61.6bc A	73.1a A	14.0a B
Hickory	50.2c A	67.8a A	5.0a B
Average	70.0 A	83.7 B	5.9 c

[a] Values in a column followed by the same lower case letter do not vary at p = 05.
'Values in a row followed by the same upper case letter do not vary at p = 0.05.

In the WSI study, target stems have been evaluated at the end of both one and two growing seasons following injection. The original research on this injection method revealed that two years could be required for full effect of the treatment to be realized. After one growing season, all target species except American holly exhibited more than 90 percent average crown reduction (table 3). After two growing seasons, all target species were more than 99 percent controlled. On the untreated areas, PCR ranged from 3-7 percent for the target species after two growing seasons. Based on these results, late growing season injections are considered extremely effective.

Wildlife habitat evaluations revealed browse production had been increased more than 300 percent in injected areas. White-tailed deer had begun using the injected areas by the second evaluation timing. In addition, the injection was highly desirable aesthetically, as no heavy equipment disturbed the site and no large debris piles were created. The dead stems deteriorated, fell, and were often taken from the site by winter flooding.

Table 3-Percent crown reduction on target species after late growing season injection with 25 percent Arsenal AC@ (all stems on all treatment areas)

Species	Evaluation time Year 1	Year 2
American hornbeam	95.6a[a]	99.2a
Deciduous holly	97.8a	99.9a
American holly	52.3b	99.1a
Sweetgum	100.0a	100.0a
Drummond red maple	98.3a	99.6a

[a] Values in a column followed by the same letter do not differ at p = 0.05.

SUMMARY

Wide spacing injection using imazapyr is an extremely effective management tool. Late growing season and dormant season injections can both be highly successful, but early growing season (bud break - July) injections should be avoided if difficult-to-control species are present in substantial numbers. Control can still be obtained with early season injections, but efficacy is notably enhanced by applications at the other timings.

No crop damage should result to desirable overstory stems or seedlings if this method is used properly. lmazapyr is soil-active, so care should be exercised when applying this material in desirable stands.

By controlling the undesirable understory and midstory, the availability of sunlight for oak seedlings will be increased and regeneration efforts should be enhanced. This method holds great potential for forest managers in both hardwood and pine stands.

Bottomland Regeneration

Moderator:

JOHN HODGES
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FACTORS AFFECTING SPROUTING SUCCESS IN A BOTTOMLAND MIXED HARDWOODS FOREST [1]

Michael S. Golden[2]

Abstract-A study of reproduction in patch cut areas was established in a mature mixed-hardwoods forest on the floodplain of the Tombigbee River in southwestern Alabama. Five 132 by 264 ft (0.8 acre) patches were harvested in early summer (June) and five in early fall (October). All trees >10 ft tall were mapped before harvest. During the third June (32 or 36 months) after harvest each cut stump was relocated and measurements on sprouting were obtained. Presence of viable sprouts for commercial tree species was related to d.b.h., species, and season of harvest. Only 31 percent of the 1257 cut stumps of commercial species had live sprouts. Sprouting success declined with increasing tree size, but was fairly consistent within three broad dbh classes. Oaks (*Quercus* spp. L.) generally had low sprouting success, partly due to the low numbers of small oaks in the understory, which is a common situation in mature bottomland stands. Cherrybark oak (Q. *pagoda* Raf.) had a higher proportion of stumps with viable sprouts and taller sprouts than the other oaks. The proportion of sprouting stumps was almost twice as high in the fall-cut patches compared to those cut in summer. Sweetgum (*Liquidambar styraciflua* L.) sprouts were significantly taller than other species.

INTRODUCTION

Stump sprouting is usually considered an important source of natural reproduction for hardwood tree species, especially after stands have been clearcut (Beck and Hooper 1986, Johnson 1993, Mann 1984, Martin and Tritton 1991, McQuilkin 1975, Sander and others 1984). Numerous studies have reported on various aspects of sprouting for upland hardwoods (Johnson 1977, Lowell and others 1987, Zahner and Myers 1984). However, published data on sprouting among mixed bottomland stands is less common. The importance of sprouting for bottomland stands has been reported (Krinard and Johnson 1986, Bowling and Kellison 1983), but amounts and influences were not fully addressed. Johnson (1980, Johnson and Deen 1993) used size of trees to be cut as a variable in a predictive model for bottomland oak reproduction, but did not differentiate among species or other factors. This study examined the relationship of stump sprouting success and height growth to season of cut, species, and tree diameter in a bottomland mixed hardwood forest.

METHODS

Study Site

The study area is a stand comprising about 75 acres on the floodplain of the Tombigbee River in Choctaw County, Alabama. Choctaw County is in southwestern Alabama, bounded on the west by the state of Mississippi and on the east by the Tombigbee River. The study site is within the Naheola Reserve tract of Ft. James Corporation. Physiographically, the Reserve is in the Hilly Coastal Plain Province (Hodgkins and others 1979). The site is just south of and downstream from the Black Belt.

The stand was predominately bottomland mixed oak forest, with the dominant canopy mostly 65-75 years old and 1 10-135 ft tall at the time of cutting. It is on a broad floodplain, with the cut areas on low ridges and moderate to well drained flats. Typically, most of the sites are covered by river floodwater for brief periods once or twice during the winter and spring. The flats and sloughs can also fill with water from rainfall, resulting in their having surface water 1-3 inches deep even in late spring. Soils have been mapped as a complex of three soil series: Mooreville, Urbo, and Una. The ridges are predominantly Mooreville soils, which are deep and moderately well drained. Most of the flats have Urbo soils, which are deep and somewhat poorly drained. The Una series occupies some of the lower, wetter flats. Both of these latter two series are formed from clayey alluvium and have very slow permeability. Soils of the Mooreville series predominated in the treatment areas of this study, and the very poorly drained Una soils occupied only scattered small areas.

Study Design

Rectangular clearcut patches of 0.8 acre, 132 by 264 ft, were the basic units of the study. This size falls within acceptable size limits for a group selection regeneration method (Smith and others 1997), since they approximate one tree height wide by two tree heights long. Ten patches, centered among clusters of larger dominants and oriented generally east-west, were delineated. A minimum of 150 ft width of uncut forest was maintained between all patches. Prior to harvest, all trees greater than 10 ft tall in and slightly beyond the marked boundaries of each patch were inventoried and their locations mapped to a grid for relocation. Species and d.b.h. were recorded for each tree.

One purpose of the ongoing study is to test the effects of harvesting at different times of the year. Five patches were randomly selected and harvested in early June ("summer-cut" patches), and the remaining five were harvested in early October ("fall-cut" patches). These were operational commercial harvests conducted by loggers contracted by Linden Lumber Company of Linden, Alabama. Trees were felled by chainsaws, delimbed and topped where they fell, and pulled by grapple skidders to one of two centrally-located loading decks. When measured by remaining perimeter trees, all of the cut openings were slightly more than 0.9 acre in size. In aggregate, the ten cut patches totaled approximately 9.1 acres. Following the commercial harvests, all remaining trees that were larger than 2 inches d.b.h. in the openings were felled.

Measurements and Analyses

Early in the third June after cutting (36 or 32 months after the summer and fall harvests, respectively), the cut stump of

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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each tree was located. For each, the number of living sprouts and the height of the tallest sprout were recorded. For all analyses, only commercially valuable overstory species were included. Three understory non-commercial trees, possumhaw (*Ilex decidua* Walter), American hornbeam (*Carpinus* virginiana Walter), and two-winged silverbell (*Halesia diptera* Ellis), were abundant in the understory stratum, but were not included in analyses.

Categorical data analyses were used to test for differences between sprouting and non-sprouting stumps when classed by season of cut, species, and d.b.h. class and combinations of these. Chi-square or Mantel-Haenszel tests were conducted where appropriate (Stokes and others 1995) using PROC FREQ of the Statistical Analysis System (SAS 1990). Differences among mean heights of the tallest sprouts were tested for seasons, species, and d.b.h. classes and combinations of these using the Tukey's Studentized Range Test, as performed by PROC GLM of the SAS system (SAS 1989). A probability level of 0.05 was generally used in assessing significance for the tests, but the term "highly significant" will be used to denote a probability level of 0.01.

RESULTS

Preharvest Tree Composition

A total of 1257 trees (taller than 10 ft) of commercial species were tallied before the harvests in the ten patches. The species composition of all trees, by four d.b.h. size classes, is presented in Table 1. Sweetgum (*Liquidambar styraciflua* L.) was present in all ten patches and was most abundant overall, with 373 stems. However most of these trees were less than 12 inches d.b.h. Hickories, mostly shagbark (*Carya* ovata (Mill.) K. Koch) and bitternut (C. *cordiformis* (Wang.) K. Koch), comprised 208 stems and elms (U. *alata* Michx. and *Ulmus* americana L.) comprised 147 stems (table 1). Stems of these species were also primarily less than 12 inches d.b.h.

As a group, the oaks comprised 323 stems (28 percent of the total). Except for swamp chestnut oak (*Quercus michauxii* Nutt.), the preharvest oaks were mostly larger than 12 inches d.b.h. (table 1). Consequently, if measured by basal area, all of the patches were dominated by oaks. Cherrybark oak *(Q. pagoda* Raf.), was the most common and most abundant, with 128 stems in the total sample. It was present in the overstory of all ten of the patches, with a minimum basal area of 17.7 ft^2 per acre and a maximum of 95.1 ft^2 per acre in the individual patches. Water oak (Q. *nigra* L.) was also present in the overstories of all ten patches, but with smaller basal areas in most groups and a total of 57 stems. Willow oak (Q. *phellos* L.) was present in four of the summer-cut patches and three of the fall-cut. It strongly dominated (82.4 ff per acre) one of the summer-cut patches that had a large, somewhat poorly drained flat. Swamp chestnut oak was present in nine of the ten patches, but was never a leading dominant. Shumard oak (Q. *shumardii* Buckl.) was a leading species (39 ff per acre) in one fall-cut group and present in another, but was absent from the other eight groups. Two other oaks, overcup (Q. *lyrata* Walt.) and swamp laurel oak (Q. *laurifolia* Michx.), were present but were scattered and in low numbers within the groups. Green ash (*Fraxinus pennsylvanica* Marsh.) and sugarberry (*Celtis laevigata* Willd.) were present in most of the patches, but were never among the dominant species. Other trees present in low numbers were black tupelo (Nyssa sylvatica Marshall), red mulberry (Morus rubra L.), persimmon (Diospyros virginiana L.), and boxelder (Acer negundo L.) (table 1).

Table l-Number of commercial trees >10 ft tall in the ten patches, by species and size class

Species	D.b.h. < 6	6 to 12	12.1 to 22	22.1 to 42	All sizes combined
	Inches				
Sweetgum	150	138	80	5	373
Hickories	141	46	19	0	206
Elms	139	8	0	0	147
Cherrybark oak	2	8	43	75	128
Green ash	45	25	12	1	83
Water oak	0	7	23	27	57
Willow oak	0	5	18	33	56
Swamp chestnut oak	23	15	8	10	56
Sugarberry	16	26	13	0	55
Black tupelo	34	8	1	0	43
Red mulberry	13	9	0	0	22
Shumard oak	0	2	4	8	14
Overcup oak	2	2	5	2	11
Persimmon	4	0	0	0	4
Swamp laurel oak	0	0	0	1	1
Boxelder	1	0	0	0	1
Total	570	299	226	162	1,257

Sprouts

In all patches taken together, only 31 percent (393) of the 1257 cut stumps of commercial species had live sprouts in the third June after cutting. This provided an average of just 44 trees per acre (clumps treated as one tree) that originated as stump sprouts in the regenerated stand. So, stump sprouting alone was not sufficient to obtain adequate regeneration of commercial species. Contributions of advance reproduction and post-harvest germination to early tree reproduction in this stand were reported earlier (Golden 1995).

Effect of season of cut-For all trees combined and when stratified by species or broad size classes (defined below), fall-cut stump sprouting proportion was significantly higher than that for the summer-cut. Of the 578 stems cut in summer (early June), only 21 percent had living sprouts at 36 months after harvest. Reproduction density from the summer-cut stumps averaged only 27 per acre. Forty percent of the 679 fall-cut (early October) stumps had live sprouts, almost twice the summer-cut rate, with a density of **60** per acre.

Effect of species-To provide species categories with adequate numbers for meaningful statistical analyses and interpretation, all of the oaks other than cherrybark were grouped together as "other oaks", comprising a total of 195 stumps. Additionally, elms, sugarberry, black tupelo, red mulberry, persimmon, and **boxelder** were grouped as "other" species, with a total of 272. The other four species categories used were cherrybark oak (CBO), sweetgum, hickories, and green ash.

When classed in these six species categories, the effect of species on proportion of stumps sprouting was highly significant. Overall, green ash had the highest sprouting frequency, at 55 percent (fig. 1). The hickories and sweetgum, at 49 and 48 percent, respectively, were the next most successful in sprouting. Cherrybark oak (CBO) had the highest overall success rate among the oaks, but this was only 13 percent. Taken together, the other oaks had only a 4 percent success rate **(fig.** 1).

In terms of reproduction density, stump sprouting contributed only 5, 11, and 20 per acre for green ash, hickories, and sweetgum, respectively. For the oaks, regeneration numbers from stump sprouts alone were very low. They averaged only about 2 per acre for CBO and less than 1 per acre for other oak species.

When stratified by season of cut, the effect of species remained significant. Green ash, sweetgum, and hickories were more successful than the other species for both seasons. These three species sprouted at a rate above 50 percent where cut in fall and below 50 percent where cut in summer.

Effect of tree dbh-Grouped in two-inch d.b.h. classes, the effect of tree diameter was also highly significant. There was a clear negative relationship between tree d.b.h. and live stump sprouts, but it appeared to be "stepped" rather than linear. When percentage sprouting was plotted for all trees in two-inch d.b.h. classes, sprouting proportions approximated three (or possibly four) reasonably distinct levels (fig. 2). Differences within each level were minor and trendless. The highest degree of sprouting among these levels was by trees of 0.4 to 11.9 inches d.b.h. (less than 12 inches, **"<12"** class). Sprouting of trees in this size range within two-inch classes varied from 33 to 48 percent and averaged 38 percent. Since the smallest tree size was defined by height (10 ft), the smallest size class was truncated at the low end, having no trees smaller than 0.4 inch d.b.h. Trees of 12.0 to 21.9 inches d.b.h. ("12-21" class) formed another irregular plateau of sprouting success, at 12 to 28 percent within two-inch classes and averaging 14 percent. At a third level, trees in the 21 to 32 inch sizes only occasionally had live sprouts, averaging 2 percent. No stumps of the 33 trees larger than 32 inches had live sprouts (fig. 2). Those larger than 32 inches d.b.h. might be considered a fourth level, but in analyses and discussion they will be included in one class composed of all stems larger than 21 inches **(">21"** class).

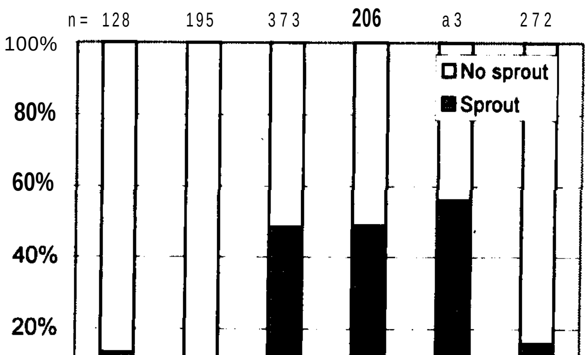

Figure l-Percentage of stumps sprouting for the six species classes. Total number of trees for each species is shown at the top.

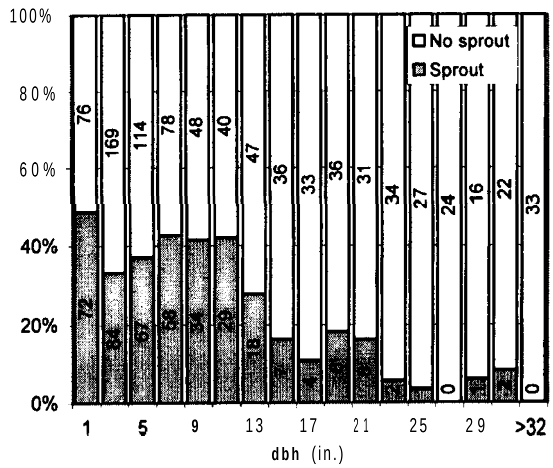

Figure 2-Percentages of stumps with live sprouts, by two-inch dbh classes. Numbers of trees are shown within each bar.

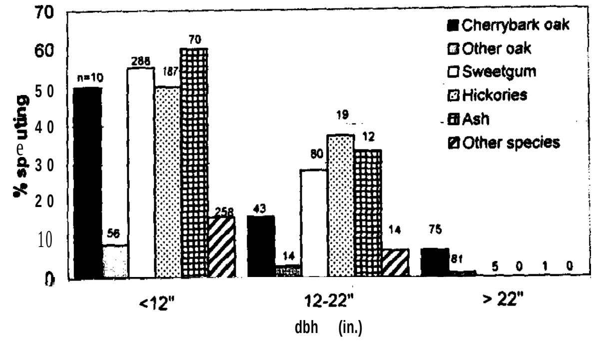

Figure 3-Percentages of stumps with live sprouts, by species within three dbh size classes. Total stumps for each species-size combination are shown at the top.

When stratified by species, sprouting success was significantly different among the three broad d.b.h. classes. When tree species were compared within the broad size classes defined by these three levels of sprouting, green ash, hickories, and sweetgum were most successful in both the <12 (50 to 60 percent) and the 12-21 classes (28 to 36 percent) (fig. 3). However, only six trees of non-oak species were present in the >21 class, and none of these sprouted. Cherrybark oaks less than 12 inches d.b.h. were fairly successful, with 50 percent sprouting. The sample was rather small, however, with only 10 CBO trees of that size present collectively in the ten patches. The "other oaks" were least successful among species in sprouting for the <12 and the 12-22 classes, at 3 and 9 percent, respectively (fig. 3).

Of the 162 trees larger than 22 inches d.b.h., 156 were oaks, and no species other than oaks had sprouts. Sprouts from these large oaks contributed an average of less than 1.5 trees per acre to reproduction.

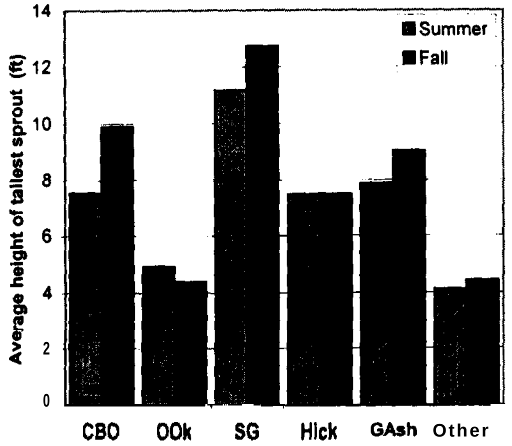

Figure 4-Average height of tallest sprout from each stump, by species and season of cut.

Sprout heights-Heights of the tallest sprout from each stump varied from 0.3 to 23.0 ft, with an overall mean height of 9.4 ft. In spite of having one less summer of growth, the fall-cut sprouts averaged 0.6 ft taller than those of the summer-cut (9.6 vs 9.0 ft), though this difference was not significant. The test of differences for average sprout heights among species was significant. Average sprout heights by species and season combinations are compared in figure 4. Though differences were not significant, average sprout heights from the fall-cut stumps were equal or taller than the summer-cut for all species except the "other oaks" group, where it was slightly smaller. Sweetgum sprouts were significantly taller than any of the other species, while cherrybark oak sprouts were significantly taller than for other oaks (fig. 4).

DISCUSSION

The low recruitment of reproduction by stump sprouting of large saplings and trees of commercial species may be partly a reflection of the size distribution of the preharvest stand. This was a relatively mature mixed hardwood stand, with most of the canopy stratum dominated by large trees. The stumps of these large trees sprouted poorly and weakly. Many large stumps had sprouts that originated during the first year after cutting but died before the third June. Probably more of these will die in the following several years, as has been found in other studies (Johnson 1977, Lowell and others 1987). Much of the stand also had a well-developed understory stratum containing a high proportion of non-commercial trees. This resulted in the forest floor being heavily shaded during the growing season, inhibiting development of sapling-sized trees, which sprout more readily than the larger sizes of intolerant commercial species. Even so, less than half of the 95 stems per acre of 0.4 to 11.9 inch d.b.h. trees sprouted successfully.

Of particular concern is the low percentages and numbers of stump sprout regeneration among the oaks. Although oaks dominated the canopy of the preharvest patches, the small numbers of stump sprouts cannot contribute very much to their prominence in the developing new stand. Whether they are abundant in the future stand will depend primarily on the presence and development of advance reproduction and post-harvest establishment.

Dormant season cutting has generally been found to produce more sprouting than growing season cutting (Johnson 1977, Kays and others 1985), presumably due to higher food reserves in the root system. The significant contrast between fall and summer cutting found may be of more practical value than one between winter and summer cutting. Winter harvesting in bottomlands is frequently impractical due to wet or saturated soils. The fall harvest here was in early October, when trees had not yet lost their leaves and become dormant, which may partly explain the low sprouting rates even for small stems. Still, the increase in sprouting for fall cutting compared to summer was dramatic, and provides evidence that timing of harvest can be an important factor in regeneration success.

The decline in sprouting with increasing tree diameter was t be expected, since this has been reported from many hardwoods studies. The stepped levels of sprouting found here should be further investigated in future studies of sprouting in mixed bottomland stands. If verified as generall valid, division of trees into the three (or four) d.b.h. classes identified could improve the prediction of reproduction in such stands.

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WHEN THE SMOKE CLEARS: WILL BOTTOMLAND OAKS BENEFIT?[1]

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Abstract-In Drew County, Arkansas on the Cut-off Creek Wildlife Management Area, bottomland hardwood regeneration was measured in wildlife habitat openings maintained by tire. Density of all species and height and growth for selected species were measured. Analysis of the data showed that wildlife habitat openings tended to support early-successional species such as persimmon and winged elm. No difference was found in seedling height in openings (burned one time or multiple times) compared to controls. Growth, however, was greater in the openings compared to the controls and in multiple-burned openings versus once-burned openings and controls. Sprouting followed the same trend as growth for this area. Given that both growth and sprouting was greater in multiple-burned openings, multiple prescribed fires appear not to be detrimental to bottomland hardwood reproduction. Multiple burns may even increase the root/shoot ratio of seedlings thereby increasing vigor.

INTRODUCTION

Oaks (*Quercus* spp) represent one of the most dominant species in North American eastern deciduous forests(Braun 1950). They provide important wildlife habitat and valuable forest products (Keyser and others 1996). Successful regeneration of oak-dominated forests on better sites has been difficult because of competition from established shade-tolerant trees and from invasive, fast-growing shade-intolerant trees (Sanders and others 1983; Loftis 1990; Abrams 1992; Van Lear and Watt 1993; Keyser and others 1996). Researchers generally agree that fire played a key role in the establishment of many oak-dominated stands at the turn of the century (Sanders and others 1983; Crow 1988; Maslen 1989; Van Lear and Watt 1993). However, relatively little research exists concerning the use of fire to promote oak-dominated ecosystems (Van Lear and Watt 1993). Until recently, most of the research on fire-oak relationships has dealt with the use of fire to control oaks in pine (*Pinus* spp.) stands. Today, researchers are recognizing the importance of simulating natural disturbances, including fire, to maintain the species composition of forested ecosystems (Van Lear and Watt 1993). The objective of this study was to determine the effects of prescribed burning, multiple fires versus one burn, on bottomland hardwood regeneration in previously established wildlife habitat openings.

MATERIALS AND METHODS

Study Site

The study was conducted in wildlife habitat openings on Cut-off Creek Wildlife Management Area, Drew County, in southeastern Arkansas. This area is managed by the Arkansas Game and Fish Commission. Soils are Portland and Perry clays supporting a diverse bottomland hardwood species composition. The Arkansas Game and Fish Commission, according to agency guidelines, must maintain 5 percent of the suitable forested acreage in wildlife habitat openings ranging in size from three to five acres. The wildlife habitat openings were created in the mid-1980's and burned multiple times or created in 1995 and burned only once. Ring fires were used to burn these openings. The last prescribed burn for all openings was in 1997.

Measurements

Eight wildlife habitat openings, four established in the mid-1980's and four established in 1995, were randomly selected. One of the wildlife habitat openings established in 1995 was burned before measurements could be conducted, therefore it was excluded from measurement (table 1). Twelve O.Ol-acre circular plots were established in each opening on 3-4 line transects. Six plots of the same size were established along the same transects in the surrounding areas as controls where no burning occurred. Measurements taken for each plot included stem counts of all seedlings by species and height classes (dot-tally: < 1 foot, l-3 feet, > 3 feet to 0.5 inches in dbh, 0.6-3.5 inches in dbh). Permanent seedlings were selected to be oaks and green ash (*Fraxinus pennsylvanica* Marsh.). Permanent seedling measurements involved dividing the plot into four quarters (NE, SE, SW, NW). A permanent seedling from each size class in each quadrant: if available, was measured for total height and previous year's growth in centimeters using a meter stick. Total height was measured as the linear relationship from the highest point on the seedling to the ground. Stem growth was measured as the stem length from the previous year's terminal bud. Dieback, sprout, type of sprout (stump, fire, or natural) and number of sprouts were also recorded for permanent seedlings.

Analyses

Dot-tally data were converted into per acre values (density) and presented in tabular format. Permanent seedling data were analyzed using SAS, a Shapiro-Wilks Test for Normality was performed using a alpha-level of 0.05 (Ott 1993). The normality test indicated the data were normal. Following the normality test, a subsampling complete randomized design was used to analyze the permanent seedling data. Wildlife habitat openings (multi-burned and once-burned) were combined and compared against the controls for analysis. Each opening was separated by age and analyzed against the control treatments. Tukey's Honestly Significantly Difference approach was run to determine which openings, once-burned, multiple-burned and control were significantly different.

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Table l-Historical overview of the wildlife habitat openings used in this study on the Cut-off Creek Wildlife Management Area, Drew County, Arkansas

	Opening numbers						
Years	106	113	114	116	408	409	415
1983				E			
1984							
1985		E/B	E/B	B			
1986	E						
1987							
1988	B	B	B	B			
1989		B	B	C/AB			
1990		C	C	AB			
1991	B	B	B				
1992							
1993				B			
1994		B	B				
1995					E/B	E/B	E/B
1996							
1997	AB	B	B	C/B	B	B	B

E - year established, B - year burned, AB - year attempted bum, C - year seedlings too big for burning chainsaw felled.

Table 2—Species density (per acre basis) in wildlife habitat openings on the Cut-off Creek Wildlife Management Area, Drew County, Arkansas

	Size classes			
Species and treatment	< 1 ft. tall	l-3 ft. tall	> 3 ft. tall to ≤ 0.5" d.b.h.	> 0.5" d.b.h.
	- - - - - - - - - *Stems/acre* - - - - - - - - -			
Green ash				
Once-burned	0	25	34	3
Multi-burned	0	120	145	0
Control	22	134	431	231
Cherrybark oak				
Once-burned	3	14	12	0
Mult-burned	5	28	48	0
Control	117	62	70	14
Willow oak				
Once-burned		28	25	0
Multi-burned	22	25	81	0
Control	100	98	70	34
Overcup oak				
Once-burned	0	20	6	0
Multi-burned	12	39	62	0
Control	84	31	37	9
Persimmon				
Once-burned	0	78	123	0
Multi-burned	5	348	925	0
Control	5	50	75	37
Hickories				
Once-burned	0	32	3	0
Multi-burned	15	157	140	0
Control	12	123	190	20
Winged elm				
Once-burned	14	231	64	0
Multi-burned	31	278	364	0
Control	24	145	584	298
Total				
Once-burned	20	453	303	3
Multi-burned	96	973	1862	0
Control	377	706	1606	795

Hickories include shagbark hickory (*Carya ovata* Mill.), mockemut hickory (C. *tomentosa* Poir.), and water hickory (C. *aquatica* Michx. f.). Totals include all species - honeylocust (*Gleditsia triacanthos* L.), red mulberry (*Morus rubra* L.), cottonwood (*Populus deltoides* Marsh.), black willow (*Salix nigra* Marsh.), slippery elm (*Ulmus rubra* Muhl.), red maple (*Acer rubrum* L.), sugarberry (*Celtis occidentalis* L.), sweetgum (*Liquidambar styraciflua* L.), loblolly pine (*Pinus taeda* L.), black cherry (*Prunus serotina* Ehrh.), and Shumard oak (*Quercus shumardii* Buckl.).

RESULTS AND DISCUSSION

Regeneration Density

Density results indicated that the wildlife habitat openings favored early-successional species such as persimmon (*Diospyros virginiana* L.) with 1,479 seedlings per acre, and winged elm (*Ulmus alata* Michx.) with 983 seedlings per acre (table 2). Densities of desirable timber species (oaks and green ash) increased with the age of the opening (table 2). The older, multiple-burned openings were considered well-stocked with desirable species (Johnson, 1980). The densities of all species were greater in the > 3 ft. - 0.5 in. diameter at breast height (DBH; larger advance regeneration). Few seedlings in the wildlife habitat openings were > 0.5 inch in DBH, since the Arkansas Game and Fish Commission burns each opening every 2-3 years. Controls have greater densities of all species except persimmon (table 2). Recent disturbances, including a 1994 ice storm and subsequent salvage operations, opened the canopy in the stands surrounding the wildlife habitat openings. This resulted in increased light levels combined with an available seed source resulted in the high densities of seedlings in the controls. Persimmon, an early-successional species, apparently was widely dispersed in the wildlife openings by small mammals.

Permanent Seedlings

A total of 494 seedlings were measured as permanent seedlings (table 3). No difference was found in height of permanent seedlings between controls and openings ($p = 0.0739$; table 4). Growth, however, was found to be significantly greater in openings than in the controls ($p < .0016$). Growth was also shown to be greater in multi-burn openings compared to once-burned openings and controls ($p < .0001$; table 5). Green ash and oaks, including cherrybark oak (*Quercus pagoda* Raf.), willow oak (*Q. phellos* L.), and overcup oak (Q. *lyrata* Walt.), response to burning with increased height growth could be a result of seedlings with greater root/shoot ratios due to stem dieback. These seedlings could allocate more carbon and nutrients for growth than control seedlings with expected lower root/shoot ratios. Another indication of greater vigor of seedlings in the openings is the number of sprouts per seedling, doubled in the openings compared to the controls

Table 3-Total number of permanent seedlings by treatment and opening type for Cut-off Creek Wildlife Management Area, Drew County, Arkansas

	Treatment		Opening type	
Species	Control	Opening	Once-burned	Multi-burned
Green ash	83	96	18	78
Cherrybarkoak	54	39	10	29
Willow oak	76	63	18	45
Overcup oak	21	48	9	39
Total	236	258	59	199

Totals include Shumard oak, cottonwood, and delta post oak (*Quercus stellata* Wang. var. *paludosa* Sarg.).

Table 4-Average height (cm) for permanent seedlings by treatment and opening type on the Cut-off Creek Wildlife Management Area, Drew County, Arkansas

	Treatment		Opening type	
Species	Control	Opening	Once-burned	Multi-burned
Green ash	109	105	100	106
Cherrybark oak	70	101	77	109
Willow oak	58	101	81	108
Overcup oak	61	86	78	88
Total	79a[a]	101a	87	105

[a] Total treatment means followed by the same letters are not different at $p \leq .05$.

Table 5—Height growth (cm) of permanent seedlings by treatment and opening type on the Cut-off Creek Wildlife Management Area, Drew County, Arkansas

	Treatment		Opening type	
Species	Control	Opening	Once-burned	Multi-burned
Green ash	22	53	37	57
Cherrybark oak	17	43	32	47
Willow oak	21	34	26	37
Overcup oak	22	28	17	31
Total	21a[a]	42	30a	46b

[a] Since total treatment means were different, control mean and opening type means followed by the same letters are not different at $p \leq .05$.

Table 6-Average number of sprouts per seedling for selected species by treatment and opening type on the Cut-off Creek Wildlife Management Area, Drew County, Arkansas

	Treatment		Opening type	
Species	Control	Opening	Once-burned	Multi-burned
Green ash	1.4	6.3	5.0	6.6
Cherrybark oak	1.3	3.8	2.7	4.2
Willow oak	1.5	3.8	4.0	3.7
Overcup oak	1.3	4.8	3.6	5.1
Total	1.4a[a]	4.9	4.0b	5.2b

[a] Since total treatment means were different, control mean and opening type means followed by the same letters are not different at $p \leq .05$.

(table 6). Sprouting was shown to be greater in both multiple-burned and single-burned openings than controls ($p < .0010$).

CONCLUSIONS

Oaks on better sites are being replaced by other species in the southeastern United States (Lorimer, 1993). The historical fire regime that existed in this region, in conjunction with biological adaptations of oak ecosystems to this regime, suggests that the current replacement of oaks by other species is a result of today=s different fire regime or lack thereof (Abrams, 1992; Van Lear and Watt, 1993). Van Lear (1998) recently found that areas treated with a high-intensity spring burn may develop into an oak-dominated stand after one burn. Tueke and Van Lear (1982) stated that advantages of burning included an increased in oak reproduction density especially for large advance reproduction, a decrease in competitor density, and improved wildlife habitat. The major disadvantage of prescribed burning was the potential loss of advance regeneration (Teuke and Van Lear, 1982).

Although the results in this study must be viewed as preliminary, observations indicate that prescribed burning on bottomland hardwood sites enhances wildlife habitat through increased forage production. Furthermore, multiple-burned openings do not appear to have a detrimental effect on desirable regeneration (green ash, oaks, and persimmon).

Although densities were less in openings than the controls, multiple-burned openings were adequately stocked. Controls, in this study, were also adequately stocked because of an open canopy due to the 1994 ice storm and subsequent salvage harvesting.

Overall findings have potential management implications for today's foresters/wildlife managers trying to regenerate desirable hardwood species while maintaining desirable wildlife habitat in bottomland hardwoods. Possible management implications from this study, especially for public lands and non-industrial private landowners, are to open small patches (three to five acres) and maintain them for IO-12 years by burning on a two to three year cycle. Following this burning regime, openings can then be allowed to mature and new openings can be created. For the Arkansas Game and Fish Commission, this scenario would allow the management area to be maintained in the mandated 5 percent wildlife habitat opening.

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MICROTOPOGRAPHICAL EFFECTS ON TREEFALL GAP FORMATION IN AN EAST TEXAS BOTTOMLAND HARDWOOD FOREST[1]

B. Eric Almquist, Michael G. Messina, and Steven B. Jack[2]

Abstract-This study examined differences in the treefall gap regime among three microtopographical classes - bowl, ridge, and slope - in a hardwood forest on the Neches River floodplain in Tyler County, Texas. We estimated the microtopographic variation throughout the site with a clinometer at systematically arranged points along transects. The line intersect method was used to select gaps for sampling, and to determine the density (abundance) and percent cover (fraction) of treefall gaps. We found that gap abundance and gap fraction were statistically different between the microtopographical classes, with ridges having the most area under gaps. Gap area and frequency did not vary with microtopography. However, these initial findings suggest that microtopography could have a critical role in gap patterns in a bottomland hardwood forest.

INTRODUCTION

In recent years, bottomland hardwood forests (BHFs) have come under increased pressure as a source of high-quality timber species, such as baldcypress (*Taxodium distichum* L.), sweetgum (*Liquidambar styraciflua* L.), and cherrybark oak *(Quercus* pagoda Raf.). In addition to high productivity of desirable species, BHFs are also valued for other wetland functions, including threatened and endangered species habitat, the ability to improve water quality, and the capacity to limit severe flooding (Mitsch and Gosselink 1993).

Most BHFs managed for timber production are done so using natural regeneration techniques. However, compared to southern pines, there is relatively little known about the influence of environmental factors on the early survival and growth of bottomland hardwood species. A more complete understanding of these processes will become increasingly important as utilization of BHFs expands.

Seedling survival and growth are affected by the availability of several resources. The most important are light and water (Hall and Harcombe 1998), the availability of which in a BHF is highly variable, and is affected by site-specific factors such as microtopography and canopy openness. It is generally widely accepted that microtopography affects water availability which in turn influences seedling distribution, but it is not often considered that microtopography affects light availability which can then influence species occurrence. BHFs occur on relatively very flat terrain, but small topographical changes create differences in inundation probability that affects site moisture availability. Flooding in low positions will likely prevent seedling establishment by some species, whereas drought may prevent establishment on high positions (Wharton and others 1982). Alternatively, light availability at the forest floor in late-succession forests is highly dependent upon gaps in the canopy. Gaps, formed by the death of a tree or part of a tree, are small-scale disturbances that open the canopy and alter the amount of light that penetrates to seedlings on the forest floor (Runkle 1992). The frequency of gap formation is affected by weather patterns, topography, disease, pests, and tree physiological characteristics (Abe and others 1995, Battles and others 1995).

Several researchers have examined the effects of topography on a gap regime (Battles and others 1995, Hunter and Parker 1993); however, gap formation has not been examined relative to a microtopographical scale. This study investigated relationships between microtopography and gap regime characteristics, including fraction, abundance, area, and frequency, in an east Texas bottomland hardwood forest. We tested the null hypothesis that gap regime characteristics do not vary with microtopographical position.

SITE

The study site was a 300-ha second growth (approximately 60-80 years old) bottomland hardwood stand within Forest Lake Experimental Forest, a research area owned by Temple-Inland Forest Products Corporation. The site was located in the heart of the Big Thicket region of east Texas in the Neches River floodplain (30°39'N, 94°5'W). The climate is humid subtropical, with average annual rainfall ranging from 115 to 150 cm. Temperatures average 27.2% in July and 10.0°C in January. Forest Lake is about 20 m above sea level. Topography and species composition there are similar to other BHFs in the Big Thicket. Common tree species include willow oak *(Quercus phellos* L.), water oak *(Quercus nigra* L.), swamp chestnut oak *(Quercus michauxii* L.), sweetgum, green ash *(Fraxinus pennsylvanica* Marsh.), and ironwood (Carpinus caroliniana Walt.). Flooding of the lower terrain on the study site is common in late winter through early spring.

METHODS

Nine parallel transects were established to sample microtopography and treefall gaps. Transects were placed only within hardwood areas, but certain parts of the stand were avoided, such as permanently inundated backswamps, slough bottoms, and any recently harvested areas. Transect length varied from 480 m to 1540 m. The distance between transects was always at least 80 m to avoid sampling the same gap twice.

Microtopography was point sampled at 20-m intervals along each transect using a clinometer and two rods marked at the same level (fig. 1). The minimum detectable change in elevation was 10 cm. Because site hydrology often

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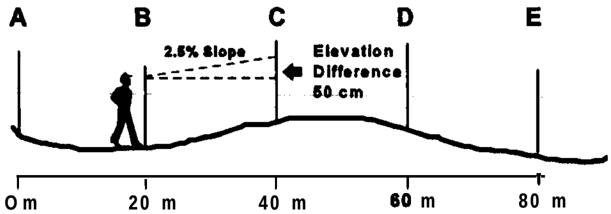

Figure l-Measuring microtopography with a clinometer. Paint marks at 172 cm on PVC rods were used as references for all clinometer measurements. A clinometer reading of 2.5 percent and a distance of 20 meters would yield an "elevation difference" of 50 cm. Note that in this figure point B is in a bowl, C is on a ridge, and D is on a slope. Points A and E cannot be classified because they do not have two neighbors.

correlates to relative position as opposed to absolute elevation, each measured point was classified as ridge, slope, or bowl based on its elevational relationship to neighboring points. The total number of points in each class along each transect was used to determine the relative length of transect in each microtopographical position. Thus, if there were 30 total points on a transect, and 10 of them were on ridges, then it was assumed that 33 percent of the transect was on a ridge.

Gaps were sampled using the line intersect method (sensu DeVries 1988, Runkle 1992). Gaps were defined as any opening caused by the death of 1/2 to 10 canopy trees. There are generally two kinds of forest gaps to consider: canopy gaps and expanded gaps (Runkle 1992). Canopy gaps include the area in which there is no leaf cover, while the expanded gap includes beyond the open area to the tree boles that surround the gap. Canopy gaps that were smaller than $25m^2$ were not included in this study, since small gaps generally close from lateral expansion of surrounding tree branches. A canopy gap was also considered closed when trees within the gap reached 66 percent of the height of surrounding trees.

In this study, the expanded gap was used for all characterizations, including area, fraction, frequency, and abundance measurements. An expanded gap was sampled if any of the nine transects crossed it. The area of each sampled gap was measured by establishing a central point in'the expanded gap and measuring the distance and azimuth to each of the surrounding tree boles (sensu Lertzman and Krebs 1991, Runkle 1992, Spies and others 1990). A global positioning system receiver was used to obtain the position of each central point, and the distance and azimuth to each tree were recorded in a geographic information system. The area, perimeter, and mathematical center of each gap was calculated from the resulting map.

Each gap was classified as bowl, ridge, or slope based upon the class of the nearest transect point to the mathematical center of the gap. Two characteristics of the gap regime, fraction and abundance, were calculated from the line intersect sampling. The first, gap fraction, is the percent of all forest area under gaps at a given time. It is calculated using the equation:

$$GF = \frac{1}{L}\sum_{j=1}^{n}\frac{A_j}{d_j} \quad (1)$$

where GF is gap fraction, L is the total length of one transect, n is the number of gaps intersected by a transect, Aj is the area of the jth gap, and dj is the effective diameter of a gap (Battles and others 1996, DeVries 1986). The effective diameter is a variable calculated to eliminate the bias caused from the higher probability of a transect intersecting a large gap versus a small gap. It is calculated using equation 2 (Battles and others 1996):

$$d = \frac{\text{convex perimeter}}{\Pi} \quad (2)$$

The convex perimeter is the smallest convex cover of the gap polygon. Using equation 1, the gap fraction for each topo-class (bowls, ridges, and slopes) was determined by substituting the length of one transect within a respective topo-class for L and the number of gaps in that class for n. Gap abundance, which indicates the number of gaps per unit area of forest, was calculated using the equation:

$$GAB = \frac{1}{L}\sum_{j=1}^{n}\frac{1}{d_j} \quad (3)$$

where GAB is gap abundance, L is the length of a single transect, n is the number of gaps intersected, and d, is the effective diameter of the jth gap (Battles and others 1996, DeVries 1986). The gap abundance for each transect in bowls, ridges, and slopes was determined by letting L equal the length of the transect within the respective topo-class, and n equal the number of gaps found in that class along the transect.

After the gap fraction and abundance were determined for each topo-class on each transect, the overall fraction and abundance for the entire site was estimated. To account for variation in transect lengths, a weighted mean was calculated by using equation 4 (DeVries 1986):

$$X_w = \frac{\sum_{j=1}^{n} L_i X_i}{\sum_{j-l}^{n} L_j} \quad (4)$$

where X_w is the weighted mean for gap fraction or gap abundance, n is the number of transects (which always equals 9), L_j is the length of the jth transect, and X_j is the gap fraction or abundance for a topo-class on the jth transect. The variance of the weighted mean is calculated using equation 5 (DeVries 1986):

$$\text{variance of } X_w = \frac{\sum_{j=1}^{n} L_j (X_j - X_w)^2}{(n-1) * \sum_{j=1}^{n} L_j} \quad (5)$$

where X_w is the weighted mean, n is the number of transects, L_j is the length of the jth transect, and X_j is the fraction or abundance of gaps located on the jth transect.

We used Welch's T-test (Ott 1993, Welch 1938) and Bonferroni's multiple comparison test to detect any differences in expanded gap area, fraction, and abundance among ridges, bowls, and slopes. In addition, we used a chi-square goodness of fit test (Ott 1993) to determine if gaps occurred at the frequency expected in each topo-class, as estimated by the transect length in each class.

RESULTS

Using 431 elevation samples, we found a maximum topographic variation of 4.2 m along the 8.6 km of transects placed at Forest Lake. A total of 29.2 percent of the length of all transects occurred on ridges; 42.2 percent occurred on slopes; and 28.5 percent occurred in bowls.

The nine transects intersected 54 expanded gaps. The expanded gap areas ranged from 100 m^2 to 2005 m^2, and the total area of these expanded gaps was 3.55 ha. Each gap was classified as occurring on a ridge, slope, or bowl based on the nearest elevation point to the gap's mathematical center. The expanded gap area did not statistically differ between any topo-classes. In addition, the chi-square goodness of fit test revealed that the number of gaps in each topo-class was proportional to the length of transect in each topo-class. Thus, both the size and frequency of gaps did not vary with topography. Table 1 shows summary statistics for the sampled expanded gaps at Forest Lake.

We found that the weighted mean gap fraction for the nine transects at Forest Lake was 11.3 percent (using equation 4). The weighted mean fraction for ridges, bowls, and slopes was 15.1 percent, 9.2 percent, and 11.6 percent, respectively. Weighted standard deviations were 3.19 for ridges, 1.51 for slopes, and 3.09 for bowls. Using Welch's T and Bonferroni's multiple comparison tests, significant differences were found between all microtopographic classes to at least $\alpha=0.10$ (table 2). In other words, gap fraction differed between ridges and slopes, ridges and bowls, and slopes and bowls.

The weighted mean gap abundance of the nine transects was 2.13 gaps/ha. The weighted mean abundance for ridges was 2.78 gaps/ha; for bowls, 1.97 gap/ha; and for slopes, 1.79 gaps/ha. The weighted standard deviations were 0.69 for ridges, 0.33 for slopes, and 0.56 for bowls. Significant differences were found between ridges and slopes **($p=0.012$)** and between ridges and bowls **($p=0.006$)** (table 3). However, no difference was found in gap abundance between slopes and bowls.

INTERPRETATIONS AND CONCLUSIONS

The effects of topography on disturbance patterns have been examined by many researchers, including Battles and others **(1995),** Bergeron and Brisson **(1990),** Hunter and Parker **(1993),** and Worrall and Harrington (1988). Most have shown that steep topography affects disturbance patterns, but there is little research showing that microtopography has similar effects. However, in floodplain forests such as Forest Lake, small changes in elevation can have dramatic effects on hydrology, soil characteristics and species composition. This study presents evidence that microtopography can also affect disturbance patterns in these systems.

Our conclusions that gap fraction and abundance vary with microtopography is not surprising, considering the effect that microtopography has on other BHF dynamics. It remains unclear, however, why ridges have higher gap fraction and abundance than the other topographical classes.

First, topographic features can impact gap regime characteristics in both direct and indirect ways (Hunter and Parker 1993). Direct effects typically occur in steep terrain, which creates slope failures and differences in wind patterns. Indirect effects include altered resource availability (e.g. hydrology and soils) and subsequent species composition.

At Forest Lake, terrain is not steep enough to directly affect gap formation. Slopes do not play a large role in gap formation in floodplain forests, except on the banks of sloughs where slope failure may cause some disturbance. Slough banks comprise a very small portion of Forest Lake, and we found no gaps caused from gap-makers on collapsed banks. In addition, wind patterns likely do not vary between ridges and bowls, as they may in deep mountain valleys.

Table l-Summary statistics for sampled expanded gaps in the Forest Lake stand, sorted by microtopographic class

Topoclass	Length of transects in class	Percent of total length	Number of gaps	Percent of all gaps	Mean area	Standard error
	m				*m²*	*m²*
Ridge	2520	29.23	20	37.04	667.0	104.3
Slope	3640	42.23	20	37.04	549.2	68.8
Bowl	2460	28.54	14	25.92	796.4	141.7
Entire site	8620	100.00	54	100.00	656.9	59.4

Table 2—Statistical analysis for differences in gap fraction among microtopographic classes, using Welch's T-test and Bonferroni's multiple comparison test

Class comparison	Degrees of freedom	Difference in weighted mean abundance	One-tailed p-value	Bonferroni's p-value
		Gaps/ha		
Ridge-slope	11	5.95	0.0002	0.0006
Ridge-bowl	15	3.54	.0160	.0480
Slope-bowl	11	2.41	.0290	.0870

Table 3-Statistical analysis for gap abundance among microtopographic classes, using Welch's T-test and Bonferroni's multiple comparison test

Class comparison	Degrees of freedom	Difference in weighted mean abundance	One-tailed p-value	Bonferroni's p-value
		Gaps/ha		
Ridge-slope	11	0.81	0.004	0.012
Ridge-bowl	15	.99	.002	.006
Slope-bowl	12	.18	.212	.636

Hydrology, as affected by microtopography, is possibly the primary factor affecting differences in gap formation. For example, in low sites where the water table is close to the surface, tree roots spread farther laterally than vertically, making the tree more likely to uproot during a windstorm (Kozlowski and others 1991). If all trees in bowls have shallower roots than those on ridges, then we would expect to find far more gaps in bowls than at any other topographic position. However, we found the opposite at Forest Lake. Most gap-makers were trees that died standing and collapsed after rotting. Of the live trees that created gaps, most were uprooted. Very few trees snapped at the base, which would indicate a strong tap-root system. Thus, the water table is high enough on all microtopographic positions to induce shallow rooting in most trees, so roots are likely not a differentiating factor. While shallow roots may account for some difference in the gap regime at Forest Lake, they are likely not the main reason.

A third possible cause for gap pattern variation at Forest Lake is species variation among microsites. While almost all of the trees in the sampled site are roughly the same age, dissimilarity in life-spans, root growth patterns, disease susceptibility, and tolerance to drought or flooding all could cause differences in gap patterning among species. These differences would become apparent along a microtopographical gradient as species composition changed, and could explain the variation in the gap regime we detected. Empirical data for species composition and gap-maker species among microtopographical classes would be necessary to determine if species variation is the cause for gap regime variation. However, we feel that this is the most likely reason for the variation detected in this study.

The results of this study show that BHFs have diverse gap characteristics among microtopographical positions. These differences ultimately affect the light environment and seedling survival. Knowing that gap characteristics change among microtopographic classes is an important step toward understanding seedling recruitment and species composition patterns in bottomland hardwood forests. This initial research suggests that seedlings growing in low sites will have more difficulty reaching the canopy than seedlings on ridges, and highlights the important relationship between light and water in floodplain forests.

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ESTABLISHMENT AND GROWTH OF CHERRYBARK OAK SEEDLINGS UNDERPLANTED BENEATH A PARTIAL OVERSTORY IN A MINOR BOTTOM OF SOUTHWESTERN ARKANSAS: FIRST YEAR RESULTS[1]

Emile S. Gardiner and Jimmie L. Yeiser[2]

Abstract-Advance regeneration is frequently inadequate to sufficiently restock the oak component of many bottomland stands, especially on productive sites with high levels of competition. We initiated a study near Beirne, AR to examine the effects of pre-plant control of Japanese honeysuckle (*Lonicera japonica* Thunberg) and seedling quality on establishment success and vigor of oak reproduction beneath a partial canopy. Nine, 2-acre plots were delineated in the stand that was harvested to a residual stocking level of 30 percent in the fall of 1996. Honeysuckle pre-plant control treatments randomly applied to the nine plots were an Escort application in the spring of 1997, an Escort application in the late summer of 1997, and a control (no herbicide application). In 1998, 1-O cherrybark oak (Quercus *pagoda* Raf.) seedlings were planted at a 12 ft x 12 ft spacing in each treatment plot. One-half of each treatment plot received seedlings with four or more lateral roots > 0.04 in. diameter, while the other half of each plot received seedlings with fewer than four lateral roots > 0.04 in. The spring application of Escort provided effective control against Japanese honeysuckle, thereby producing potentially promising conditions for oak seedling growth and development. First-year seedling survival and growth did not respond to honeysuckle control treatments. Survival was not related to seedling quality, and first-year differences in seedling size were attributed to initial size differences in stock types.

INTRODUCTION

The problem of obtaining adequate oak regeneration on high quality hardwood sites has been documented for several decades in many different forest types (Clark 1993). Encouraging advances have been made towards techniques that promote size and vigor of natural oak regeneration (Janzen and Hodges 1987, Loftis 1990). But, artificial regeneration techniques are still needed where stands lack an adequate stocking of advance oak reproduction.

One successful method of establishing artificial reproduction was developed by Johnson and others (1986) for northern red oak *(Quercus rubra* L.) in the Missouri Ozarks. Their prescription calls for controlling undesirable vegetation, reducing the overstory canopy to increase light reaching the forest floor, and underplanting large seedlings. Overwood is removed about 3 years after planting when seedlings are well established. Typically, about 50 to 60 percent of the planted seedlings are free-to-grow 5 years after the overwood is removed (Johnson 1989). A modification of this prescription has been successfully applied to establish northern red oak regeneration in Wisconsin (Teclaw and Isebrands 1993). Though very different forest systems, these practices may serve as a starting point for developing regeneration strategies for bottomland oaks.

A growing interest surrounds the use of partial cutting and underplanting to establish oak regeneration in bottomland hardwood stands, but few studies have evaluated these practices. In two different studies, 1-O Nuttall oak *(Quercus nuttallii* Palm.) seedlings were successfully underplanted on bottomland sites of Louisiana (Chambers and Henkel 1988, Chambers and others 1986). Unfortunately, these seedlings were never released from overwood, so long-term success can not be evaluated. In South Carolina, Nix and Cox (1987) found that cherrybark oak seedlings were successfully established, but logging activities during overwood removal destroyed a significant amount of regeneration. Nevertheless, underplanting beneath a partial overstory to establish artificial oak regeneration in hardwood bottoms appears promising.

Midstory and partial overstory removals benefit underplanted seedlings by improving the light environment, but light may also invigorate competition (Nix and Cox 1987). Competition from vines, such as, Japanese honeysuckle (*Lonicera japonica* Thunberg), is of particular concern on many bottomland sites. Japanese honeysuckle grows poorly under the heavy shade of mature bottomland forests. Under these conditions, it can be difficult to control because of low physiological activity or litter coverage over foliage (Yeiser, In press). However, honeysuckle grows aggressively once released (Schmeckpeper and others 1987), and can quickly overtop slow growing hardwood regeneration. Vegetation control may be necessary to optimize establishment of oak regeneration where honeysuckle competition is likely. Johnson (1989) found that vegetation control improved regeneration establishment of northern red oak, but he stressed that large seedlings are still essential to success.

This manuscript reports first-year results from a study designed to address two gaps in our knowledge about underplanting cherrybark oak *(Quercus pagoda* Raf.) in bottomlands. Objectives of this study were 1) to test the importance of pre-plant control of Japanese honeysuckle and season of application to establishment and growth of underplanted oak seedlings; and 2) to compare the suitability of two oak stock types for underplanting.

METHODS

The study site was located adjacent to the Little Missouri River, near Beirne in Clark County, Arkansas. The mixed bottomland hardwood stand on the site was considered typical of many minor bottoms throughout the South, with an

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overstory of mature red oak (*Quercus* spp.) and sweetgum (*Liquidambar styraciflua* L.). Basal area averaged about 118 ft^2 per acre with oaks comprising about 26 percent of the standing basal area. A dense midstory layer of American holly (*Ilex opaca* Ait.), bluebeech (*Carpinus caroliniana* Walt.), winged elm (*Ulmus alata* Michx.), American elm (*Ulmus americana* L.), and other tolerant species was present in the stand. The understory was stocked with about 1,000 oak seedlings per acre. This amounted to only 15 percent of the total hardwood regeneration pool, and most of the oak seedlings were less than 12 in. tall.

In June 1996, a series of nine, 2-acre (5 chains x 4 chains) plots were delineated on the site. Plots were arranged in three blocks to provide three replications of three honeysuckle control treatments. Honeysuckle pre-plant control treatments included 1) a spring application (May 1997) of herbicide, 2) a late summer application (August 1997) of herbicide, and 3) a control • no herbicide applied. The herbicide solution was 1 oz (product) per acre Escort (metsulfuron-methyl), 1.5 percent Red River 90 non-ionic surfactant, and 30 gal of water which was broadcast with backpack sprayers. Prior to herbicide application (October 1996), two-thirds of the plots (those scheduled to receive a herbicide application) were harvested to a residual stocking level of about 30 percent (basal area ≈ 35 ft^2 per acre)(Goelz 1995). Most stems > 1 in. d.b.h. were severed during the logging operation, and all merchantable volume was removed from the site. The partial cutting was done on the site to increase light availability at the forest floor and promote a growth response by Japanese honeysuckle. Control plots were harvested in October 1997, so that seedlings underplanted in these treatment plots would not be planted amongst a year's growth of competition.

The entire study site was underplanted in February 1998 on a 12 ft x 12 ft spacing with 1-O bareroot, cherrybark oak seedlings. Seedlings were graded into two classes to determine if stock type influenced establishment and growth of underplanted seedlings. The first stock type (grade 1) included seedlings with four or more first-order lateral roots having a diameter > 0.04 in., and the second stock type (grade 2) included seedlings with fewer than four first-order lateral roots having a diameter > 0.04 in. One hundred seedlings of each stock type were flagged in each plot to serve as measurement seedlings.

First-year measurements taken on the outplanted seedlings included initial and final stem height, initial and final root-collar diameter, and presence of honeysuckle contact. Data were analyzed according to a randomized block design with split-plots (table l), and percentages were transformed with a square root transformation prior to analysis. All tests were conducted at an alpha level of 0.05, and Duncan's Multiple Range Test was used for mean separations.

RESULTS AND DISCUSSION

Pre-plant herbicide treatments were designed to reduce Japanese honeysuckle competition, because observations indicate that planting sites with severe honeysuckle competition may result in early growth reductions and shoot malformations from honeysuckle twining. Partial cutting in the stand prompted a vigorous growth response by honeysuckle present on the site. As a result, 19 percent of seedlings planted in control plots were in direct contact with honeysuckle by the end of the first growing season (table 2).

Table l-Analysis of Variance sketch for a randomized block design with split-plots, used for analysis of response variable plot means

Source	Degrees of freedom[a]
Total	rab - 1 = 17
Block	(r-l)= 2
Honeysuckle control	(a-l)= 2
Error (Honeysuckle control)	(r-1)(a-1) = 4
Stock type	(b-1) = 1
Honeysuckle control x stock type	(a-1)(b-1) = 2
Error (honeysuckle control x stock type)	a(r-2)(b-1) = 6

[a] r = 3 blocks, a = 3 honeysuckle control levels, b = 2 stock types.

Table 2-Percentage of underplanted cherrybark oak seedlings in direct contact with Japanese honeysuckle 1 year after underplanting on a minor bottom site near Beirne, AR

Treatment effect	Percent[a]
Honeysuckle control[b]	
Spring application of Escort	2.7 b
Late-summer application of Escort	20.5 a
Control	19.1 a
Stock type"	
1) ≥4 first-order-lateral roots	13.6 a
2) <4 first-order-lateral roots	14.6 a

[a] For each treatment effect, means followed by the same letter are not different at alpha = 0.05.
[b] Probability = 0.0486.
[c] Probability = 0.7734.

The spring application of Escort, however, provided very effective honeysuckle control. Only 3 percent of seedlings planted in plots receiving the spring application were in direct contact with honeysuckle after the first growing season (two seasons after herbicide application) (table 2). This pre-plant treatment appears to have reduced honeysuckle substantially enough to allow for potentially promising early oak seedling development. In contrast, the late-summer herbicide application provided no noticeable honeysuckle control (table 2). It is likely that rank herbaceous competition established on the site by the time of the late-summer application reduced application efficiency and protected honeysuckle vines from receiving an adequate amount of herbicide for effective control. Honeysuckle vines established a similar percentage of contact with both grades of seedlings (table 2).

Seedling survival was excellent across the study site averaging about 98 percent after 1 year. Though honeysuckle contact was greatly reduced on seedlings planted in plots receiving the spring application of herbicide, first-year seedling survival was not influenced by honeysuckle control (table 3). This finding is in agreement with other research on cherrybark oak regeneration (Kennedy 1985, Nix 1989). Kennedy (1985) found that disking or mowing did not increase survival on a minor bottom site with grass and herbaceous weed competition. Likewise, mulching or herbicide application did not increase cherrybark oak survival on a bottomland site in South Carolina (Nix 1989). In contrast, Ezell and Catchot (1998) reported a 20 percent increase in first-year survival of cherrybark oak after pre-bud break applications of herbaceous weed control treatments. We note that our study site received abundant rainfall throughout the growing season which may have helped to maintain early seedling survival. Root system development provided no early survival benefit as both stock types exhibited similar mortality (table 3).

Table 3—First-year survival of chertybark oak seedlings underplanted on a minor bottom site near Beirne, AR

Treatment effect	Percent[a]
Honeysuckle control[b]	
Spring application of Escort	98.6 a
Late-summer application of Escort	97.4 a
Control	98.5 a
Stock type"	
1) ≥4 first-order-lateral roots	98.4 a
2) <4 first-order-lateral roots	97.9 a

[a] For each treatment effect, means followed by the same letter are not different at alpha = 0.05.
[b] Probability = 0.2868.
[c] Probability = 0.3833.

First-year height growth of cherrybark oak seedlings was not influenced by pre-plant control of honeysuckle, as all seedlings showed a 75 percent height increment (table 4). Nevertheless, we feel the substantial reduction in honeysuckle achieved in plots receiving the spring application of herbicide will prove important to seedling growth and form in future years. Though others have demonstrated increased growth of cherrybark oak seedlings receiving broad spectrum weed control in bottomlands (Nix 1989), we did not expect our honeysuckle pre-plant control treatments to provide early growth benefits. Two factors may attribute to the lack of an early growth response to the herbicide application in this study. First, Escort has a fairly narrow spectrum of control, and species not controlled by the Escort applications were released prior to oak underplanting. Secondly, the oak seedlings were underplanted the year following the pre-plant herbicide applications. We did not expect residual weed control, other than for Japanese honeysuckle, to extend into the first oak growing season.

Seedling size and root morphology is of great concern when planting oaks, because it is believed that seedlings must be relatively large and have a well developed root system to be competitive (Kormanik and others 1998). On upland sites in Missouri, Johnson and others (1986) suggests underplanting northern red oak seedlings with an average height greater then 3 feet (before shoot clipping) and an average diameter of at least 0.5 in. measured 1 in. above the root-collar. Seedlings underplanted in this study were small (table 4 & 5) compared to recommendations for oaks in other regions of the country (Bowersox 1993, Johnson and others 1986). Stock types did have different initial heights, as grade 2 seedlings were about 1 in. shorter than grade 1 seedlings. The initial difference in seedling height was maintained through the first growing season with grade 1 seedlings averaging about 3 in. taller than the others. However, relative growth of both stock types was similar (table 4).

Seedling root-collar diameter increased about 51 percent regardless of honeysuckle control treatment (table 5). As expected, grade 1 seedlings had a root-collar diameter

Table 4-First-year height variables (mean ± standard error) for cherrybark oak seedlings underplanted on a minor bottom site near Beirne, AR

Treatment effect	Initial	Final	Growth
	- - - - - - - - Inches - - - - - - - -		*Percent*
Honeysuckle control[a]			
Spring application of Escort	12.5±0.1 a	21.1k0.3 a	72.5±2.9 a
Late-summer application of Escort	12.7±0.1 a	22.4i0.4 a	81.0k3.4 a
Control	12.2±0.1 a	20.9±0.3 a	74.9±2.9 a
P-value	.36	.4868	.7800
Stock type			
1) ≥4 first-order-lateral roots	12.9±0.1 a	22.9±0.3 a	79.1±2.3 a
2) <4 first-order-lateral roots	11.8±0.1 b	19.9±0.3 b	72.5k2.7 a
P-value	.0001	.0001	.0762

[a] For each treatment effect, means followed by the same letter are not different at alpha = 0.05.

Table !&First-year root-collar diameter (mean ± standard error) variables for cherrybark oak seedlings underplanted on a minor bottom site near Beirne, AR

Treatment effect	Initial	Final	Growth
	----------- *Inches* ----------		*Percent*
Honeysuckle control[a]			
Spring application of Escort	0.15±0.001 a	0.22±0.002 a	49.4kl.8 a
Late-summer application of Escort	.16±0.001 a	.23±0.003 a	53.1i2.1 a
Control	.15±0.001 a	.23±0.002 a	52.5il.6 a
P-value	.7387	.6877	.8685
Stock type			
1) ≥4 first-order-lateral roots	.17±0.001 a	.25±0.001 a	44.8±1.2 b
2) <4 first-order-lateral roots	.13±0.001 b	.20±0.001 b	59.5±1.8 a
P-value	.0001	.0001	.0001

[a] For each treatment effect, means followed by the same letter are not different at alpha = 0.05.

initially larger than the others. This initial difference was maintained through the first growing season even though growth rate of grade 2 seedlings was greatest (table 5).

We should note that a problem with our planting stock was noticed after seedlings broke bud. About 9 percent of the seedlings outplanted were southern red oak (*Quercus falcata* Michx.) (table 6). Interestingly, a large percentage of the southern red oak was found among the grade 2 seedlings (table 6). Since success at establishing high quality hardwood stands hinges on matching appropriate species to site conditions, care should be taken to procure high quality planting stock when planning reforestation activities on bottomland hardwood sites.

CONCLUSIONS

Excellent survival was observed across the entire study site, but was not influenced by pre-plant control of honeysuckle control or seedling stock type. Pre-plant control of honeysuckle did not influence first year height and diameter growth of cherrybark oak seedlings. Differences found among the two stock types were mostly initial size differences maintained through the first growing season. Japanese honeysuckle competition was most effectively reduced with a spring application of Escort, and this control is expected to benefit future oak seedling form and growth. If vegetation control treatments target honeysuckle, applications should be timed to maximize coverage on foliage. Late season applications where dense herbaceous cover is expected to develop may not prove effective. Care should be taken when purchasing seedlings for hardwood reforestation projects so that appropriate species are outplanted.

Table 6-Percentage of southern red oak seedlings underplanted on a minor bottom site near Beirne, AR

Treatment effect	Percent[a]
Honeysuckle control[b]	
Spring application of Escort	8.9 a
Late-summer application of Escort	11.1 a
Control	7.2 a
Stock type"	
1) 24 first-order-lateral roots	3.5 b
2) <4 first-order-lateral roots	14.7 a

[a] For each treatment effect, means followed by the same letter are not different at alpha = 0.05.
[b] Probability = 0.4473.
[c] Probability ≤ 0.0004.

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UNDERPLANTING OAKS IN RIVERFRONT HARDWOOD STANDS ALONG THE MISSISSIPPI RIVER: SUCCESSES AND FAILURES[1]

Rodney J. Wishard, Brian R. Lockhart, and John D. Hodges[2]

Abstract-Riverfront hardwood stands along the Mississippi River are primarily composed of sugarberry (*Celtis laevigata* Willd.), American elm (*Ulmus* americana L.), boxelder (*Acernegundo* L.), sycamore (*Platanus occidentalis* L.), and green ash (*Fraxinus pennsylvanica* Marsh.). Such stands usually contain few oaks (*Quercus* spp.) due to the immature nature of the soils including a relatively high pH. As the soil matures, oaks will eventually become more prominent. Since oaks represent one of the most valued species, attempts to increase the oak composition of future stands have been underway for the past seven years. Underplanting oaks in association with midstory competition control and partial overstory harvesting has proven to be an effective silvicultural tool to increase the oak composition of regeneration size classes. Not all attempts to underplant oak have been successful though, due primarily to flooding early in the growing season following planting. Observations of successes and failures along with steps to increase success are presented.

INTRODUCTION

Underplanting can be defined as an artificial regeneration technique where seedlings are planted underneath an existing forest canopy. It can also be referred to as supplemental planting, enrichment planting (Nix and Cox 1986), enhancement planting, pre-harvest planting (Chambers and others 1986), or interplanting (Johnson 1976). The objective of this paper is to review the progress of an ongoing underplanting program on Anderson-Tully Company (ATCO) lands along the lower Mississippi River. Successes and failures of various underplantings will be discussed. Recommendations will also be made, based on past experiences, on ways to improve the success of underplanting operations.

Most of ATCO's riverfront hardwood stands have been managed by single-tree and group selection methods in the past. In the mid 1980's ATCO foresters became concerned about the lack of desirable advance regeneration in many of the company's timber stands. On sites with lower elevations that flooded periodically desirable regeneration was established often, but the single-tree selection method did not allow enough light to reach these young seedlings and allow them to develop. Development of a pulpwood market along the Mississippi River and the use of chemical injection has allowed ATCO foresters to manipulate the understory to allow more light to reach the forest floor for seedling development. This understory reduction coupled with more attention to larger group openings when performing selection harvests has allowed for the development of excellent advance regeneration in many stands, though primarily on sites on lower elevations which have almost annual deposition of silt and seed.

Higher elevation sites are flooded infrequently and receive little silt deposition when they do flood. It was these sites that were targeted for underplanting of oak when ATCO started experimenting with oak underplantings in 1992. Since that time ATCO has operationally planted over 1500 acres of riverfront hardwood stands with several different oak species including Shumard *(Quercus shumardii* Buckl.), cherrybark(*Quercus* pagoda Raf.), water *(Quercus nigra* L.), and willow *(Quercus phellos* L.) oaks. The majority of the oak seedlings have been planted on a 12 by 12 foot spacing and have been 1-O nursery stock. Wider spacings have been used in some plantings and included planting of 2-O stock. Success of these plantings has ranged from complete failure to 66 percent survival and seedlings averaging over eight feet in height after six growing seasons.

OBJECTIVES OF ATCO UNDERPLANTING

There were five major objectives when ATCO started operational underplanting in 1992. Underplanting seedlings on sites that were lacking desirable regeneration in adequate numbers would be a way to increase the number of desirable seedlings per acre. Typically higher elevation sites in riverfront hardwood stands are more difficult to regenerate naturally, therefore underplanting could help solve regeneration problems on these sites. Underplanting oaks in stands lacking an oak component would increase the value of these stands. Introduction of oaks into stands would establish a seed source for future natural regeneration and would also provide a source of hard mast for wildlife.

CASE STUDIES

Oaks have been underplanted on over twenty different sites since 1992. In the following sections two planting sites will be presented in detail to give examples of underplanting successes and failures. An overview of all sites will also be presented.

Hurley Site

In 1994, 150 acres were underplanted with 1-O Shumard oak seedlings on a 15 by 15 foot spacing. Soil types were Commerce silt loam and Bowdre silty clay with pH ranging from 7.0-7.6. This underplanting was a cooperative research effort between ATCO and the School of Forest Resources at the University of Arkansas - Monticello. It was designed to study the effects of various log and pulpwood cutting intensities and chemical removal of shade tolerant midstory and understory trees on underplanted oak seedling survival and growth. Floods on the Mississippi River (fig. 1) during the growing season in 1994 and 1995 completely inundated the planting site with water levels four to five feet above flood stage. Survival after the first growing season was 33

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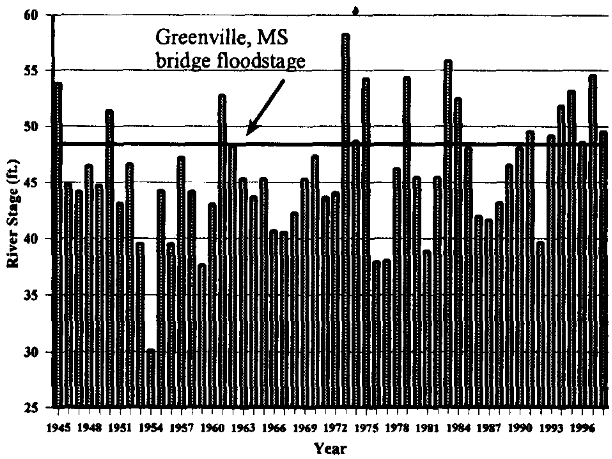

Figure l-Mississippi River Greenville Gauge (floodstage is 48 feet) yearly maximum reading (unpublished data U.S. Army Corps of Engineers, Vicksburg, MS).

percent while seedling heights were less than when planted. Most of the surviving seedlings died back to the ground and sprouted near ground-line. After being flooded again during the growing season in their second year seedling survival was less than one percent at which point the study was abandoned.

Ozark Site

In 1993, 65 acres were underplanted with 1-O Shumard oak seedlings on a 12 by 12 foot spacing. The soil was Commerce silt loam with a pH of 7.0. The stand received select harvests in 1971, 1982, and 1991. The remaining overstory was in scattered groups and consisted of sweetgum (*Liquidambar styraciflua* L.), sycamore (*Platanus occidentalis* L.), sweet pecan (*Carya illinoensis* K. Koch.), sugarberry (*Celtis laevigata* Willd.), green ash (*Fraxinus pennsylvanica* Marsh.), and American elm (*Ulmus americana* L.). A severe ice storm in 1994 broke many of the limbs from trees in the overstory and in the shade tolerant midstory and understory which led to increased light reaching the seedlings delaying the need for chemical removal of midstory and understory competition until 1997. Portions of the site were inundated by extremely high flood waters of the Mississippi River during the growing season in 1995 which adversely affected seedling survival (fig. 1). Seedling survival was 92 percent after the first growing season and gradually dropped to 66 percent after the sixth growing season (fig. 2). Seedling growth was slow during the first few years but after six growing seasons, seedlings increased nearly four times in height and nearly two and one-half times in root-collar diameter (fig. 3). Average height of the seedlings after six years were over eight feet while dominant seedlings exceeded 18 feet in height.

Overview of All Planting Sites

Survival

Underplanted oak seedling survival has varied from zero to as high as 66 percent after six growing seasons. Survival on most planting sites after the first growing season has exceeded 90 percent. On many of the sites there have been a number of factors that were detrimental to seedling survival. Poor quality seedlings or poor planting quality negatively affected seedling survival on some sites. On other sites heavy browse by deer or small mammals

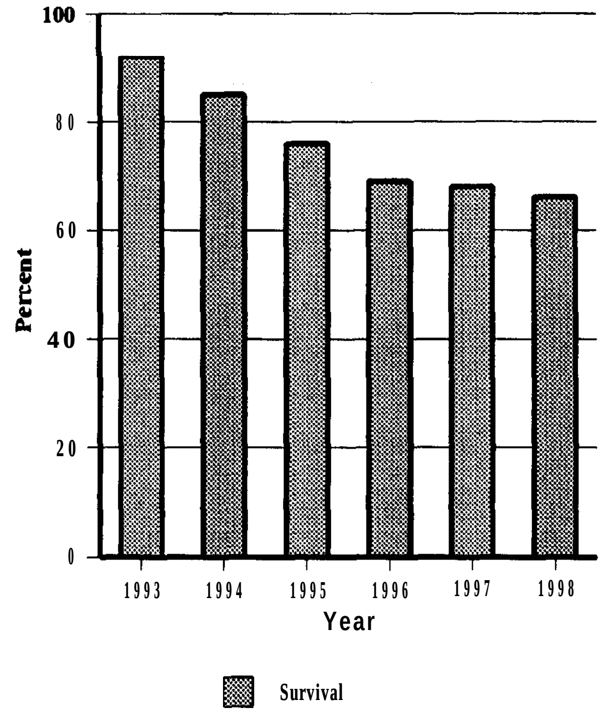

Figure 2—Ozark oak underplanting study seedling percent survival over time.

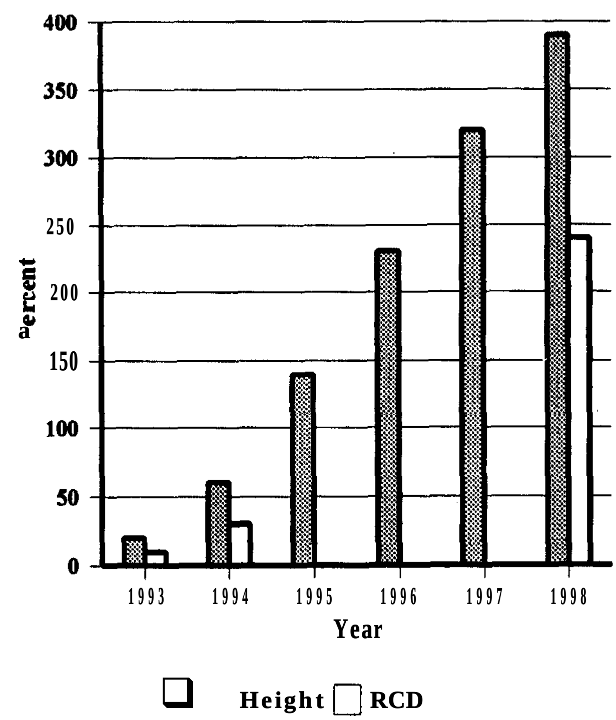

Figure Z-Ozark oak underplanting study seedling percent height and root collar diameter (RCD) growth over time.

hampered survival. Drought in 1995 contributed to reduced survival of water oak seedlings planted on sand-field edges. However, flooding during the growing season had by far the greatest adverse affect on survival. Unprecedented flooding of the Mississippi River during the growing season from 1993 through 1998 made survival rates of oak plantings on relatively high elevation sites unpredictable (fig. 1).

Growth

Seedling growth on the various planting sites has been initially slow. Many of the sites had negative height growth after the first growing season which in some cases was attributed to animal browse but in most instances was due to dieback caused by flooding during the growing season. On the more successful sites, seedlings have, on average, increased four times in height and over two and one-half times in root collar diameter after six growing seasons. After six growing seasons on three different sites, seedlings average over eight feet in height with dominant seedlings over 18 feet in height and diameter breast height (d.b.h.) of 1.5 inches.

RECOMMENDATIONS

Planting Site and Species Selection

When selecting a site for underplanting with oak it is important to examine the characteristics of the site as well as timing of silvicultural treatments. The first question to ask is can desirable regeneration be obtained naturally and in adequate numbers? If desirable regeneration cannot be obtained naturally then it is important to determine the species best suited for the site. If planting in flood prone areas, the timing, frequency, and duration of floodwaters must be considered. Sites with sandy soils will probably be better suited for water oak, while sites with very heavy clay soils may be more appropriate for willow oak. Shumard oak may be the best choice for younger, more basic soils while older more acidic soils might be more conducive to cherrybark oak. Nuttall oak may be more adapted to sites that frequently flood. However, in riverfront hardwood stands these sites are more likely to regenerate naturally to desirable species, such as green ash, and may be less of a priority for planting.

Seedling Quality, Transportation, and Storage

Obtaining a consistent supply of high quality oak seedlings can be difficult. Supplies of seedlings at hardwood nurseries are dependent on the previous year's acorn crop. ATCO has recently contracted with nurseries to supply oak seedlings that meet minimum standards of at least three-eighths of an inch root-collar diameter and with well-developed lateral roots. Once these high quality seedlings are obtained it is important that they are transported and stored properly.

Planting Quality

High quality seedlings planted on the best site may still fail if they are planted by a poorly-trained and/or poorly-supervised crew. Underplanting requires closer supervision than planting in a clearcut. Spacings in underplantings are generally wider than in plantations and it is usually more difficult for the planting crew to maintain the desired number of seedlings per acre. Pruning of seedlings roots should be held to'an absolute minimum. Many planting crews will attempt to prune nearly all of the lateral roots to ease planting but this is the worst thing that can be done in terms of seedling survival and growth. Seedlings should be planted so the root collar is level with the ground and planting slits should be closed and packed so the seedling is firmly in the ground.

Survival Checks

Underplanted oak seedlings are difficult to find after the planting site has grown-up which makes accurate estimates of survival nearly impossible without established check plots. ATCO foresters try to install survival and growth check plots throughout the planted areas as soon after planting as possible. Seedlings are numbered and flagged and also have a three-foot tall pin flag placed beside them to ease in relocation. Without these check plots it would be impossible to obtain an accurate estimate of survival and growth which may be needed to determine if additional silvicultural treatments are necessary to release seedlings.

Seedling Release

On most of ATCO planting sites underplanted seedlings have been released by removing shade tolerant species in the midstory and understory by injecting these less-desirable trees with chemicals. Care must be taken by injection crews not to contact seedlings with overspray when injecting the less-desirable trees. The chemical treatments could be done before the seedlings are planted but ATCO has not done this due to several uncertainties associated with planting hardwood seedlings. These uncertainties include the supply of seedlings, problems with planting area access, possible low survival due to flooding, and some sites may not need release treatment during the first growing season. Shade-intolerant weeds, such as giant ragweed (Ambrosia *trifida* L.), can be used as indicators of desirable light levels reaching the seedlings and can help with planning of release treatments.

Removal of the overstory will need to be planned as seedlings develop. Seedlings should be given enough time to develop a good root system before the site is logged so they will have a better chance of sprouting if damaged during the logging. If the seedlings are allowed to grow too large before the site is logged they may be more likely to break rather than bend when run over by logging equipment or hit by falling trees. Oaks that are cut or damaged during the dormant season are more likely to sprout than those cut or damaged during the growing season (Johnson 1977). Therefore, removal of the overstory during the dormant season should increase the sprout potential of seedlings damaged by logging. Sites that are logged when extremely wet will more than likely sustain more damage to the seedlings due to rutting by logging equipment.

SUMMARY

Underplanting oaks in riverfront hardwood stands on ATCO lands since 1992 has met with varied success. Less successful plantings have been affected by a number of factors including poor seedling quality, poor planting quality, heavy animal browse, and inundation by flood waters during the growing season. Unprecedented flooding of the Mississippi River during the growing season has had the most adverse affect on oak underplanting success. Where plantings have been successful seedlings have survived and grown well and have responded positively to silvicultural release treatments.

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PHOTOSYNTHETIC CHARACTERISTICS OF FIVE HARDWOOD SPECIES IN A MIXED STAND[1]

Shi Jean S. Sung, Paul P. Kormanik, and Stanley J. Zarnoch[2]

Abstract-h 1998, photosynthesis (Pn) was measured on cherrybark oak, green ash, swamp chestnut oak, sweetgum, and water hickory in a mixed stand established in February 1994. Based on the apparent quantum yield obtained from light response curves, cherrybark oak had the lowest Pn in August whereas sweetgum, green ash and water hickory were equally active in Pn. Daily August Pn of sweetgum and green ash peaked before 10 am and decreased sharply thereafter. Between 3 and 5 pm, sweetgum and green ash Pn were about 40 percent of their peak Pn. Daily September Pn did not show such sharp decreases in the afternoon for any species. Sweetgum had the highest chlorophyll level and the largest specific leaf weight in August. The ability of cherrybark oak and swamp chestnut oak to maintain leaves with adequate chlorophyll contents contributed to their active Pn in mid-December.

INTRODUCTION

Multiple species coniferous stands are generally unsuccessful because a single species usually becomes dominant in the stand due to differences in seedling growth rates. Stands with multiple hardwood species characteristically coexist in the forest with species distributions ranging from random to clumped. These mixed species stands can be invaluable for providing forest products and for providing food for wildlife.

One common and central aspect of tree physiology is that survival and growth of transplanted seedling stocks are dependent upon the availability and metabolism of sucrose (Sung and others 1994, 1995, 1998a, b). For most plants, the product of photosynthesis (Pn) is translocated in the form of sucrose to all carbon sinks such as stems and roots for growth and storage (Shiroya and others 1962). We report the photosynthetic characteristics of five hardwood species in a mixed stand 4 years after establishment. Details on the establishment of this five-hardwood species study and results of survival and growth of individual species are reported by Kormanik and others (this proceedings).

MATERIALS AND METHODS

All seedlings in this study were grown at the Georgia Forestry Commission's Flint River Nursery (Montezuma, GA) using a single hardwood nursery protocol developed by Kormanik and others (1994). Prior to sowing, soil levels of Ca, K, P, Mg, Cu, Zn, and B were adjusted to 500, 80, 80, 50, 2, 6, and 1.2 ppm, respectively. Nitrogen was applied as NH_4NO_3 at an annual rate equivalent to 1322 kg per ha. Seedling bed density for all species was 54-57 per m^2. In February 1994, two hundred 1-O seedlings from each of the five hardwood species—cherrybark oak (CBO, *Quercus pagoda* Raf.), green ash (GA, *Fraxinus pennsylvanica* Marsh.), swamp chestnut oak (SCO, Q. *michauxii* Nutt.), sweetgum *(SG, Liquidambar styraciflua* L.), and water hickory (WH, *Carya aquatica* Nutt.)—were selected from the top 50 percent of the crops based on first-order lateral root number, root collar diameter, and height (Kormanik and others, this proceedings). These seedlings were randomly planted at a 3.3 x 3.3 m spacing on a cleared 2.5-ha site at the National Environmental Research Park (Savannah River Natural Resource Management and Research Institute, New Ellenton, SC). Soil series on this site is mainly Rembert sandy loam with Hornsville fine sandy loam, Neeses loamy sand, Norfolk loamy sand, Ailey sand, and Albany loamy sand in some areas. Fertilization and vegetation control on this stand is reported in detail by Kormanik and others (this proceedings).

In 1998, three areas within the stand were systematically selected so that five species were located within a radius of 10 m of each other. These areas were at least 30 m apart. One tree from each species was tagged within each area. In August 1998, Pn light response curves were determined from each tagged tree in the three areas using a portable open-system infra-red gas analyzer (LiCor 6400) equipped with an internal red-blue light source and a CO, mixer. Measurements were made between 8 am and 11 am (Eastern Standard Time) on one fully expanded, attached leaf from the outside canopy of each tagged tree. The same leaf was measured over a range of different levels of photosynthetic photon flux density (PPFD, 400 ~ 700 nm) levels. During Pn measurements, selected PPFD levels were used randomly with a 3- to 5-min adjustment period between measurements. The reference chamber CO, was set at 350 ppm for all measurements. Individual values of Pn obtained from three CBO, three SCO, two GA, two SG, and two WH were pooled to construct a light response curve for each species using the model of Long and Hällgren (1993):

$$Pn = \frac{Pmax\ .\ PPFD}{Km + PPFD} - Rd\ , \qquad (1)$$

where

Pmax = the maximal Pn,

Rd = the dark respiration rate, and

Km = the PPFD at one-half of Pmax.

Light compensation point (Γ, PPFD at which Pn equals zero) was calculated as

$$\frac{Rd \cdot Km}{Pmax - Rd}.$$

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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The apparent quantum yield (the slope (derivative) evaluated at the midpoint between Γ and 100 μmol m^2 per s PPFD) was

$$\frac{Pmax \cdot Km}{\left(Km + \frac{\Gamma + 100}{2}\right)^2}.$$

Light response curves were fit to the individual photosynthesis observations using PROC NLIN (SAS Institute Inc. 1987). Parameter estimates and asymptotic standard errors were obtained for Pmax, Km, and Rd. Apparent quantum yield, Γ, and Pn at 2000 μmol per m^2 per s PPFD were calculated from the estimated parameters. Due to the complex mathematical nature of these quantities, no standard errors were computed.

The same tagged trees used to obtain light response curves were measured for daily Pn between 7 am and 5 pm (Eastern Standard Time) in August and September. One fully expanded leaf randomly selected from the outside canopy of each tree was measured throughout the day. Since the selected leaves may be shaded during measurement, Pn was measured at 1600 μmol m^2 per s. The reference chamber CO, was set at 350 ppm for all measurements. In November, because of leaf discoloration and abscission, different GA and SG trees that had adequate foliage and were in the vicinity of the previously tagged ones were measured. One GA and two SG were measured in November. By December, only CBO and SCO were measured.

Leaves were harvested at the end of the daily Pn measurements, stored on ice, transported back to the laboratory, and stored at -80 °C until chlorophyll analysis was performed. A leaf segment of 1 cm^2 was weighed, quickly placed in liquid N_2, and powdered with a pestle and mortar. Ethanol (95 percent) (30:1, volume : leaf fresh weight, ml:g) and $CaCO_3$ (1:2, weight : leaf fresh weight) were used to extract chlorophyll. Immediately after centrifugation, supernatant OD's at 649, 654, and 665 nm were determined using a Beckman DU-70 spectrophotometer.

RESULTS

Light response curves for all species are curvilinear with calculated Pmax ranging between 8.7 μmol per m^2 per s for CBO to 14.1 μmol per m^2 per s for WH (table 1). Swamp chestnut oak and CBO had similar values of Pmax and Pn at 2000 μmol per m^2 per s (equivalent to full sunlight). These values were similar to and greater than greenhouse-grown second year SCO and CBO, respectively (Angelov and others 1996). Except for the apparent quantum yield, there were no statistical differences in other light response curve parameters among species. Based on the apparent quantum yield, CBO had the lowest Pn in August whereas SG, GA, and WH were equally active in Pn (table 1).

No significant differences due to time of day were observed for CBO in either August or September (fig. la). Based on the August through December data, the highest Pn was measured in November for CBO. Surprisingly, measurements taken on a cool December morning (ambient temperature 13 °C, leaf chamber temperature 18 "C) indicated that CBO photosynthesized as much as it did during the morning measurements in September (fig. la). In fact, December CBO Pn was comparable to that measured in September for GA, SG, and SCO (fig. 1).

In August, GA Pn peaked before 9 am and then decreased 58 percent from 9 am to 3 pm (fig. 1 b). Peak daily Pn for GA occurred around noon in September and remained at the same level in the afternoon. Peak August and September Pn values for GA were similar to CBO Pn (fig. la, 1 b). In contrast to CBO, November Pn for GA was lower than peak Pn of August and September (fig. 1 b). August daily Pn for SCO was similar in trend to August CBO Pn measurements

Table l-Estimates (and asymptotic standard errors) of August photosynthesis light response curve parameters for cherrybark oak (CBO), green ash (GA), swamp chestnut oak (SCO), sweetgum (SG), and water hickory (WH) in a mixed stand

Parameters	CBO	GA	SCO	SG	WH	*P*-value[a]
Pmax[b c]	8.7±0.9a[d]	10.9±0.3a	8.9±0.3a	13.5±0.3a	14.1±0.6a	0.0553
Pn at 2000 μmol m^{-2} s^{-1}	6.7a	9.8a	7.4a	11.0a	12.1a	.0366
Km	280 ±120a	121 ±13a	118 ±16a	115 ±10a	150 ±27a	.0310
Light compensation	32.4a	5.8a	15.4a	16.6a	II.Ia	.4054
Apparent quantum yield	.0249b	.0820a	.0589ab	.0892a	.0810a	.0034
Dark respiration	.9±0.6a	.5±0.3a	1.0±0.3a	1.7±0.3a	1.0±0.5a	.2716

[a] The P-value from an analysis of variance based on parameters fitted to each individual tree.
[B] Parameters for a given species were estimated with data pooled from all photosynthetic measurements collected from two or three trees for that species. Three CBO, three SCO, and two trees for the other species were measured.
[c] All parameters are in μmol m^{-2} s^{-1} except that apparent quantum yield is in mol C mol^{-1} quanta.
[d] Parameters in a row followed by the same letter are not significantly different at the a = 0.05 experimentwise error rate based on Bonferroni pairwise comparisons.

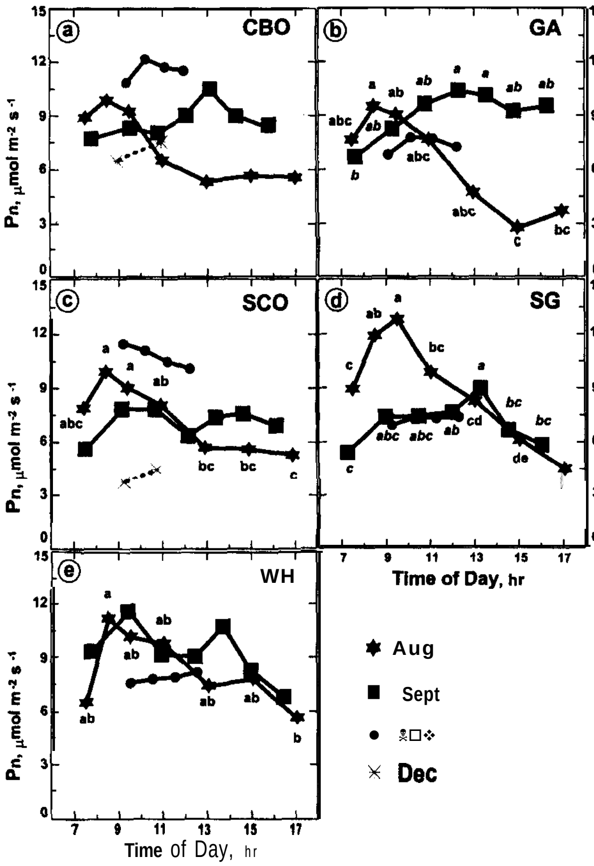

Figure l-Daily photosynthesis (Pn) of five hardwood species in a mixed stand established in February 1994. Photosynthesis (Pn) measurements were made in 1998. The same leaves were measured throughout the day with a 1800 µmol per m^2 per s photosynthetic photon flux density. (a) cherrybark oak (CBO); (b) green ash (GA); (c) swamp chestnut oak (SCO); (d) sweetgum (SG); (e) water hickory (WH). Statistical analysis was performed on time of day for August and September within each species using a randomized block design where block was tree. Symbols without a letter were not significantly different at the a = 0.05 level.

(fig. la, Ic). Peak September SCO Pn was lower than that of CBO during this month. December SCO Pn was 50 percent lower than December CBO Pn (fig. la, Ic).

Of all species Pn measurements in August, SG had the most active Pn (fig. 1). Its peak Pn occurred before 10 am. The 5 pm Pn then decreased to 33 percent of the peak (fig. Id). By mid-September, the majority of SG in this stand began to discolor. its daily peak Pn decreased from 13 µmol per m^2 per s in August to 8.5 µmol per m^2 per s in September (fig. la, 1c). By mid-November, most SG and GA leaves in the stand have completely abscised. Values of November Pn for GA, SG, and WH that still had some leaves ranged between 7 and 9 µmol per m^2 per s (fig. 1 b, 1 d, le). Unlike GA or SG, WH had similar Pn among the months.

Storage of GA leaves at -80 °C resulted in a dark discoloration. For this reason, the levels of GA chl presented in table 2 are probably under estimated. In August, SG leaves had the highest levels of chlorophyll (chl) per unit area and the largest leaf specific fresh weight (LSW) among all species (table 2). In September, chl contents increased for CBO and WH; remained the same for SCO; and decreased slightly for SG (table 2). Compared to September, November CBO and SCO chl contents increased whereas SG and WH chl decreased. The chl a to b ratios ranged from 2.07 to 3.15 and did not differ significantly among species (table 2). There were no changes in the LSW for all five species over the growing season (table 2).

DISCUSSION

To our best knowledge, this study is the first to report Pn of these hardwood species in an artificially regenerated, mixed stand. Similarities among most parameters of the light response curves for each species indicated that all five species are equally responsive to light photosynthetically. In this study all Pn measurements were conducted on leaves of the outside canopy. Light response curves might be different if leaves inside the canopy were also measured.

All species, except for CBO, had a clear daily Pn pattern in August (fig. 1). These patterns were similar among species. Furthermore, the August daily Pn patterns of all five species coincided with the summer drought (fig. 1). There was little precipitation in July and August of 1998. Low Pn in the afternoon was mainly caused by stomatal closure (data not shown). Apparently under drought conditions, these trees photosynthesize actively early in the morning and then conserve water in the afternoon by closing the stomata. By mid-September, however, several major precipitation events were recorded on this study site. No such drastic decreases in Pn (fig. 1) or stomatal conductance (data not shown) were observed in the afternoon. For most species, the daily peak Pn in September also occurred later in the morning as compared to August data.

In this study, each species had its characteristic seasonal Pn pattern. For example, WH photosynthesized similarly throughout the growing season. However, SG was most active in Pn in August but its Pn decreased the most among the five species in September. On one hand, high Pn values for SG in August were closely associated with its high chl contents. On the other hand, the summer drought of 1998 might have accelerated SG leaf discoloration thereby reducing chl contents in September. Sung and others (1994) reported g-year-old SG trees grown in sludge treated soil still had green canopy and maintained active sucrose metabolism in stems toward mid-October. However, nonfertilized SG trees discolored and their sucrose metabolism decreased sharply after August, just as in the current study. Maintenance of green leaves and thus active sucrose metabolism late in the growing season was shown to increase volume growth for sludge-grown SG as compared to the control SG (Sung and others 1994). Thus, another component relating to competitive strategies of certain tree species may be the amount of photosynthetically active leaf retention late in the growing season.

Table 2-Leaf chlorophyll a and b (chl) contents, chl a/b ratios, and leaf specific fresh weight (LSW) (and standard error) for cherrybark oak (CBO), green ash (GA), swamp chestnut oak (SCO), sweetgum (SG), and water hickory (WH) in a mixed stand

Parameters	CBO[a]	GA	SCO	SG	WH	P-value[b]
			August			
Chl, mg g^{-1}	2.13±0.07a[c]	1.46±0.21a	1.95±0.1 la	2.24±0.21a	2.23±0.16a	0.0331
Chl a/b	2.75±0.06a	2.69±0.15a	2.37±0.21a	2.07±0.28a	2.29±0.09a	.0985
Chl, mg m^{-2}	304.0±5bc	229.0±25c	296.0±26bc	472.0±12a	374.0±32ab	.0002
LSW, g m^{-2}	144.0±3b	158.0±9b	151.0±8b	213.0±14a	167.0±3b	.0010
			September			
Chl, mg g^{-1}	2.23±0.24a	1.46±0.23a	2.23±0.69a	1.80±0.17a	2.71±0.17a	.2170
Chl a/b	3.15±0.33a	3.05±0.09a	2.85±0.25a	2.29±0.27a	2.60±0.14a	.1367
Chl, mg m^{-2}	356.0±48a	249.0±53a	31 0.0±68a	432.0±64a	498.0±1 11 a	.1939
LSW, g m^{-2}	159.0±8ab	168.0±9ab	146.0±12b	239.0±17a	180.0±28ab	.0224
			November			
Chl, mg g^{-1}	2.30±0.21 a	1.39a	2.29±0.30a	1.64±0.10a	2.09±0.21a	.2204
Chl a/b	2.75±0.04a	2.58ab	3.07±0.12a	2.07±0.11b	2.30±0.02b	.0004
Chl, mg m^{-2}	471.0±59a	266a	405.0±53a	325.0±11 a	392.0±41a	.2712
LSW, g m^{-2}	203.0±11a	191a	177.0±4a	199.0±6a	190.0±17a	.5529
			December			
Chl, mg g^{-1}	1.78±0.31 a	—	1.62±0.18a	—	—	.6890
Chl a/b	2.85±0.04a	—	2.93±0.03a	—	—	.2109
Chl, mg m^{-2}	340.0±51 a	—	274.0±25a	—	—	.3083
LSW, g m^{-2}	193.0±9a	—	171 .0±16a	—	—	.3056

[a] 1-O seedlings were transplanted in February 1994. Same leaves used for daily photosynthesis measurements were harvested at the end of the day for chl analysis. One GA and two SG trees were measured in November. Only CBO and SCO were measured in December.
[b] The P-value from an analysis of variance.
[c] Parameters in a row followed by the same letter are not significantly different at the a = 0.05 experimentwise error rate based on Bonferroni pairwise comparisons.

Cherry bark oak and SCO are two examples of late season Pn. In contrast to SG, CBO and SCO increased their Pn and chl contents from August to November. The ability of CBO to maintain green leaves and photosynthesize well into the winter may enable this species to be competitive in a mixed stand. It was reported that in December both stem and taproot cambial tissue of second year nursery-grown CBO seedlings had low activities of sucrose metabolizing enzymes (Sung and others 1995). Thus, with active Pn and almost no diameter growth occurring in CBO stem and taproot in December, photosynthates probably are used for food reserves in stems and taproots and possibly for continuous lateral root development. We will follow seasonal and daily Pn in 1999 beginning in the spring to confirm the results obtained in 1998.

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ECOTYPIC VARIATION IN ATLANTIC WHITE-CEDAR IN EASTERN NORTH CAROLINA[1]

K.O. Summerville, William E. Gardner, Robert E. Bardon, and Ronald J. Myers[2]

Abstract-Remnant stands of naturally regenerated Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) are found on scattered wet sites across the North Carolina coastal plain. These sites can be grouped into three types based on soil characteristics: deep peat (organic) soils, wet mineral (usually sandy) soils, and stream flood plains. There is considerable interest in wetland forest restoration with Atlantic white-cedar because of the species' high value, and frequent failure to naturally regenerate following harvest or disturbance. Concerns about Atlantic white-cedar seedlings' potential sensitivity to site, and possible genetic variation within the species, led to this study. Open pollinated seeds were collected from five mature trees on each of five organic sites, eight wet mineral sites, and three flood plain sites across the North Carolina coastal plain. In 1993, containerized, one year old seedlings grown from these seed sources were planted on an organic soil site and a wet mineral soil site in the coastal plain of North Carolina. An additional organic site and two wet mineral sites were planted from the same seed sources in 1996. Survival and height growth for up to four years are reported and analyzed for differences among parent trees, stands seed sources, and ecotypes and soil differences. Measurements in these Atlantic white-cedar plantings show evidence of significant variation and selection opportunity with respect to early height growth and possibly seedling survival. Seedlings from parent trees found on wet mineral soils were frequently the best performers on wet mineral sites. Seedlings from parent trees found on organic soils were frequently among the best performers on organic sites. Among the collections for this study, two particular parent trees (found on wet mineral soils) produced seedlings which were among the best performers on all sites planted. Survival of planted Atlantic white-cedar in this study has been excellent despite browse damage, with significant but small differences among stands within soil groups and among parent trees.

INTRODUCTION

In recent years, landowners have expressed interest in establishing plantings of Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) in eastern North Carolina. Information from the literature does not clearly define which sites might be suitable for artificial regeneration. Mature stands are found growing on as many as three distinctive broad site types: organic soils, wet sandy mineral soils and stream flood plains (Moore and Carter 1987). Demonstration plantings have indicated that seedlings can be successfully planted on both organic and mineral soil sites. These demonstrations have also reflected adequate early seedling growth on both bedded and nonbedded sites (Gardner and others 1993).

The NC Division of Forest Resources' nursery has been refining seedling production techniques for Atlantic white-cedar for more than a decade, generally producing one year old bare root seedlings from seed easily accessible to collectors. However, concerns have remained about the species' potential sensitivity to site, and possible genetic variation. Those concerns led to the initiation of this study in 1989.

METHODS

Remnant stands throughout the range of Atlantic white-cedar across eastern North Carolina were selected for seed collections from 1989 through 1993 (fig. 1). The selected stands were categorized into three broad soil site groups: organic soils (group #1 : 5 stands); stream flood plains (group #2: 3 stands); and wet sandy mineral soils (group #3: 8 stands). Each selected parent stand was identified by a two digit number, the first digit corresponding to the soil site group and the second digit referring to the individual stand.

Within each stand up to five parent trees were identified from among the dominant and codominant trees with acceptable form and cone crops: on organic soils (group #1 : 5 stands) 25 trees; on stream flood plains (group #2: 3 stands) 15 trees; and on wet sandy mineral soils (group #3: 8 stands) 33 trees. Each parent tree was identified by a three digit number, the first digit corresponding to the broad soil site group, the second digit referring to the stand number, and the third digit referring to the individual parent tree number. Parent trees were climbed, and mature cones collected for seed extraction. The cones were collected from mid October through early December. Individual parent tree identification for all seedlings was maintained throughout the study. Additional parent tree information, such as age, height and diameter, and adjacent soil samples were collected for potential comparison with seedling performance.

Year old seedlings were grown from collected seed kept separate by parent tree and identified by soil type, stand and tree identifying numbers. Containerized seedlings were planted on study sites of both organic and wet sandy mineral soil types. Two sites were planted in 1993 (one organic in Dare County, NC and one wet mineral in Brunswick County, NC), and three additional sites were planted in 1996 (one organic in Pamlico County, NC and two wet mineral in Bladen County and Currituck County, NC). The planting design consisted of six replications per site. In 1993, enough seedlings were produced to plant 4 seedlings from each of 72 parent trees in row plots randomized within each replication. In the 1996 plantings, 6 seedlings from each parent tree were planted in randomized row plots. A seed source from New Jersey was also included in the 1996 plantings. All five sites were planted on a 6 by 8 foot

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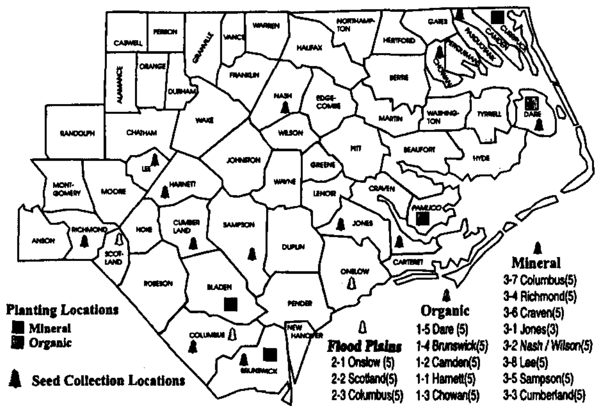

Figure l-Atlantic white-cedar seed collection and planting locations in eastern North Carolina, with stand numbers and soil groups identified.

spacing. At feast one border row of seedlings was planted around each study site, and filler trees were planted where necessary to provide surrounding competition.

Arsenal(TM) herbicide was applied before planting for vegetation control in the 1993 planting in Dare County (an old agricultural field which developed vigorous herbaceous weed cover). This organic field site was planted in May. A second application of herbicide was applied on the Dare County site in late July 1995 while the seedlings were actively growing. Some branch tip burn was produced causing a partial loss of the 1995 season's growth. The other 1993 site was a wet mineral site in Brunswick County where the previous forest cover was harvested, the site bedded, and seedlings planted on top of the beds in April. Extensive browse damage occurred on both these sites during the first growing season (1993) caused by deer and rabbits. Solar powered electric fences were erected around the sites before the second growing season (1994), and effectively reduced deer browse damage.

The 1996 plantings were established in Bladen County and Currituck County on wet sandy mineral soils and in Pamlico County on organic soil. All three of these sites were planted without bedding. On all three sites, 18 by 3 inch cylindrical plastic mesh protectors were placed around each seedling to prevent browse damage. Site preparation of the Bladen County site included harvest of the previous pine forest, drum chopping and burning, followed by planting in January. The Currituck County site was a disturbed sandy soil, planted in March. The Pamlico County site had been a cleared forest site, windrowed and used as pasture for several years prior to planting in March. Arsenal" herbicide was direct sprayed around the bases of seedlings for weed control on the Pamlico County planting in August of the second growing season (1997). The remaining two sites planted in 1996 required no control of competing vegetation.

Survival and height data were collected at various times since the plantings were established. Heights were measured to the nearest tenth of a foot. Heights at age 4 were analyzed for the 1993 plantings, and are reported here. Heights after one year were analyzed for the 1996 plantings, and compared with the older measurements for consistency in observed trends. Height measurements for seedlings have been averaged by parent tree, parent stand, and soil group for comparison of seedling performance on planting sites of different soil types.

Data were analyzed using analysis of variance with soil types, stands within soil types, and parent trees within stands (within soil types) as factors. Duncan's multiple range test was used to group stands which were not significantly different. Differences were found to be significant at the five percent level.

RESULTS

In the 1993 plantings, Atlantic white-cedar seedlings performed much better in terms of mean height at age 4 on the Brunswick County (wet mineral) site than on the Dare County (organic) site (fig. 2). On the mineral Brunswick County site, seedlings which came from parent trees in stands located on flood plain soils (group #2) produced the tallest trees on average (5.87 feet); followed by those from wet mineral soils (group #3, 5.74 feet); and finally, organic soils (group #1, 5.61 feet). On the organic Dare County site, seedlings which came from parent trees in stands located on organic soils (group #1) produced the tallest trees on average (3.95 feet); followed by the flood plain soils (group #2, 3.92 feet), with wet mineral (group #3) doing poorest (3.53 feet).

Across both 1993 plantings, the average height at age 4 of seedlings grouped by 16 parent stands ranged from tallest at 5.35 feet to shortest at 3.88 feet (table 1). Stands from flood plain soils (group #2) produced both the tallest (stand #2 3) and shortest (stand #2 1) seedlings on average.

Looking at the 1993 plantings individually, even the poorest performing parent stand on the Brunswick County site (# 2 1 at 4.4 feet) outperformed the best parent stand (#1 5 at 4.2 feet) on the Dare county site in terms of mean height at age 4 (table 2). Both the best parent stand (#2 3 at 6.6 feet) and the worst parent stand (#2 1 at 4.4 feet) as determined by

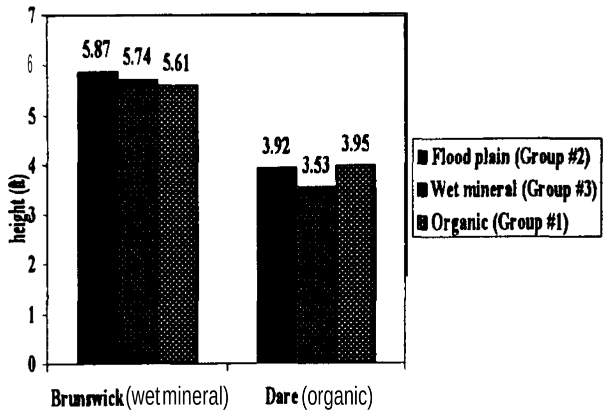

Figure P-Atlantic white-cedar mean heights after 4 years at the Brunswick and Dare County plantings, with the results grouped by parent stand soil group.

Table l-Atlantic white-cedar mean heights after 4 years combining the 1993 Brunswick and Dare plantings, with the results grouped by parent stand

Parent stand	Height	Duncan grouping
# /soil group	*Feet*	
#2 3 /flood plain	5.35	A
#1 5 /organic	5.09	AB
#3 3 /wet mineral	5.04	ABC
#1 1 /organic	4.95	ABCD
#3 1 /wet mineral	4.94	ABCD
#2 2 /flood plain	4.86	ABCDE
#3 5 /wet mineral	4.81	ABCDE
#3 4 /wet mineral	4.80	ABCDE
#1 2 /organic	4.70	BCDE
#3 8 /wet mineral	4.64	BCDE
#1 4 /organic	4.58	BCDEF
#3 8 /wet mineral	4.51	CDEF
#1 3 /organic	4.48	DEF
#3 7 /wet mineral	4.38	EF
#3 2 /wet mineral	4.09	FG
#2 1 /flood plain	3.88	G

Means associated with the same letter are not significantly different at 5 percent level by Duncan's new multiple range test.

Table 2-The parent stands which produced the tallest and shortest seedlings of Atlantic white-cedar, as indicated by height after 4 years on the Brunswick County planting and the Dare County planting

Height performance	Planting location /soil group	Parent stand	Height
		#/soil group	Feet
Tallest	Brunswick/mineral	**#2** 3 /flood plain	6.6
Tallest	Dare/organic	**#1** 5 /organic	4.2
Shortest	Brunswick/mineral	**#2** 1 /flood plain	4.4
Shortest	Dare/organic	**#3** 2 /wet mineral	3.0

seedling height at age 4 on the Brunswick County site (where height values and variation were both larger than on the Dare County site) are the same stands previously identified as best and worst in the combined analysis across both plantings. Both these stands came from flood plain soil types, though the Brunswick planting was identified as wet mineral. On the poorer performing Dare County organic site, the best performing stand was from an organic soil type, while the worst came from a wet mineral soil.

Seedlings across both 1993 planting sites were grouped by parent trees. Examining the ten parent trees with the tallest mean seeding heights at age 4, six came from wet mineral (group **#3)** soils (table 3). Note that this is a fairly high proportion, since less than half of the parent trees (35 of 72)

Table 3-The parent trees which produced the tallest Atlantic white-cedar seedlings as determined by mean heights after 4 years, combining the Brunswick and Dare plantings

Parent tree	Height
#/soil group	*Feet*
#3 5 4 / wet mineral	**5.89**
#2 3 3 I flood plain	5.87
#3 3 2 /wet mineral	5.75
#2 3 4 / flood plain	5.72
#3 7 1 / wet mineral	5.67
#3 1 1 /wet mineral	5.63
#3 3 4 / wet mineral	5.49
#2 3 5 / flood plain	5.43
#3 8 1 /wet mineral	5.41
#1 1 **4 / organic**	5.29

originated on wet mineral soils. Two of those six parent trees came from the same stand **(#3** 3). Three of the remaining four parent trees among the tallest ten ail came from a single stand **(#2** 3, flood plain soil). Seedlings from that stand averaged tallest overall as discussed above. The final parent tree among the tallest ten came from a stand originating on an organic soil **(#1** 1).

Looking at the Brunswick County wet mineral site alone, seedlings were grouped by parent trees. Examining the ten parent trees with the tallest mean seedling heights at age 4, values ranged from 7.68 feet down to 6.64 feet, considerably better than the mean value (for all 72 parent trees represented on the site) of 5.7 feet (fig. 3). The poorer performance of seedlings from these same parent trees on the Dare County organic site, and that site mean, are also included in the figure. It is notable that 8 of these ten parent trees, whose seedlings performed best in height at age 4 on this wet mineral site, came from stands found on wet mineral soils (group **#3).** This is despite the fact that seedlings whose parent trees came from flood plain soils (group **#2)** produced the tallest mean height at age 4 on this site when averaged by soil type (fig. 2). Two of these 8 wet mineral site parent trees came from a single stand **#3** 3. The remaining two parent trees among the top ten, whose average seedling performance was **2nd** and **4th** tallest, both came from stand **#2** 3, which was found on a flood plain soil. When heights of seedlings at age 4 were averaged by parent stand, **#2** 3 had the highest value both on this planting site and across both planting sites.

On the Dare County organic site, the average heights at age 4 were also grouped by parent trees. On this site, the ten parent trees with the tallest mean seedling heights ranged from 4.46 feet down to 4.20 feet, compared with a site mean (for ail 72 parent trees) of 3.8 feet (fig. 4). The performance of seedlings from these same ten parent trees is also shown for the Brunswick County wet mineral site, where most of them grew substantially taller. Six of these parent trees, whose seedlings performed best in height at age 4 on this organic site, came from stands found on organic soils (group **#1),** which also had the highest soil group average height on

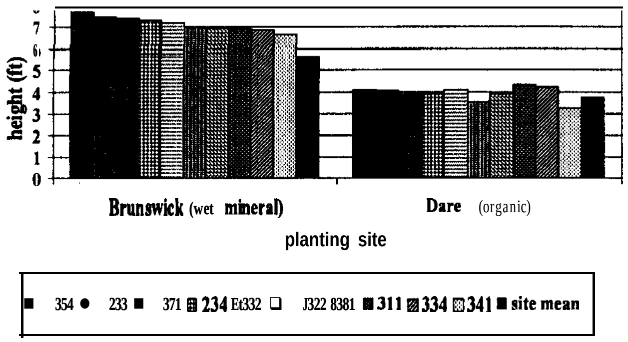

Figure 3-Atlantic white-cedar parent tree identification and mean seedling heights after 4 years for the tallest ten families on the Brunswick County mineral site, with the mean heights for the same parent trees on the Dare County planting.

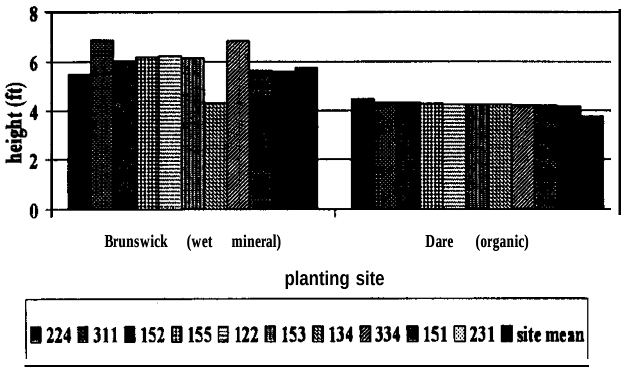

Figure 4-Atlantic white-cedar parent tree identification and mean seedling heights after 4 years for the tallest ten families on the Dare County organic site, with the mean heights for the same parent trees on the Brunswick County planting.

this site (fig. 2). This proportion can be placed in perspectiveby noting that only 25 of the 72 total parent trees were from organic sites. Four of these parent trees came from a single stand (#1 5), found in Dare County near the planting site. Two of these ten parent trees came from wet mineral sites (group #3), despite the fact that the wet mineral soil type averaged considerably poorer than the other two on this site (fig. 2). Both of the parent trees from wet mineral sites (#3 1 1 and #3 3 4) were among the ten tallest parent trees as calculated at both planting sites. The remaining two parent trees came from stands found on flood plain soils (group 2), which averaged, as a soil group, nearly as tall as the organic soil group on this planting site (fig. 2).

Measurements of seedling height and survival after one year were also made on the three 1996 planting sites. Heights at this younger age showed less variation, and most differences were not yet statistically significant. Results are reported here to the extent that they appear to support or fail to support the age 4 trends reported above.

When seedling heights after one year were averaged by parent tree for the Bladen County wet mineral planting site, four of the ten parent trees with the tallest mean seedling heights came from flood plain soils (group #2), three came from wet mineral soils (group #3) and three came from organic soils (group #1). Two of these ten parent trees were also among the ten identified as having the tallest seedlings after 4 years in the 1993 Brunswick County wet mineral planting. Four of these ten parent trees were also among those ten identified as having the tallest seedlings after 4 years on the 1993 Dare County organic planting site. One parent tree among these ten, #3 3 4, was also among the top ten identified on both 1993 plantings.

When seedling heights after one year were averaged by parent tree for the Currituck County wet mineral planting site, four of the ten parent trees with the tallest mean seedling heights came from wet mineral soils (group #3), three came from flood plain soils (group #2) and three came from organic soils (group #1). Three of these ten parent trees were also among the ten identified as having the tallest seedlings after 4 years in the 1993 Brunswick County wet mineral planting. Two of these ten parent trees were also among those ten identified as having the tallest seedlings after 4 years on the 1993 Dare County organic planting site. Again, one parent tree among these ten, #3 3 4, was also among the top ten identified on both 1993 plantings.

When seedling heights after one year were averaged by parent tree for the Pamlico County organic planting site, five of the ten parent trees with the tallest mean seedling heights came from organic soils (group #1), four came from flood plain soils (group #2) and one came from wet mineral soil (group #3). Two of these ten parent trees were also among the ten identified as having the tallest seedlings after 4 years on the 1993 Dare County organic planting site. Two of these ten parent trees were also among the ten identified as having the tallest seedlings after 4 years on the 1993 Brunswick County wet mineral planting site, both from flood plain soils (group #3).

First year seedling survival was above 90 percent for all five planted sites in spite of the extensive browse damage to both 1993 plantings. Survival after four growing seasons on the 1993 plantings still averaged 66 percent. When averaged by parent tree, survival after four years ranged from 60 percent to 96 percent. When averaged by stand, survival after four years ranged from a high of 95 percent (stand #1 5 from an organic soil) to a low of 74 percent (stand #2 1 from a flood plain soil).

CONCLUSIONS

Measurements in Atlantic white-cedar plantings show evidence of significant variation and selection opportunity with respect to early height growth and survival among parent trees, stands, and broad soil/site types in eastern North Carolina.

With respect to height at age four averaged by parent tree, most of the Atlantic white-cedar parent trees with the tallest mean seedling height across planting sites on both wet mineral and organic soils combined (six of the top ten) came from wet mineral soils. When examining height at age 4 of seedlings planted on wet mineral soil, eight of the best ten parent trees came from wet mineral soils. For seedlings planted on organic soils, six of the best ten parent trees (in terms of height at age 4) came from organic soils.

Of seed collected for this study, two Atlantic white-cedar parent trees clearly excelled in height growth of four year old offspring. Parent trees **#3 1** 1 and **#3** 3 4, both from stands found on wet mineral soils., produced seedlings among the best ten in height at age 4 when planted on both wet mineral and organic soil sites.

Based on trees sampled for this study, Atlantic white-cedar stands found on flood plain soil types appeared to exhibit more variable performance in height at age four than those from other soil types. Both the best stand **(#2** 3) and worst stand **(#2 1)** in terms of seedling height performance at age four, came from flood plain sites (group #2).

Overall survival of planted Atlantic white-cedar seedlings after four years has been good (88 percent) with statistically significant, but small differences among stands within soil groups, and among parent trees.

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INTERACTION OF SOIL MOISTURE AND SEEDLING SHELTERS ON WATER RELATIONS OF BALDCYPRESS SEEDLINGS[1]

Ty Swirin, Hans Williams, and Bob Keeland[2]

ABSTRACT—Stomatal conductance, transpiration, and leaf water potential were measured during the 1996 growing season on baldcypress (*Taxodium distichum* (L.) Rich.) seedlings. Seedlings were hand-planted from 1-O bareroot stock in mesic and permanently flooded soil conditions. One-half of all seedlings were fitted with 122-cm tall polyethylene tree shelters. Seedlings were planted 1 year before the initiation of plant water relation measurements. The study was located within the boundary of the Longhorn Army Ammunition Plant, Karnack, TX. The objective of the research was to study the feasibility of artificially regenerating baldcypress along the shores of Caddo Lake. Stomatal conductance and transpiration were consistently higher in seedlings planted in mesic soils versus seedlings planted in permanently flooded soils. Seedlings fitted with shelters regularly had higher stomatal conductance and transpiration then seedlings without shelters. Leaf water potential showed little consistency among treatments.

INTRODUCTION

Caddo Lake is an area of unique ecological importance. It is the largest natural fresh water lake in Texas with parts extending into Louisiana. Caddo Lake is divided into many smaller lakes of varying size, shape and depths separated by tree breaks and islands (Dahmer 1995). While Caddo Lake was originally formed through natural processes, a dam constructed in 1971, which replaced an original dam constructed in 1914 (Klimas 1987), now maintains the lake levels. An impressive aspect of the area is the dense stands of baldcypress (*Taxodium distichum* (L.) Rich) trees that inhabit Caddo Lake.

In the past 90 years, there has been very little recruitment of baldcypress seedlings at Caddo Lake. Baldcypress growth is below average on all but the highest annually exposed sites (Klimas 1987). Any number of factors may be responsible for the lack of baldcypress regeneration including high, stable water levels. Newly germinated seedlings can be killed by submergence in as little as 2 or 3 days (Williston and others 1980). Extended dry periods are required for seed germination and to allow the seedlings to grow tall enough to survive future flooding events (Conner and others 1986).

Herbivory may be another factor involved with the lack of baldcypress regeneration. Nutria (*Myocastor* coypus) has thwarted many efforts in artificial regeneration of baldcypress seedlings. This rodent species, introduced to Louisiana from South America in the 1930's, clips young seedlings near the root collar and eats the succulent bark (Conner and others 1986).

In natural habitats such as ponds, streams, and lakes, removal of these herbivores would be impractical. Seedling survival might be greatly increased, however, through the use of protective tree shelters. These protective shelters have also been shown to accelerate the initial height growth of seedlings (Windell and Haywood 1995).

Forested wetlands, such as Caddo Lake, perform important functions by acting as filters to help purify water and provide essential habitat for flora and fauna (Wilen and Frayer 1990). Baldcypress also acts as an important food and habitat species for many different types of wildlife. Seeds are eaten by wild turkey (*Meleagris gallopavo*), squirrels (*Sciurus* sp.), and wood ducks (*Aix sponsa*). Baldcypress foliage provides nesting habitat for bald eagles (*Haliaeetus leucocephalus*), osprey (*Pandion haliaetus*), and other top nesting birds. Catfish (*Ictalurus* sp.) use the buttress hollows for spawning (Wilhite and Toliver 1991).

OBJECTIVES

Research objectives of this proposal are: (1) to study the transpiration, stomatal conductance, and leaf water potential of baldcypress seedlings planted along different flood gradients: and (2) to study effects of protective tree shelters on transpiration, stomatal conductance, and leaf water potential of baldcypress seedlings.

METHODS

Planting

The study was located at a pond within the boundary of Longhorn Army Ammunition Plant (LHAAP) near Karnack, TX. On March 15, 1995,231 1-O bareroot seedlings were hand planted by the National Biological Service in mesic soils at 1 m by 1 m spacing. These seedlings were arranged such that every other seedling was fitted with a 122-cm tall, white polyethylene protective tree shelter. On the same date, 208 1-O bareroot seedlings were hand planted at 1 m by 1 m spacing in flooding levels ranging from 0.14 m to 0.40 m in depth. These seedlings were also arranged such that every other seedling was fitted with the polyethylene tree shelter.

Water Relations

Stomatal conductance and transpiration measurements were obtained using a LI-COR 1600 Steady State Porometer (LI-COR, Inc., 4421 Superior Street, PO Box 4425, Lincoln,

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NE., 68504, USA). Measurements were performed by randomly selecting three or four seedlings from each treatment combination. The number of seedlings measured was dictated by weather for the in-situ conditions. Measurements were physically performed by rotating through each treatment combination four times within the hour using different randomly selected seedlings. Different seedlings were utilized to prevent defoliation of young seedlings and artificially changing water relations within the seedling. The upper most mature leaf in full sunlight was selected.

Following stomatal conductance and transpiration measurements, the leaf was removed from the seedling, cataloged, and kept in cool storage. **Exact leaf area** measured in the chamber of the porometer was determined by processing each leaf through a LI-COR 3000A leaf area meter. This area was utilized to obtain corrected stomatal conductance and transpiration data.

Leaf water potential was determined by standard pressure chamber techniques (Scholander and others 1965) using a PMS pressure chamber (PMS Instruments, Corvallis, OR 97333). From each seedling, another mature sun leaf was removed using a razor blade to make a clean sharp cut.

Measurements of stomatal conductance and transpiration were conducted for a 2-day period in June 1996, a 2-day period in July 1996, a 3-day period in August 1996 and 1-day in September of 1996. Leaf water potential readings were taken for the same 2-day period in June 1996, August 1996, and the l-day reading in September 1996. Stomatal conductance and transpiration measurements were taken at midmorning, mid-day, and mid-afternoon time periods. Leaf water potential readings were taken at these same time periods but also included a predawn reading.

Analysis

Analysis of variance for a randomized complete block (RCB) design (SAS 1996) was used to test for any statistical differences in seedling water relations caused by the four treatment combinations. Significant differences between treatments are discussed at the 5 percent probability level. For each measurement period, the analysis used days as replications (blocks) with flooding and shelters as main effect. The dependent variables were transpiration, stomatal conductance, and leaf water potential.

RESULTS AND DISCUSSION

Plant Water Relations

In June 1996, stomatal conductance and transpiration were not significantly different within the flooding or shelter treatments at any of the three daily time periods. Also there was no significance among treatment interaction (table 1). Leaf water potential displayed no significant differences for this same period (table 2).

In July, transpiration was significant ($P>$ 0.0491) (table 3) during the AM readings for the seedlings planted on mesic soils. Seedlings on mesic soils were 3.30 mmols per m^2 per s compared to the flooded seedlings at 1.71 mmols per m^2 per s. There was no significance among treatment interaction for the month of July. For all treatments, observable patterns do seem to exist. In the flood treatment, seedlings planted in mesic soils recorded higher readings for all time periods of the month over the seedlings planted in permanently flooded conditions. Sheltered seedlings recorded higher readings over the nonsheltered seedlings except for the AM stomatal conductance in which both readings were similar. Mesic sheltered seedlings consistently recorded higher readings than all other treatment combinations. Only the AM stomatal conductance failed to follow the trend but was only 0.3 mmols per m^2 per s from having the highest reading.

Table l-Mean stomatal conductance (g, mmol per m^2 per s) and mean transpiration (E, mmol per m^2 per s) of 1 -year-old bare-root baldcypress (*Taxodium distichum* L.) seedlings planted March 15, 1995, near Caddo Lake on Longhorn Army Ammunition Plant at Karnack, TX. Measurements were taken June 4-5, 1996, using a Li-Cor 1600 Steady State Porometer

Treatment	AM *g*	Midday g	PM *g*	AM *E*	Midday *E*	PME
Flooding						
Mesic	41.72	63.09	51.07	0.72	2.18	1.77
Flood	51.53	55.95	40.26	1.02	2.03	1.43
P>F	.5864	.5600	.5244	.3524	.7322	.5424
Shelters						
No shelters	55.51	53.95	44.71	1.04	1.90	1.57
Sheltered	37.75	65.09	46.61	.70	2.30	1.63
P>F	.3518	.3826	.9076	.2956	.3774	.9035
Flood X shelter						
Flood-no shelter	74.75	56.52	42.38	1.44	1.97	1.48
Flood-sheltered	28.34	55.34	38.14	.60	2.08	1.51
Mesic-no shelter	36.28	51.33	47.05	.65	1.83	1.52
Mesic-sheltered	47.16	78.84	55.08	.80	2.52	1.42
P>F	.1744	.3398	.7107	.1672	.5126	.7710

Table 2-Mean leaf water potential (M Pa, Mega Pascals) of l-year-old bare-root baldcypress (*Taxodium distichum* L.) seedlings planted March 15, 1995, near Caddo Lake on Longhorn Army Ammunition Plant at Karnack, TX. Measurements were taken June 4-5, 1996 using a PMS Pressure Bomb

Treatment	Predawn	A.M.	Midday	P.M.
	Mega Pascals			
Flooding				
Mesic	-0.20	-1.14	-1.45	-1.47
Flood	-.22	-.95	-1.41	-1.44
P>F	.3390	.3505	.8064	.6652
Shelters				
No shelters	-.19	-1.12	-1.51	-1.44
Sheltered	-.23	-.97	-1.35	-1.46
P>F	.0880	.2580	.3302	.7552
Flood X shelter				
Flood-no shelter	-.21	-1.16	-1.46	-1.37
Flood-sheltered	-.23	-.74	-1.37	-1.51
Mesic-no shelter	-.16	-1.09	-1.57	-1.52
Mesic-sheltered	-.24	-1.19	-1.33	-1.42
P>F	.1873	.1088	.6481	.1419

Table 3-Mean stomatal conductance (g, mmol per m^2 per s) and mean transpiration (*E*, mmol per m^2 per s) of one-year-old bareroot baldcypress (*Taxodium distichum* L.) seedlings planted March 15, 1995, near Caddo Lake on Longhorn Army Ammunition Plant at Karnack, TX. Measurements were taken July 11-12, 1996 using a Li-Cor 1600 Steady State Porometer

Treatment	AM *g*	Midday g	PM *g*	AM *E*	Midday E	PME
Flooding						
Mesic	514.14	545.47	234.80	3.30	3.75	4.17
Flood	202.66	375.21	40.60	1.71	3.03	1.48
P>F	.0505	.1410	.9720	.0491	.3054	.9302
Shelters						
No shelters	368.19	350.02	88.30	2.48	2.53	2.09
Sheltered	348.60	570.65	251.90	2.54	4.24	4.45
P>F	.8547	.0821	.5225	.9132	.0606	.4569
Flood X shelter						
Flood-no shelter	222.10	342.12	24.57	1.83	2.26	.93
Flood-sheltered	183.21	408.29	56.59	1.90	3.80	2.03
Mesic-no shelter	514.28	357.92	120.13	3.12	2.81	2.67
Mesic-sheltered	513.99	733.02	349.53	3.48	4.69	5.67
P>F	.8568	.1691	.6898	.6012	.7870	.7404

No significant differences were found in the month of August for stomatal conductance or transpiration for either of the two treatments or for treatment interaction (table 4). Definite trends continue to exist with the mesic seedlings and sheltered seedlings exhibiting the highest water relation readings throughout all three time periods for this month. Trends for interaction carry over this month with mesic, sheltered seedlings indicating the highest readings through all time periods. A significant difference for leaf water potential for the afternoon flooding treatment did exist **($P > 0.02$)**, with the mesic seedlings having an average leaf water potential of -1.48 M Pa and flooded seedlings one of -1.29 M Pa (table 5).

Table 4—Mean stomatal conductance (g, mmoi per m^2 per s) and mean transpiration (*E*, mmoi per m^2 per s) of l-year-old bare-root baldcypress (*Taxodium distichum* L.) seedlings planted March 15, 1995, near Caddo Lake on Longhorn Army Ammunition Plant at Karnack, TX. Measurements were taken August 13-15, 1996, using a Li-Cor 1600 Steady State Porometer

Treatment	AM *g*	Midday g	PM *g*	AM *e*	Midday E	PME
Flooding						
Mesic	343.04	243.88	229.54	3.40	5.47	4.22
Flood	261.38	186.59	161.82	2.74	4.72	3.71
P>F	.3289	.2106	.1213	.2418	.4268	.4896
Shelters						
No shelters	272.13	188.50	177.42	2.77	4.66	3.80
Sheltered	332.30	241.97	213.94	3.37	5.58	4.12
P>F	.4635	.2388	.3682	.2922	.3633	.6615
Flood X shelter						
Flood-no shelter	225.25	165.37	186.79	2.37	4.19	4.23
Flood-sheltered	297.52	207.80	136.85	3.11	5.25	3.18
Mesic-no shelter	319.01	211.63	168.05	3.18	5.13	3.37
Mesiosheltered	367.08	276.13	291.02	3.63	5.81	5.06
P>F	.8800	.7962	0608	.7867	.8352	.0961

Table 5—Mean leaf water potential (M Pa, Mega Pascais of 1 year-old bare-root baldcypress (*Taxodium distichum* L.) seedlings planted March 15, 1995, near Caddo Lake on Longhorn Army Ammunition Plant at Karnack, TX. Measurements were taken August 14-15, 1996, using a PMS Pressure Bomb

Treatment	Predawn	Midday	P.M.
	.... *Mega Pascals*		
Flooding			
Mesic	-0.16	-1.62	-1.48
Flood	- .17	-1.50	-1.29
P>F	.7803	.2960	.0214
Shelters			
No shelters	- .14	-1.54	-1.4200
Sheltered	- .18	-1.59	-1.36
P>F	.2243	.5939	.4105
Flood X shelter			
Flood-no shelter	- .14	-1.45	-1.33
Flood-sheltered	- .19	-1.55	-1.25
Mesic-no shelter	- .14	-1.62	-1.50
Mesic-sheltered	- .18	-1.62	-1.47
P>F	.7500	.5939	.7195

In September of 1996, weather curtailed ail measurements to just 1 day. No significant differences were found within treatments for stomatal conductance or transpiration (table 6). There was no significance for treatment interaction. Leaf water potential did show significance for pre-dawn readings (P> 0.01) between sheltered seedlings (-0.27 M Pa) and nonsheltered seedlings (-0.16 M Pa) (table 7).

CONCLUSIONS

Some plant water relation trends are evident. in the flood treatment, seedlings planted in the mesic soils tended to have higher rates of transpiration and stomatal conductance then those planted in permanently flooded conditions. For the shelter treatments, seedlings fitted with protective tree shelters transpired at higher rates then those seedlings with out shelters. Treatment interactions suggest that, in general, the dry-sheltered seedlings exhibit the highest rates of transpiration and stomatal conductance. While there were some significant differences in leaf water potential, there were no apparent tendencies. The one constant among the water potential data was that sheltered seedlings tended not to recover as well from the previous day's stress.

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Table 6—Mean stomatal conductance (g, mmol per m^2 per s) and mean transpiration (*E*, mmol per m^2 per s) of 1 -year-old bareroot baldcypress (*Taxodium distichum* L.) seedlings planted March 15, 1995, near Caddo Lake on Longhorn Army Ammunition Plant at Karnack, TX. Measurements were taken September 13, 1996, using a Li-Cor 1600 Steady State Porometer

Treatment	AM *g*	Midday g	PM *g*	AM *e*	Midday *E*	PME
Flooding						
Mesic	242.70	246.66	361.64	3.01	3.51	4.99
Flood	214.13	240.67	246.84	2.16	3.36	3.69
P>F	.5706	.8546	.1271	.0588	.7754	.1872
Shelters						
No shelters	242.38	209.18	276.21	2.56	2.97	3.76
Sheltered	210.36	280.35	354.27	2.49	3.89	4.93
P>F	.5217	.1295	.3542	.8604	.1000	.2328
Flood X shelter						
Flood-no shelter	271.73	167.43	259.44	2.52	2.41	3.50
Flood-sheltered	156.52	313.91	238.26	1.79	4.30	3.88
Mesic-no shelter	203.25	250.92	292.98	2.60	3.53	4.02
Mesic-sheltered	282.15	246.80	470.29	3.42	3.48	5.98
P>F	.0744	.1107	.2440	.0816	.0848	.4142

Table 7—Mean leaf water potential (M Pa, Mega Pascals) of 1 -year-old bare-root baldcypress (*Taxodium distichum* L.) seedlings planted March 15,1995, near Caddo Lake on Longhorn Army Ammunition Plant at Karnack, TX. Measurements were taken September 13, 1996, using a PMS Pressure Bomb

Treatment	Predawn	A.M.	Midday
	- - - - - - - - *Mega Pascals* - - - - - - -		
Flooding			
Mesic	-0.25	-1.48	-1.47
Flood	- .18	-1.42	-1.42
P>F	.0546	.5951	.5770
Shelters			
No shelters	- .16	-1.42	-1.42
Sheltered	- .27	-1.47	-1.47
P>F	.0117	.7030	.6889
Flood X shelter			
Flood-no shelter	- .13	-1.37	-1.37
Flood-sheltered	- .22	-1.47	-1.47
Mesic-no shelter	- .18	-1.48	-1.48
Mesic-sheltered	- .32	-1.47	-1.47
P>F	.4747	.5951	.5770

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INFLUENCE OF CANOPY DENSITY ON GROUND VEGETATION IN A BOTTOMLAND HARDWOOD FOREST[1]

Sarah E. Billups and Marianne K. Burke[2]

Abstract-We investigated the influence of canopy density on ground vegetation in naturally formed gap and non-gap habitats (environments) in a blackwater river floodplain. Tree seedlings were more important (relatively more abundant) in the non-gap habitat, and grass was more important in the gap habitat, but there were elevation x habitat interactions. Also, there was an elevation x habitat interaction for species richness, with more species occurring higher on the elevational gradient and in the non-gap habitat. Because tree seedlings were similar in size in the two habitats, we concluded that naturally formed canopy gaps in this bottomland forest neither significantly increase light levels nor stimulate tree seedling growth. Also, because there was a habitat effect even after accounting for the covariates of light and elevation, we concluded that something besides elevation or light level is influencing the ground vegetation composition. Apparently, small canopy openings can increase the importance of competing plant species without improving conditions for tree seedling growth.

INTRODUCTION

Managers of bottomland hardwood forests report problems in regenerating stands to contain a component of valuable tree species, particularly oak, similar to pretreatment stands. We have a limited understanding of conditions that improve the regeneration of valuable trees in bottomland hardwood forests, although it is generally accepted that oak reproduction should be well established before the overstory is removed (Aust and others 1985). Large oak seedlings are rare in such forests due to developing oak seedlings' increasing intolerance to shade (Carvell and Tyron 1961). Hence, on moist sites, crown openings that provide sufficient sunlight for seedling establishment and survival of these relatively slow growing trees may be necessary to establish sufficient oak regeneration during the last years of rotation.

Because advance reproduction of fairly large seedlings (minimum l-cm diameter at ground level) should be present before clearcutting (Sander 1971), opening the canopy to encourage growth of advance regeneration oaks has become a common silvicultural practice in bottomland hardwood forests (McKevlin 1992, and Personal Communication with Steve Meadows, 1999, Research Forester, Southern Research Station, Stoneville, MS 38776). However, canopy openings also may stimulate the growth of potentially competing plant species such as intolerant trees, grasses, sedges, and forbs. Although regeneration of woody plants in floodplain forests has received some attention in the literature (DeSteven and Sharitz 1997, Jones and others 1994a, Streng and others 1989), little has been done on the regeneration of woody plants relative to herbaceous plants in floodplain forests.

Demographic analyses in forests undergoing gap formation or major disturbances is a useful approach for determining tree seedling pool contributions to long-term overstory dynamics (Jones and others 1994b). In Southern forested wetlands, flooding is the dominant disturbance factor, thus plant species usually are distributed along a growing-season flood gradient (Franz and Bazzaz 1977, Burke and others, In press). Flooding is not, however, the sole factor affecting vegetation dynamics within these systems. Light availability also can constrain regeneration of wetland plants (Menges and Waller 1983). The frequency, size, and distribution of canopy disturbances can influence the composition of bottomland hardwood forest stands because of differences in quality and quantity of light available to plants (Streng and others 1989).

We investigated the relative influence of light and elevation (as an index of flooding intensity) on ground vegetation diversity and the importance (relative abundance) of tree seedlings, grasses, and forbs in non-gap and naturally formed canopy gap habitats (environments). Although the community structure of ground vegetation in this bottomland hardwood forest was closely related to elevation (Burke and others, In press), little has been published about plant community structure in canopy gap and non-gap habitats along elevational gradients.

STUDY SITE

We conducted our research on the Coosawhatchie Bottomland Ecosystem Study site (fig. 1) near Coosawhatchie in Jasper County, SC (32° 40' N and 80° 55 W). The Coosawhatchie River drains a 400 km^2 watershed where forestry and agriculture are the major land uses. It is a fourth-order, anastomosing blackwater river that has a floodplain surface about 1.6-km wide and a relief of about 2-m.

The study area is composed of two weakly developed terraces, distinguished primarily by flooding frequency and surface sand size. Soils on the lower terrace consist of highly variable loamy and clayey marine and recent fluvial sediments over older, sandy fluvial sediments with an alluvial surface layer. Soils in the sloughs are silts and clays deposited by overbank flooding. Flood waters remain on the very poorly drained, low permeability soils; thus swampy, shallow pools persist. Generally, soils consist of a thick loamy surface layer underlain by interbedded, silty slackwater deposits and lenses of point bar and channel sands, surrounding reworked, relict islands of Pamlico terrace material (Murray and others, In press).

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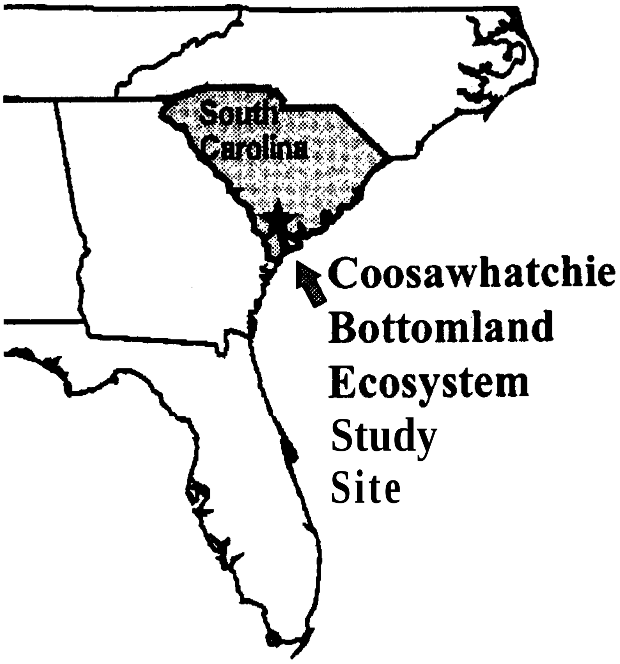

Figure I-Location of the Coosawhatchie Bottomland Ecosystem Study site.

Most soils on the site were classified in the **Brookman** series: a fine, mixed, thermic, Typic Umbraqualf, which has thick, black loamy surface layers and dark gray clayey subsoils. Scoured areas have higher silt content. Approximately 15 percent of the site was classified in the Meggett series: a fine, mixed, thermic, Typic Albaqualf. Those soils are found at a slightly higher elevation (< l-m) than the rest of the floodplain, on large islands and adjacent to upland areas. Black or dark gray surface layers are less than 25-cm thick. The Nakina series: a fine-loamy, siliceous, thermic, Typic Umbraqualf, is found in the western part of the study area, adjacent to the upland. To a depth of about **50-cm,** surface layers consist of black loam. Approximately 20 percent of the soils are characteristic of the Okeetee, **Coosaw,** Elloree, Grifton, Osier, and Rutledge series. All are composed of siliceous, sandy, and sandy loam surface layers; however, the Osier and Rutledge series are devoid of leached E and argillic B horizons. This lack of profile development in the Osier and Rutledge series supports a recent **fluvial** origin, whereas the Okeetee, **Coosaw,** Elloree, and Grifton series, which exhibit well-developed horizons, are composed of older terrace sediments.

There are four main forest community types that are closely related to hydroperiod on the site (Burke and Eisenbies, In press) : (1) the Water Tupelo Community is flooded half the time, is almost always saturated, and > 30 percent of the basal area is water tupelo *(Nyssa* ***aquatica)*** ; (2) the Sweetgum/Swamp Tupelo Community is flooded 40 percent of the time, is saturated about 80 percent of the time, and > 50 percent of the basal area is water tupelo, swamp tupelo (Nyssa ***sylvatica*** var. biflora), **sweetgum** *(Liquidambar* ***styraciflua)*****,** and red maple **(*****Acer rubrum*****)** ; (3) the Laurel Oak Community is flooded about 10 percent of the time and is saturated less than half the time. More than 15 percent of the basal areas in laurel oak *(Quercus* ***laurifolia)*** and > 40 percent is a combination of laurel oak, sweetgum, and red maple ; and (4) the Mixed Oak Community, where surface flooding has not occurred during the last 5 years and soil is saturated about 20 percent of the time. More than 30 percent of the basal areas is water oak (Q. ***nigra*****),** willow oak (Q. ***phellos*****),** and cherrybark oak (Q. ***falcata*** var. ***pagodaefolia*****).**

A prolific crop of laurel oak seedlings, established in the winter of 1995-l 996, provided a cohort of advance regeneration, which allowed us to compare ground vegetation along elevation gradients and between the gap and non-gap habitats (environments).

METHODS

The objective of this study was to estimate the influence of natural canopy openings on the composition of ground vegetation, particularly related to the tree seedling component. During the summer of 1997, ground vegetation was surveyed in plots (2- x 2-m) established in 32 canopy gaps and in 63 non-gap areas (fig. 2). The non-gap plots had been established as part of an earlier study of vegetation on the site (Burke and others, In press), and the gap plots were located at the center of established canopy gaps (King and others, In press).

Each plot was divided into four equal 1 -m^2 quadrants, and one randomly selected quadrant was used in the survey. Species composition, stem densities and percent cover for

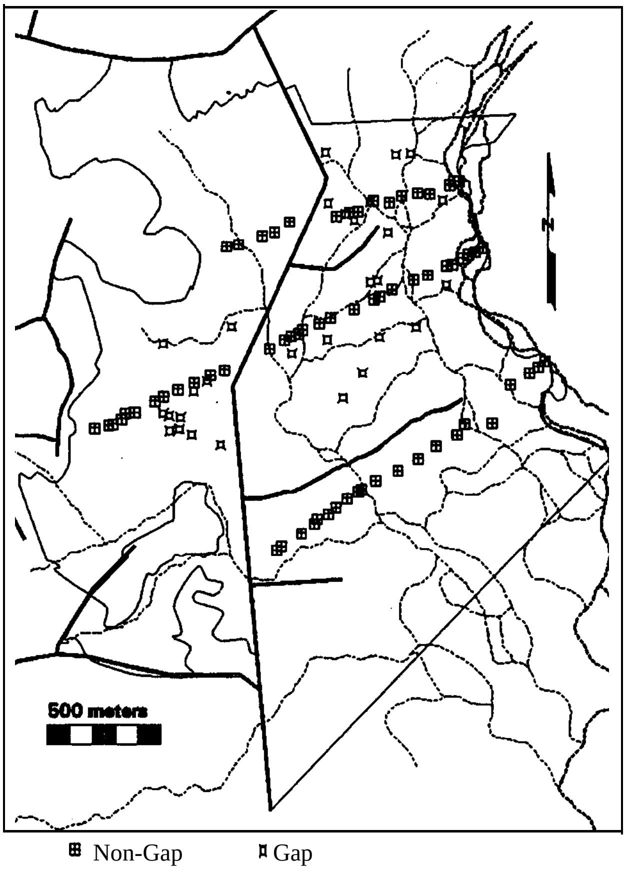

Figure **2—Map** of the study site showing the locations of the gap and non-gap plots.

each species, and relative density and relative cover were measured for all woody seedlings (< 2.5-cm diameter) and herbaceous species. Percent cover was categorized by class, based on a geologic method for estimating percent of facial surface area composed of a particular mineral (Terry and Chilingar 1955) using, instead of mineral composition, percent cover of plant **taxa.** Categories were 0= does not 'occur, 1 = > O-5 percent, 2 = 6-20 percent, 3 = **21-40** percent, 4 = 41-60 percent, 5 = 61-80 percent, 6 = 81-100 percent, and 7 = > 100 percent.

Light regimes were quantified using a portable LiCor® quantum line sensor and point sensor, connected to a LiCor® data logger. Spectral irradiance in gap and plot centers was scanned at waist height within a 350 to 800 pm waveband, which is considered photosynthetically active radiation (PAR). Eighteen readings over 5-second intervals were taken at each gap and non-gap plot center. Concurrent light measurements were taken using another LiCor® quantum point sensor place in an open field on the site. Spectral irradiance measurements were taken under clear conditions between 10:30 am and 13:30 pm, solar time, to avoid variation from sky conditions and sun elevation (St. Jacques and Bellefleur 1993).

Elevation (m) at each plot center served as an index for flooding intensity, based on the correlation between elevation and percent of time soil was inundated or saturated (Eisenbies and Hughes, In press).

Data for gap and non-gap habitats were tested for homogeneity of variance using Bartlett's test (Winer 1971) and were log-transformed before analysis when necessary. T-tests and Analysis of Covariance (ANCOVA) were used to test for habitat differences. ANCOVA was used to reduce the experimental error and remove potential sources of bias that were impossible to eliminate by study design. A probability level of 0.05 was used throughout. The effects of light and elevation served as covariates, and the response variables were richness (number of species within each plot), Shannon-Wiener diversity index (H' = $2^{H'}$, where H' represents the information for a community) (Shannon and Weaver **1949),** and absolute and relative (as percent of total) cover of trees, forbs, and grasses. Data were analyzed using SAS (SAS User's Guide 1985). Three-dimensional plots were prepared to illustrate the relationship among important response variables-by-habitat to light and elevation.

RESULTS

There were no significant differences in the percent of incident light or elevation between habitats (table 1).

Neither index of species diversity showed differences between the two habitat types when data were analyzed using t-tests: although the ANCOVA revealed that there was a habitat effect, an elevation effect, and an almost significant habitat x elevation interaction for species richness (table 2). Several plant species occurred only in canopy gaps, including fetterbush ***(Lyonia lucida)***, *Rumex* sp., spleenwort ***(Asplenium platyneuron)***, water ash *(Fraxinus caroliniana),* and persicaria ***(Polygonum*** *setaceum).* By contrast, American elm ***(Ulmus*** *americana)* and Virginia willow *(/tea* ***virginica)*** occurred only in non-gap habitats.

Laurel oak comprised 86 percent of the seedlings and 10 percent of the seedlings were red maple. Other tree species present but unimportant (<4 percent total density) were water ash, green ash *(Fraxinus* ***pennsylvanica)***, water locust ***(Gleditsia aquatica)***, American holly ***(Ilex*** *opaca),* sweetgum,

Table l--Mean (and standard error) values for response variables in non-gap and gap habitats on the Coosawhatchie Bottomland Ecosystem Study site[a]

Variable	Non-gap habitat	Gap habitat
Species richness (no. of species)	9.6 (0.67)	9.0 (0.62)
Shannon-Weiner diversity index	1.3 (0.84)	1.2 (0.10)
Density of tree seedlings (# m^{-2})	141 (24.8)	102 (23.1)
Density of grasses (# m^{-2})	31 (6.1)	46 (10.7)
Density of forbs (# m^{-2})	84 (15.2)	95 (29.5)
Relative density of tree seedlings	.49 (0.04)	.42 (0.06)
Relative density of grass	.12 (0.02)a	.24 (0.04)b
Relative density of forbs	.38 (0.04)	.32 (0.05)
Cover of tree seedings[b]	4.02 (0.26)	2.99 (0.24)
Cover of grass[b]	1.93 (0.26)a	2.84 (0.32)b
Cover of forbs[b]	5.19 (0.51)	5.14 (0.60)
Relative cover of tree seedlings	.42 (0.02)a	.28 (0.02)b
Relative cover of grass	.14 (0.01)a	.28 (0.03)b
Relative cover of forbs	.44 (0.02)	.44 (0.03)
Light (percent of incident)	.04 (0.01)	.06 (0.01)
Elevation (MSL)	4.5 (0.06)	4.4 (0.04)

'Values followed by different letters are significantly different ($p < 0.05$) based on t-tests.
[b] Categories were 0 = does not occur, 1 = > 0 to 5 percent, 2 = 6 to 20 percent, 3 = 21 to 40 percent, 4 = 41 to 60 percent, 5 = 61 to 60 percent, 6 = 61 to 100 percent, and 7 = > 100 percent.

Table 2-Results (p values for each variable and covariate) of Analysis of Covariance on ground vegetation response variables using habitat (non-gap versus gap plots) as the major independent variable of Interest and light and elevation as covariates

Source	Species richness	Shannon-Weiner Diversity Index	Relative density of tree seedlings	Relative density of grass	Relative density of forbs	Relative cover of tree seedlings	Relative cover of grass	Relative cover of forbs
Habitat	0.052	0.118	0.086	0.117	0.364	0.042	0.018	0.718
Light	.329	.580	.891	.619	.269	.380	.648	.256
Elevation	.023	.255	.893	.150	.851	.678	.207	.219
Habitat x light	.179	.137	.399	.968	.378	.218	.792	.318
Habitat x elevation	.065	.328	.085	.156	.359	.081	.038	.779

magnolia (Magnolia *grandiflora),* **blackgum (*Nyssa sylvatica*** var. ***sylvatica),*** swamp tupelo, spruce pine **(*Pinus*** *glabra),* water elm **(*Planera aquatica*), overcup** oak (Q. ***lyrata*),** swamp chestnut oak (Q. ***michauxii*),** water oak, baldcypress *(Taxodium* ***distichum*),** and American elm.

There were no differences between habitats for plant density, or for the density of tree seedlings, grasses and sedges, and forbs (table 1). In both habitats, relative tree seedling density was greater than relative forb density, which was greater than relative grass density. Relative cover in the non-gap habitat was similar for tree seedlings and forbs, which were greater than for grass cover. In the gap habitats, relative forb cover was greater than relative tree or grass cover, which were similar in magnitude. Both relative density and relative cover for grass were greater in the gap than in the non-gap habitat.

Analysis of covariance revealed no effects of light or interactions between light and habitat for any response variable. However, ANCOVA showed elevation effects and a habitat and elevation interaction for species richness, as well as habitat and elevation interactions for relative cover for grass, relative cover for tree seedlings, and relative density for tree seedlings (table 2).

The interaction between elevation and habitat was apparent when individual plot values for response variables were plotted along light and elevation gradients. High on the elevational gradient, species richness was highest in the non-gap habitat; but values were similar between habitats lower on the elevational gradient (fig. 3). Similar interactions were evident for relative density of tree seedlings (fig. **4),** relative cover of tree seedlings (fig. **5),** and relative cover of grass (fig. 6).

DISCUSSION

Previous studies have shown that canopy gaps can influence the community structure of ground vegetation via greater light levels (Platt and Strong 1989); however, the light environment did not differ between habitats in this study. Probably this was due to the small size of gaps-96 percent were substantially smaller than the estimated minimum diameter (30-m, or canopy height) needed to

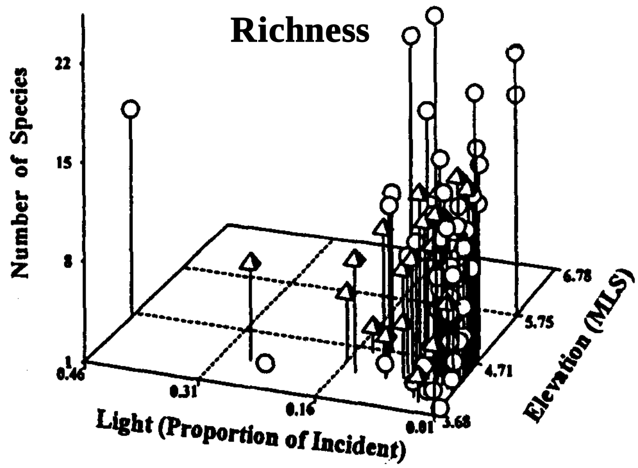

Figure 3-Three-dimensional diagram of plant species richness along elevation and light gradients in gap (pyramid) and non-gap (circle) plots.

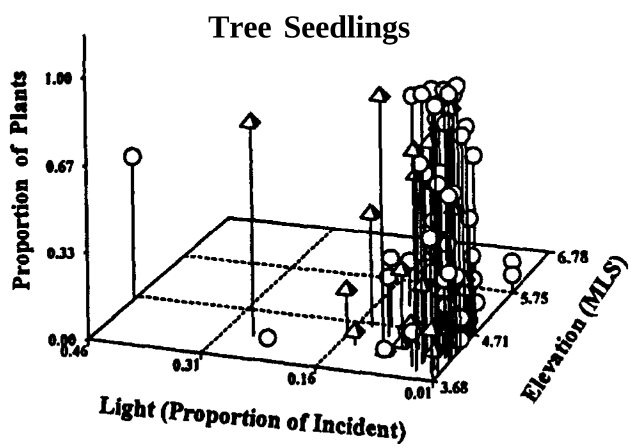

Figure 4-Three-dimensional diagram of the relative density of tree seedlings along elevation and light gradients in gap (pyramid) and non-gap (circle) plots.

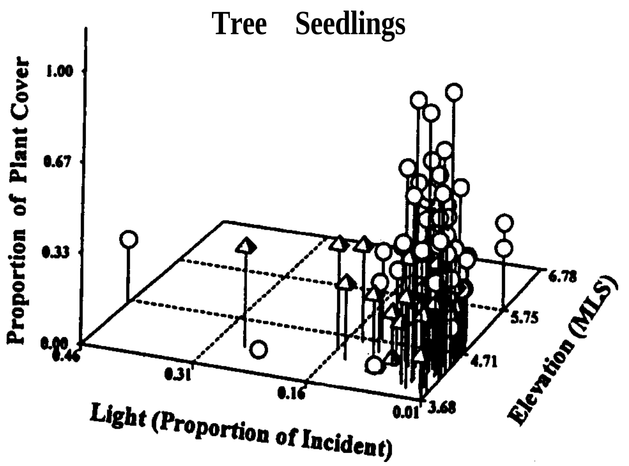

Figure 5—Three-dimensional diagram of the relative cover of tree seedlings along elevation and light gradients in gap (pyramid) and non-gap (circle) plots.

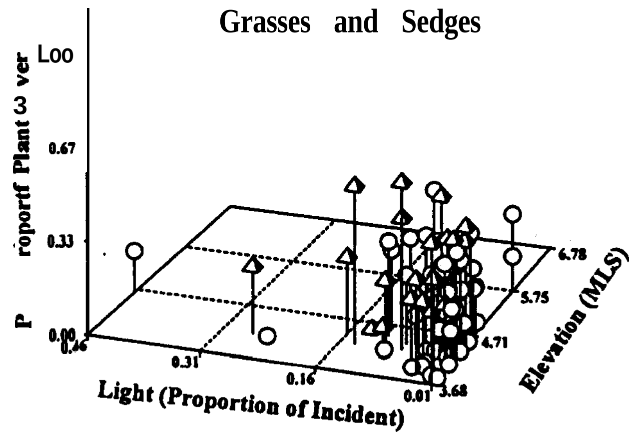

Figure 6—Three-dimensional diagram of the relative cover of grasses and sedges along elevation and light gradients in gap (pyramid) and non-gap (circle) plots.

stimulate tree seedling growth (Personal Communication. Beverly Collins. 1998. Ecologist, Savannah River Ecology Laboratory, Aiken, SC 29802). Single-tree gaps, with high canopy height-to-gap diameter ratios have little effect on understory light regimes, e.g., Canham and others 1990, and for this reason gap formation may not always prompt a strong growth response in bottomland hardwood community composition or improve tree seedling survival (Streng and others 1989).

Most ground vegetation species were not dependent on gaps. However, five species were found only in gap habitats, hence these species may be gap-phase species. The small gap size and low intensity of disturbance in gap formation (windthrow or mortality) probably provided a minimally different microenvironment, which is not typical in larger gaps. Generally, large gaps have more light, more extreme temperature and moisture regimes, and exposed mineral soil, all of which are necessary for the germination of plants more typical of gaps.

Burke and others (In press) noted the effect of elevation on species richness on the Coosawhatchie Bottomland Ecosystem Study site, but this study illustrated that habitat also affects species richness-non-gap habitat was more diverse than gap habitat. Two species were found only in non-gap habitats. However, non-gap plots were sampled more intensively (n = 63), so the study may have been biased toward identifying species that occurred in non-gaps.

Because tree seedlings were more important in the non-gap habitat and grasses were more important in the gap habitat, both might be responding to a flooding gradient in a similar way. Nonetheless, they appear to respond in a different way to canopy densities along the flooding gradient. Because we detected a habitat effect even after accounting for the covariates light and elevation, we concluded that something besides elevation or light level influenced the ground vegetation composition. Although the exact mechanism is not known, some possibilities include (1) grasses may more effectively use the small increase in light, which is characteristic of small gaps, (2) if gaps pre-date the oak regeneration, more acorns may have fallen in non-gap plots than in gap plots, where the gap-makers may have been oak trees, (3) the loss of the gap-makers removed root competition, thus liberating herbaceous plant roots from competition, and (4) windthrow exposed mineral soil in gaps, providing substrate more conducive to the germination of non-woody plant seeds. It is clear that differences between habitats could not be attributed to differences in plant communities, because elevations of the habitats were similar and elevation is the factor most important in structuring ground vegetation species composition at the site (Burke and others, In press). Nevertheless, the interaction effects between elevation and habitat suggest that further exploration of the nature and sources of this nonadditivity in the data is needed.

When tree seedling size was indexed using cover/density, tree seedlings were identical in size between habitats. This supports the finding by Streng and others (1989) that gap formation may not necessarily stimulate survival of tree seedlings. Instead, small canopy openings appear to increase the importance of other plant species that can compete for light and edaphic resources without improving conditions for growth of tree seedlings.

Not yet documented are the influence of greater light levels on growth and survival of individual tree seedlings, or the long-term significance of a thinned canopy on post-harvest tree seedling success.

ACKNOWLEDGMENTS
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SUCCESSFUL PLANTING OF TREE SEEDLINGS IN WET AREAS[1]

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Abstract-Restoration of former cypress/tupelo swamp areas in the southeastern United States usually calls for planting seedlings in standing water. Standard techniques of planting with a dibble or shovel are difficult and time-consuming. Therefore, new techniques of planting are required. We have been planting baldcypress (*Taxodium distichum* [L.] Rich.), water tupelo (*Nyssa aquatica* L.), and green ash (*Fraxinus pennsylvanica* Marsh.) at various flooded sites in South Carolina and Louisiana by several methods. One method was to simply grasp the seedling at the root collar and push them into the soil, after heavily pruning the lateral roots. Other methods included planting of commercial balled and burlap seedlings and similar homemade planting units. These were planted on the sediment surface and allowed to "settle" into the sediment over time. Excellent results have been obtained with root-pruned and balled and burlap baldcypress, while green ash was most sensitive to root pruning and water depth. Water tupelo was intermediate in response. In addition, tree shelters have been tested to see how well they protect seedlings from herbivory and increase early growth of seedlings. Tree shelters do reduce herbivory but do not eliminate it. Early growth is increased, but there are indications that non-tree shelter trees may catch up in height growth in later years.

INTRODUCTION

Although the regeneration of bottomland hardwood forests on drier sites has been the subject of considerable research, and well established methods for regenerating these stands to desired species composition have been developed (Johnson 1985), regeneration research in flooded wetland forests is limited (Clewell and Lea 1989). In many wetland areas, natural regeneration is insufficient to restock stands to desired species after disturbance (Conner and others 1986, Conner 1988). Establishment of wetland tree species requires fairly precise soil moisture conditions over several weeks to be successful. The widespread occurrence of flood-control structures and the subsequent regulation of river flows have changed the seasonality and extent of flood events, limiting natural regeneration (Schneider and others 1989). The return of the beaver (*Castor canadensis*) and the introduction and spread of nutria (*Myocastor coypus*) have also limited regeneration through herbivory. Successful regeneration of wetland forests may depend strongly on new planting techniques and methods to control herbivory.

Baldcypress (*Taxodium distichum* [L.] Rich.)and water tupelo (*Nyssa aquatica* L.) are very tolerant of flooded conditions (Hook 1984) and grow well in wet areas. Green ash (*Fraxinus pennsylvanica* Marsh.) is a common associate of baldcypress and water tupelo and is moderately tolerant to flooding. Because natural regeneration cannot be relied on, planting is often necessary to ensure that desirable species become established in the stand. Innovative planting methods are often required for these sites because of standing water, unconsolidated sediments, and herbivory. Over the past several years, we have tested several methods of planting in wet areas to determine which ones are the most effective. These methods have taken two basic approaches. First, heavily root prune seedlings so that they may be planted by simply inserting them into the soil/sediment without the necessity for any type of planting hole to be dug. Second, test a basally heavy unit (e.g. ball and burlap) that could be planted by simply placing the unit on the flooded sediment and letting it settle into the bottom. Subsequent root growth outside the root ball would stabilize the seedlings. In addition, the effectiveness of tree shelters has been tested in several areas of known beaver or nutria occurrence.

METHODS

Numerous individual studies are summarized in this paper with unique characteristics of each experiment detailed in the cited publications. Aspects common to multiple experiments are detailed below. Habitats range from standing water (backwater) to flowing water (stream), coastal to inland, and from Louisiana to South Carolina.

Root Pruning

In the first type of planting units, bareroot seedlings of baldcypress, water tupelo, and green ash were pruned to three different seventies (moderately, severely, and cutting) (figure 1). The least severe treatment (moderately) had lateral and tap roots pruned to a 23 cm spread. Severely-pruned seedlings had all of the lateral roots removed and their tap roots pruned to 23 cm. Seedlings of both of these treatments were planted by grasping the seedling at the root collar and simply inserting it into the soft sediment. Cuttings were prepared by removing all of the root system below the root collar and dipping the cut end into Rootone F, then planting by inserting the cutting 20 cm into the sediment.

Hand Bagging

A second type of planting unit was created by taking containerized or bareroot seedlings, pruning the roots as with the moderately root-pruned seedlings, and placing it in a burlap bag which was then filed with topsoil. These units were planted by placing them directly onto the bottom sediment and securing the stem to a stake driven through the bag to keep the seedling upright. The heavy basal ball settled into the sediment over time.

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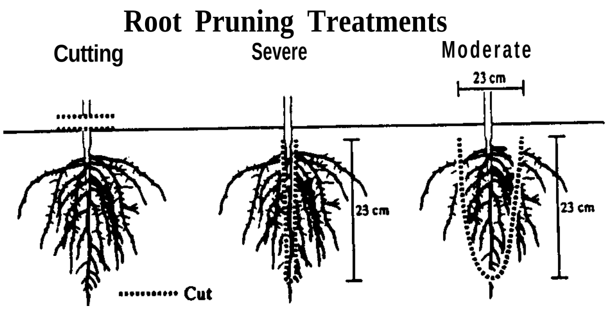

Figure 1 – Illustration of the various root pruning treatments tested.

Table I-Percent survival after 3 years for three wetland species planted with different root pruning intensities. See text for description of the different pruning techniques

Species	Cutting	Severe	Moderate
Baldcypress	33	100	100
Water tupelo	13	78	100
Green ash	0	0	0

Ball and Burlap
Balled and burlapped seedlings were purchased from a commercial nursery. These units were planted in the same manner as the hand bagged seedlings.

Tree Shelters
Sixty to 150 cm tall plastic tree shelters were used in various experiments to test their effectiveness on growth and survival. Double wall plastic shelters made by Tubex and TreePro protect seedlings from herbivores and create microenvironments with increased CO_2, humidity, and temperature. Vexar plastic mesh tubes were tried in earlier experiments (Conner and Toliver 1987) but did not provide protection from nutria.

RESULTS AND DISCUSSION
Standing water in a swamp or wetland forest is not thought to be unusual, nor are flood tolerant species thought to be killed by flooding. Yet, establishing flood tolerant species in standing water is stressful to the seedlings. Transplant shock is widely recognized to occur when transplanting seedlings into terrestrial situations. Additional shock occurs due to transplanting into standing water. Plants require water, but few species are adapted to withstand being flooded for extended periods of time. This acclimation or development of the adaptive traits has an energetic cost and would compound any stress associated with outplanting tree seedlings into any terrestrial environment. Thus, outplanting tree seedlings into standing water habitats causes a much greater stress on the seedling than does outplanting into a terrestrial environment. In addition to the normal “shock” of outplanting bareroot stock, with the need to reestablish root growth, absorption, and translocation, the existing root system would be discarded, since it is not appropriate for life in saturated soils. This is the same response that one would get when flooding any existing flood-tolerant species. The existing root system is discarded since it is not morphologically or anatomically adapted for life in standing water, and a totally new root system is produced. This discarding of the root system would also occur when seedlings are transplanted into a flooded habitat. This is a very large energetic drain on a plant during a time when the plants are exceptionally vulnerable to other damages.

No amount of root pruning was appropriate for green ash seedlings (table 1). Poor survival of this species after three years is likely due to almost permanently flooded conditions (water level at or above the soil surface) at the planting sites. Survival of baldcypress and water tupelo seedlings was excellent in both the severe and moderately root-pruned treatments. Both of these species are well suited to wet environments (Hook 1984), and pruning the root systems allows for quick and easy planting in standing water situations. Total removal of the root system was not appropriate for either baldcypress or water tupelo, although there was minimal (33 percent) survival of baldcypress cuttings after three years.

Survival of hand-bagged seedlings of baldcypress and water tupelo was similar to planting of moderately root-pruned seedlings in shallow (O-30 cm) water when protected by tree shelters (table 2). Hand-bagged green ash seedlings, however, did not do well compared to bareroot seedlings. Balled and burlapped seedlings of baldcypress and green ash survived as well as moderately root-pruned seedlings in shallow water. Balled seedlings planted on the sediment surface produced sufficient rooting down into the sediment to withstand complete drying of the surface water. Overall, there was no real benefit to using the hand-bagged or bailed and burlapped seedlings. Moderately to severely root-pruned baldcypress and water tupelo seedlings are less costly and easier to plant and survive just as well.

Moderately root-pruned seedlings of baldcypress and water tupelo planted in deeper water (30-60 cm deep) had similar survival to other types of planting units and shallower depths of water (table 2). These deeper water locations exceed the flood tolerance of green ash, and total mortality of this species was observed.

Pruned baldcypress seedlings have been planted in a number of sites throughout the southeastern United States (table 3). Survival rates range from 0 to 100 percent depending upon whether or not herbivory is a problem. The use of plastic tree shelters is essential to reduce animal damage in most wet areas. While 30 cm shelters generally tend to be enough to prevent nutria or rabbit clipping, taller shelters are necessary to prevent deer browsing. Tree shelters increased survival rates for baldcypress, water tupelo, and green ash in our experiments (table 2). The only exception was for green ash planted in 30-60 cm of water. Green ash apparently cannot survive in the deep water and should not be planted in wet areas. Similar results were reported by Conner and others (in press).

Tree shelters are not a guarantee that animal herbivory will not occur. We observed beaver herbivory on seedlings if

Table 2-Percent survival after 3 years of winter-planted seedlings with and without tree shelters for three wetland species planted as moderately root-pruned (MP), hand-bagged (HB), and balled and burlapped (B&B) seedlings in shallow (S; O-30 cm) and deep (D; 30-60 cm) water in backwater and stream edge sites

	Backwater site							
	No tree shelter				With tree shelter			
Species	SMP	DMP	HB	B&B	SMP	DMP	HB	B&B
Baldcypress	95	100	100	100	100	100	100	100
Water tupelo	60	60	65	NA	80	90	70	NA
Green ash	65	10	25	95	100	0	30	100
	Stream edge							
	No tree shelter				With tree shelter			
Baldcypress	55	100	95	100	175	100	100	100
Water tupelo	35	25	50	NA	85	65	75	NA
Green ash	45	0	30	45		0	30	75

NA = not available.

Table 3-Percent survival of root-pruned baldcypress seedlings planted in Louisiana and South Carolina. Seedling protection in all sites was by tree shelters except for wire fences used by Conner and Flynn (1989) and Hesse and others (1998)

	Percent survival			
Site	No protection	Protected	Problem	Reference
Chacahoula, LA	0	—	Nutria	Conner 1988
Bayou Chevreuil, LA	0		Nutria	"
Golden Star, LA	0	- 0	Nutria	"
Lake Boeuf, LA	0	0	Nutria	"
Melodia, La[a]	0	0	Nutria	"
Lake Verret, La[b]	63	65	Nutria	"
	0	70	Nutria	Conner and Flynn 1989
Thibodaux, LA	—	0	Nutria	Hesse and others 1996
Georgetown, Sc[a]	99	100	Deer	Conner 1993
	80	92	Deer	"
	38	72	Deer	"
Pocotaligo, SC	80	—	Beaver	Conner and others 1998
Four Mile, Sc[b]	—	100	Beaver	Reed and McLeod 1994
	95[c]	100	Beaver	This paper
	55[d]	100	Beaver	"

[a] After 2 years.
[b] After 3 years.
[c] Backwater.
[d] Stream.

floodwaters exceeded the height of the tree shelter. The only way to prevent this occurring is to use shelters tall enough to be above any expected flood event. Of the three species we planted, baldcypress was the best resprouter (76 percent compared to 0 percent for water tupelo and 35 percent for green ash).

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TREE SPECIES-SOIL RELATIONSHIPS ON MARGINAL SOYBEAN LANDS IN THE MISSISSIPPI DELTA'

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Abstract-h the Mississippi Alluvial Plain, marginal soybean lands are those lands that are frequently flooded and have relatively low average soybean yields. These marginal farmlands might be regenerated to bottomland hardwood species if species-site relationships and silvicultural systems were better developed. Cost effective establishment and management of these stands will require an understanding of species-soil compatibility as well as an appreciation of the impacts of long-term soybean cropping on this relationship. Published site selection systems are evaluated within the context of afforestation on marginal soybean land in the Delta. Projected site indices and species-site suitability is given for former soybean lands on soil series that are marginal for soybean production. Potential improvements in species-site selection methods for soybean land afforestation are discussed.

INTRODUCTION

Soybean price increases during the 1970's resulted in a large amount of cleared land in the lower Mississippi Valley (Delta) (Sternitzke 1976). Some of this land is now apparently of marginal value for agriculture. In 1996, a consortium of industry, conservation and economic development agencies sought to evaluate the potential of these lands to enhance the economic and environmental integrity of the region (Amacher and others 1998). While the relative costs and benefits of soybean agriculture are well known for these lands, productive potential following reforestation remains poorly understood. Landowners, forest industry and government agencies would benefit from knowing the productivity of afforested former soybean lands to aid in land use decisions, regionwide raw material projections and development of reforestation incentive programs. Guidelines making site-specific species recommendations and productivity predictions would be most useful toward these ends.

To date, three published systems are available for matching species with site for reforestation efforts:

1. Broadfoot (1976) provides specific species recommendations and estimates a range of productivity for a limited number of soil series in the mid-south region.
2. County soil surveys are widely available in this region. The newer editions include estimates of forest productivity and recommend tree species for planting by soil series. However, these estimates are based on limited data and may be unreliable.
3. Baker and Broadfoot (1979) predict site index for several bottomland hardwood species by evaluating soil and site attributes. In the past, use of this system required intensive sampling of the planting site. However, recent county soil surveys now include necessary information and soil mapping of the region is virtually complete. In the case of former soybean lands, soil survey data combined with assumptions regarding soil and site attributes can be made permitting generic modeling of potential productivity for soil series.

The objectives of this study were to evaluate tree species-soil productivity guides to make species selection and predict potential productivity for several soil series representative of marginal soybean lands. Improvements are suggested for the further development of species selection and productivity estimation tools for old fields.

METHODS

Selection of Soils for Consideration

The study area was limited to counties located entirely or partially within the Delta in the states of Arkansas, Louisiana and Mississippi (fig. 1). Ten Delta soil series were selected for study according to the following criteria:

1. Soybean cultivation is commonly practiced.
2. Soils are poorly or somewhat poorly drained.
3. Flooding frequency ranges from occasional to frequent.
4. Soils are classified as hydric.

All soils used in this study met each of these criteria except the Dundee series, which is not hydric but often occurs in close association with several of the other soil series (Soil Conservation Service 1987). Tree species were selected for evaluation on the basis of potential to occupy bottomland sites and eventual merchantability.

Site Productivity Estimates

Estimated site productivity was calculated using the methodology developed by Baker and Broadfoot (1979). This system involves assigning point values for several soil and site criteria. For each criterion, point values are assigned in accordance with its relative importance to the growth of a particular species. When values have been assigned for each criterion, point values are summed to provide an estimate of site index for the given species and site conditions. In order to make generic estimates for economically-marginal soybean fields, several assumptions were made (table 1). In this way, species productivity estimates could be made for each soil series entirely on the basis of information available in published soil surveys. This evaluation eliminates the costs associated with on-site soil

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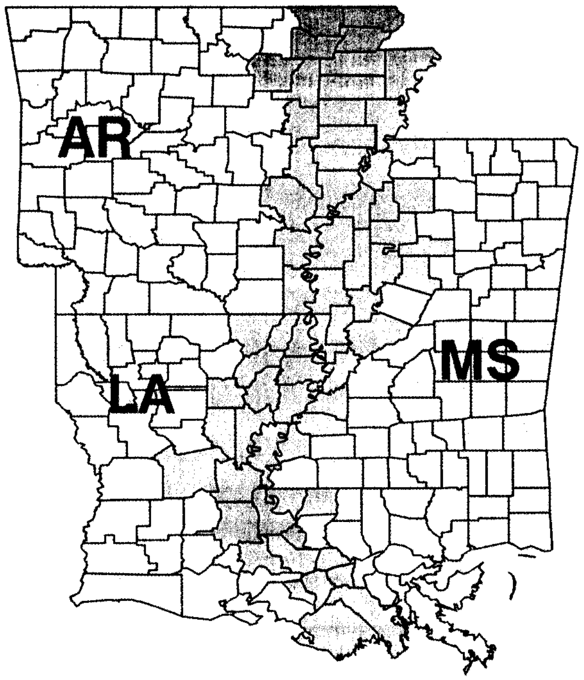

Figure 1 - Counties included in acreage estimates for soils of potentially marginal productivity for soybeans.

and site evaluation, but also may sacrifice the accuracy of these direct determinations.

RESULTS

The Soil Resource

Ten soil series meeting the established criteria cover nearly 30 percent of the Delta with Sharkey soils by far the most prevalent region wide (table 2). While current information is not available regarding the exact proportion of each of these soils in soybeans, forest, abandoned and other land uses, large portions of each of these series have been cleared for agricultural purposes. For example, the soil survey for Coahoma County, Mississippi indicated in excess of 90 percent of most selected soil series were in cultivation. Total acreage represented by selected soil series are in excess of two million acres in each of the target states for a total of greater than 7.5 million acres across the three state region.

Estimated Productivity

Cottonwood (*Populus deltoides* Bartr. ex Marsh.) tended to have high estimated productivity values on silty soils with Nuttall oak (*Quercus nuttalli* Palmer) projected to have the highest site indices on less productive clay soils, a trend generally consistent with Broadfoot (1976) and soil surveys based on non-agricultural soils (tables 3 and 4). Two of the tree species considered, Nuttall oak and green ash (*Fraxinus pennsylvanica* Marsh.), were determined to be appropriate for afforestation of former soybean fields using Baker and Broadfoot (1979) criteria, regardless of soil series (table 3). Sycamore (*Platanus occidentalis* L.), sweetgum (*Liquidambar styraciflua* L.), swamp chestnut oak (Q.

Table I-Criteria used by Baker and Broadfoot (1979) for site evaluation in bottomland hardwoods and assumptions used in this study. Values for soil type-dependent variables (SD) were obtained from soil surveys and are shown in table 2

Criterion	Source of information/assumption
Soil depth	County soil survey (all soils are deep)
Presence of a pan	County soil survey (no soils have an inherent pan, assume deep plowing to disrupt plow pans)
Soil texture	County soil survey
Soil compaction	County soil survey
Soil structure	County soil survey
Past use and cultivation	Assume more than 20 years continuous
Present cover	Assume soybean cultivation is the equivalent of annual fertilization
Water table depth	County soil survey
Topographic position	All sites are floodplain
Microsite	Assume all microsites are flat due to leveling associated with cultivation
Flooding	Soil Conservation Service 1987; County soil survey
Geologic origin	Mississippi River alluvium
Organic matter content	Assume less than one percent due to repeated cultivation
Depth of topsoil	County soil survey
Soil age	County soil survey
pH in rooting zone	County soil survey
Swampiness	County soil survey
Depth to mottling	County soil survey
Soil color	County soil survey

Table 2-Soil series with some or ail phases considered marginal for soybean production in the Mississippi Alluvial Plain of Arkansas, Louisiana and Mississippi

Series	Percent of Delta region	Area (thousands of acres)		
		Arkansas	Louisiana	Mississippi
Alligator	4.9	229	280	739
Amagon	.8	209	0	0
Bowdre	.3	52	0	31
Dundee	4.0	315	238	461
Forestdale	2.5	81	55	484
Mhoon	.6	92	48	3
Newellton	.4	58	43	5
Sharkey	13.9	1,080	1,660	781
Tensas	1.2	0	292	0
Tunica	1.2	91	105	95
Total	29.8	2,207	2,721	2,599

Table 3-Site index predictions based on Baker and Broadfoot (1979) for seven hardwood tree species for soil series likely to support marginal soybean agriculture in the lower Mississippi Valley. Missing values indicate species-soil combinations projected to be too low for further management (Baker and Broadfoot 1979)

Series	Green ash	Nuttaii oak	Sycamore	Sweetgum	Swamp chestnut oak	Water oak	Cotton-wood
Alligator	74	80	75	78	66	—[a]	—
Amagon	76	83	82	82	73	77	89
Bowdre	74	77	71	78	65	71	—
Dundee	79	83	82	88	72	80	91
Forestdale	71	76	—	—	—	—	—
Mhoon	78	82	71	76	68	—	92
Newellton	77	81	76	81	66	72	80
Sharkey	72	78	70	75	66	70	—
Tensas	73	79	70	76	66	72	—
Tunica	71	77	—	—	—	—	—

[a] No data.

michauxii Nutt.) and water oak (Q. *nigra* L.) were projected to be suitable for ail but the less productive series among the clay soils. Cottonwood was projected to be suitable for the silty soils as well as Mhoon and Newellton series, two of the more productive clay textured series.

Projected site indices for marginal soybean lands were consistently lower than estimates published in soil surveys with discrepancies typically ranging between 10 and 20 percent (table 4). Estimates calculated for soybean fields were typically below or near the lower extreme of Broadfoot (1976) for soil series where these estimates were made.

Green ash differed least between estimates based on agricultural and non-agricultural soils.

DISCUSSION

Differences between soil survey values and our estimates based on Baker and Broadfoot (1979) may reflect differences in assumptions made in forest conditions. Estimates made by Broadfoot (1977) and those incorporated in soil surveys assume natural regeneration of natural, well-stocked stands with no evidence of cutting or burning. Our assumptions using the Baker and Broadfoot (1979) guide incorporated likely changes in soil and site condition

Table 4—Estimates of soil productivity for selected species on ten soil series in the Mississippi Alluvial Plain

Series	Species	Soil survey average	Broadfoot (1976) range	Baker and Broadfoot (1976) estimate for former soybean lands	Percent difference Baker and Broadfoot (1979) and soil survey
Alligator	Cottonwood	90	80-I 00	76	-16
	Green ash	70	70-90	74	+6
	Sweetgum	80	75-95	78	-3
	Water oak	90	75-95	72	-20
Amagon	Cottonwood	100	NA	89	-11
	Green ash	80	NA	76	-5
	Nuttali oak	100	NA	83	-17
	Sweetgum	100	NA	82	-18
	Water oak	100	NA	77	-23
Bowdre	Cottonwood	110	NA	73	-34
	Sweetgum	95	NA	78	-18
	Water oak	95	NA	71	-25
Dundee	Cottonwood	100	90-I IO	91	-9
	Sweetgum	100	90-I IO	88	-12
	Water oak	95	85-105	80	-16
Forestdale	Cottonwood	100	85-105	79	-21
	Green ash	78	70-90	71	-9
	Nuttaii oak	95	80-I 00	76	-20
	Sweetgum	95	85-105	71	-25
	Water oak	90	80-I 00	65	-28
Mhoon	Cottonwood	110	NA	92	-16
	Green ash	90	NA	78	-13
	Sweetgum	100	NA	76	-24
Newellton	Cottonwood	100	105-125	80	-20
	Green ash	75	70-90	77	+3
	Nuttali oak	85	90-I IO	81	-5
	Sweetgum	95	90-I IO	81	-15
	Water oak	90	80-I 00	72	-20
Sharkey	Sweetgum	90	80-I 00	75	-17
	Water oak	90	80-I 00	70	-22
Tensas	Sweetgum	100	90-I IO	76	-24
	Water oak	95	85-105	72	-24
Tunica	Cottonwood	90	90-I IO	75	-17
	Sweetgum	90	85-I 05	73	-19

NA = not available.

associated with long-term row crop cultivation. Given the constraints of this project, it has not been possible to validate these estimates.

Agricultural soils are characterized by higher bulk density, presence of a piowpan, lower soil organic matter, altered fertility and smaller available rooting volume due to the presence of piowpans (Francis 1985; Stanturf and others, in press). However, the shrink-swell clay mineralogy and previous agricultural amendments may counteract these potential limitations. Several practices including weed control treatments, fertilizer applications, fallowing and deep plowing have been recommended to ameliorate the adverse effects of long-term agronomic practices (Baker and Biackmon 1978; Biackmon and White 1972; Francis 1985) and may largely overcome these limitations on former agricultural lands.

Over the past several decades, siivicuiturists and soil scientists have sought to improve forest regeneration success and increase yields of bottomland species. Most of this work has involved regeneration of recently cutover lands with less emphasis on afforestation of old fields. Changes in site and soil properties resulting from agriculture make extrapolation from cutover lands to marginal soybean fields difficult. Growth and yield data have not been published for hardwood stands established on old fields for at least two reasons. 1. Most stands are not well enough developed to yield reliable long-term yield data, 2. No database or survey has been published compiling growth and yield data from existing stands.

Virtually ail of the published information describing conditions and making recommendations for Delta old fields is restricted to the seedling establishment phase (Alien and

Kennedy 1989; Bullard and others 1992; Kennedy 1992). The lack of information from old field stands allowing the direct projection of rotation age yield estimates restricts us to the use of relatively speculative estimates used here. Several questions need to be addressed to quantify and increase productivity and regeneration success rate of forest stands established on old fields:

1. Does deep plowing improve productivity of hardwood plantations on soils with a large component of 2:1 clays? An informal comparison of deep plowed versus unplowed soils suggests that second year survival is not enhanced by this practice due to drying of the roots associated with soil shrinkage (Miwa, personal observation). Further, deep plowing may fail to break plowpans because of incomplete drying and the shrink and swell action of 2:1 clay soils, negating any long term benefits.
2. How do soil series differ in terms of the impact of long term agriculture on forest productivity potential?
3. Are the shapes of growth and yield curves affected by cultivation on old field sites? Also, a base age of 25 years for site index determinations may be desirable since utilization of smaller stems will shorten rotation lengths.
4. What intermediate treatments will be required to maximize productivity of various product size classes?
5. What is the economic feasibility of using nurse crops to enhance soil properties and improve tree form (McKevlin 1992)?
6. Guidelines for the establishment and management of Delta old fields should be revised incorporating recent improvements in hardwood cultivation techniques and changing product objectives. For example, cottonwood productivity on Sharkey soils may be adequate for pulpwood management if rotation lengths are shortened. Cooperation in this effort among government, industry and academic researchers and land managers would strengthen this effort.

CONCLUSIONS AND RECOMMENDATIONS

Evaluation of soil survey data using Baker and Broadfoot (1979) suggests that published values overestimate hardwood species productivity for old field sites and could lead to inappropriate species selections if soil survey recommendations are followed. It is critical to recognize that values and recommendations are based entirely on published guidelines. These values are not intended to serve as substitutes for the development of empirically based, region-specific guidelines for former agricultural fields. Rather, we hope these estimates will be used to further evaluate the relative importance of Baker and Broadfoot criteria in regenerated old field stands and help provide support for the development of the next generation of site selection and productivity estimators. Designed studies would complement the wealth of field observations and professional experience incorporated by Baker and Broadfoot and may correct widely observed overestimates of productivity resulting from the use of this method.

Improving the soil physical and chemical data provided in soil surveys as well as the nearly complete soils mapping of the region are a tremendous asset in implementing any multivariate species-site evaluation tool. However, further information is needed to account for frequency and duration of flooding and ponding. Changes in local hydrologic patterns due to the development of levee systems may also affect the species choice for a particular site. Local knowledge of past and current flooding regimes will help in making species selection recommendations for a specific site (Kennedy 1992). We suggest that a regionwide database of successful and failed old field plantings be developed to facilitate this process. Further, landowners would benefit from a revised compilation and synthesis of research results and anecdotal experience relating to forest establishment on economically marginal agricultural sites of the Delta.

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Ecological Relationships

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EFFECTS OF AS&/E-GROUND BIOMASS ALLOCATION ON SOIL NITROGEN DEMAND AND BELOW-GROUND PRODUCTIVITY: THE INFLUENCE OF STAND DENSITY'

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Abstract-Two stands in a loblolly pine (*Pinus taeda* L.) plantation were established in southeastern Louisiana in 1981 at three initial planting densities (1.2 x 1.2 m, 2.4 x 2.4 m, and 3.6 x 3.6 m). Height, height to the base of the live crown, and DBH measurements taken in consecutive years, coupled with allometric equations, yielded estimates of annual stand level foliage, branchwood, and stemwood biomass increment in each plot. Stemwood, branchwood, first-year foliage, second-year foliage, and litter tissues were obtained in each plot and analyzed for nitrogen concentration, and were used to provide estimates of annual foliar nitrogen retranslocation and above-ground nitrogen demands. Also, estimates of relative fine-root production for two collection periods were obtained in each plot by the coring method. Results indicated that stand density influenced stand-level partitioning to various above-ground component types. As partitioning patterns changed at different levels of stand density, the subsequent demand for nitrogen needed to produce the various components also changed. Changes in above-ground nitrogen demand were subsequently reflected in corresponding changes in fine-root biomass.

INTRODUCTION

Stand density exerts a strong influence on above-ground biomass allocation patterns in conifer stands, primarily through its effects on tree crowns (Dean and Baldwin 1996a). The initial number of seedlings that are planted after a stand replacing harvest have an effect on subsequent crown development and biomass allocation patterns; e.g., stands with greater initial numbers generally have less branchwood biomass as a result of a more limited space for lateral expansion of the branches as the stand ages.

Stand density influences crown development after canopy closure through its influence on foliage amount and distribution. There is a positive relationship in loblolly pine (*Pinus taeda* L.) stands between leaf area index (leaf area per unit ground area, LAI) and stand density (Dean and Baldwin 1996a). Likewise, stand density influences the distribution of the foliage; as stand density increases, the fraction of photosynthetically transmitted radiation through the crown decreases exponentially (Smith 1991), leading to a decline in the rate of photosynthesis per unit leaf mass (Korol and others 1995). With time, branches lowest in the canopy may experience a net carbon loss and self-prune, leading to a stand with a lowered canopy depth and live-crown ratio. Indeed, Dean and Baldwin (1996b) have shown that Reineke's stand density index (SDI) can be predicted solely from foliage density (leaf area per unit crown volume), mean live crown ratio, and canopy depth in loblolly pine stands. The net result is that as stand density increases, trees develop higher, more compact crowns. The compact crowns of high density stands then result in an increased mechanical load placed on the stem that subsequently induces increased stemwood production (Dean and Baldwin 1996a).

The above-ground biomass allocation patterns that result from stand density may affect below-ground production. Each of the above-ground components vary in nitrogen concentration (Switzer and others 1968). As the ratio of above-ground components changes with varying stand densities, the stand-level nitrogen needed to produce these components should then also change. The functional balance hypothesis states that as above-ground demands of a limiting factor (here, nitrogen) increase, below-ground production will increase proportionally to meet that demand (Davidson 1969).

The present study investigated the functional-balance hypothesis as it applies to stands of loblolly pine. Specifically, the two objectives of this preliminary study were to (1) determine if the above-ground stand structures that result from varying stand densities influence soil nitrogen demand, and (2) determine if any changes that occurred in the soil nitrogen demand were reflected in changes in below-ground production.

METHODS

Site

The study site was located on the Lee Memorial Forest in southeast Louisiana. The site annually receives 1620 mm precipitation and has a mean low and high temperatures of 12.5 °C and 25.5 °C, respectively. Soil is a Ruston series tine-loamy, siliceous, thermic typic Paleudult.

Data were blocked into two sites as a result of a slight fertility gradient across the study area. At each site, loblolly pine seedlings were planted in 25 x 25 m plots established after a 1981 clearcut at spacings of 1.22 x 1.22 m, 2.44 x 2.44 m, and 3.66 x 3.66 m for a total of six plots.

Prior to data collection, understory woody vegetation on the plots was eliminated by felling with a chainsaw. Residual stumps were treated with herbicide to minimize sprouting and thereby reduce variability from interspecific competition. Measurements were restricted to an inner 20 x 20 m plot to minimize edge effects.

Above-Ground Biomass Allocation

Each tree in each plot was numbered and measured for outside bark DBH, total height and height to the base of the

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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live crown after the 1996 and 1997 growing seasons. Using these measurements, standing first-year foliage, second-year foliage, stemwood, and branchwood dry weights for each tree for each year were calculated using allometric equations produced by Baldwin (1987) and Baldwin and others (1997). Stand-level stemwood and branchwood increments in each plot during 1997 were estimated by summing the differences in standing biomass for each component on each tree between the end of the 1996 and 1997 growing seasons and expanding to a per-hectare basis. Stand-level foliage increment in each plot during 1997 was estimated by summing first-year foliage for each tree in each respective plot in the 1997 growing season and expanding to a per-hectare basis. Trees that died during the 1997 growing season were assumed to have the same dimensions as at the end of the 1996 growing season, and therefore biomass increment was limited on these trees to first-year foliage.

Above-Ground Nutrient Demand

First-year foliage, second-year foliage, and branchwood samples were obtained in mid-September 1997 by shooting a mid-canopy branch from four trees in each plot with a 12-gauge shotgun, using #4 shot. Branches were selected so as to minimize damage to the residual canopy. Stemwood samples were obtained by coring four trees in each plot at breast height during the first week of December 1997. Senesced foliage samples were obtained during the first week of December 1997 during litter fall; four 1 -square meter litter traps were placed in each plot, and foliage that fell into the litter traps were collected one week later. Each component type was separated and bulked by plot, oven-dried, ground, and mixed. Each mixed sample then had three sub-samples analyzed for nitrogen concentration by the Louisiana State University Plant Analysis Laboratory. The amount of stand-level nitrogen in each component type was estimated by multiplying the standing biomass in each component by its nitrogen concentration and expanding to a per-hectare basis.

Retranslocated nitrogen in the foliage was estimated in each plot as the sum of (1) the amount of standing nitrogen in 1996 first-year foliage minus the amount of standing nitrogen in 1997 second-year foliage, plus (2) the amount of standing nitrogen in 1996 second-year foliage minus the amount of standing nitrogen in 1996 senesced foliage (product of the 1996 second-year foliage mass and the nitrogen concentration of senesced foliage).

Yearly estimates of nitrogen demand from the soil were then calculated as the per-hectare increment of each component type for the 1997 growing season times the nitrogen concentration of its respective component type minus the estimate of 1997 nitrogen retranslocation.

Below-Ground Production

A measure of relative below-ground fine-root production was estimated by sequential coring. Twenty soil cores were obtained in each plot during both July and October 1997 by driving a 5-cm diameter steel tube into the soil to a 30-cm depth. The soil cores were bulked by plot and placed into a device that washed soil through a mesh screen, leaving residual organic material. Pine roots <1 mm were extracted from the organic matter, oven dried, and weighed. Weights from both collection periods were summed by plot and scaled to stand level to provide an index of relative fine-root production.

RESULTS AND DISCUSSION

Nitrogen Demand

Stand density influenced above-ground biomass partitioning (fig. 1). Biomass allocation to the branchwood component decreased with increasing stand density as expected, while foliage and stemwood increment both increased from the low density plots to the mid-density plots, then decreased as stand density increased. Although the stand-level foliage and stemwood increment pattern was the same on both sites, it was not expected. Dean and Baldwin (1996a) found that as SDI increased in loblolly pine stands, LAI increased. Likewise, Dicus and Dean (1998) found a similar pattern on the same sites considered in the present study during 1993-1995, although the lowest values of SDI were not considered then. Long (1985) has argued against a decrease in stand-level stemwood production at the upper levels of stand density. He contended that because stand-level stemwood production was directly correlated with LAI, and LAI continued to increase up to the upper boundaries of stand density, stand-level stemwood increment should then also increase up to the upper boundaries of stand density. However, the present study shows that stand-level stemwood increment indeed appears to be correlated with foliage biomass, but unlike previous studies (Dean and Baldwin 1996a, Dicus and Dean 1998), foliage biomass decreased at the upper levels of stand density.

As expected, the nitrogen concentrations of the tree components varied, with first-year foliage having the highest concentration and stemwood having the lowest concentration (table 1). When N concentrations were combined with the increment for each respective component, total N needed for 1997 production was calculated. Of note, even though foliage increment amounted to less than half that of stemwood increment, about 70 percent of the total N found in new above-ground biomass production was found in the foliage, a result of its high N concentration. Plot values of the demand for N from the soil were calculated after N retranslocation was accounted for (fig. 2).

At both sites, above-ground, stand-level N demand increased from the low- to mid-density plots then decreased in the high-density plots (fig. 2). This pattern appears to likely result from changes in the high-N foliage with stand density. The resulting pattern at both sites indicate that stand density influenced N demand in the stands through its effect on above-ground partitioning to different components, each of which varied in N concentration.

The measure of fine-root biomass also varied with changes in stand density (fig. 1) and followed a pattern similar to N demand (fig. 2). Of most interest, as above-ground N demand increased, fine-root production increased (fig. 3). Nadelhoffer and Raich (1992) found that production of fine-roots was correlated with above-ground production. Here, fine-root production appears to be correlated to the above-ground demand of a limiting nutrient, and therefore gives some support to the functional balance hypothesis. It must be noted, however, that soil P may be more limiting to tree production than N on the study site, and will be analyzed in a future paper.

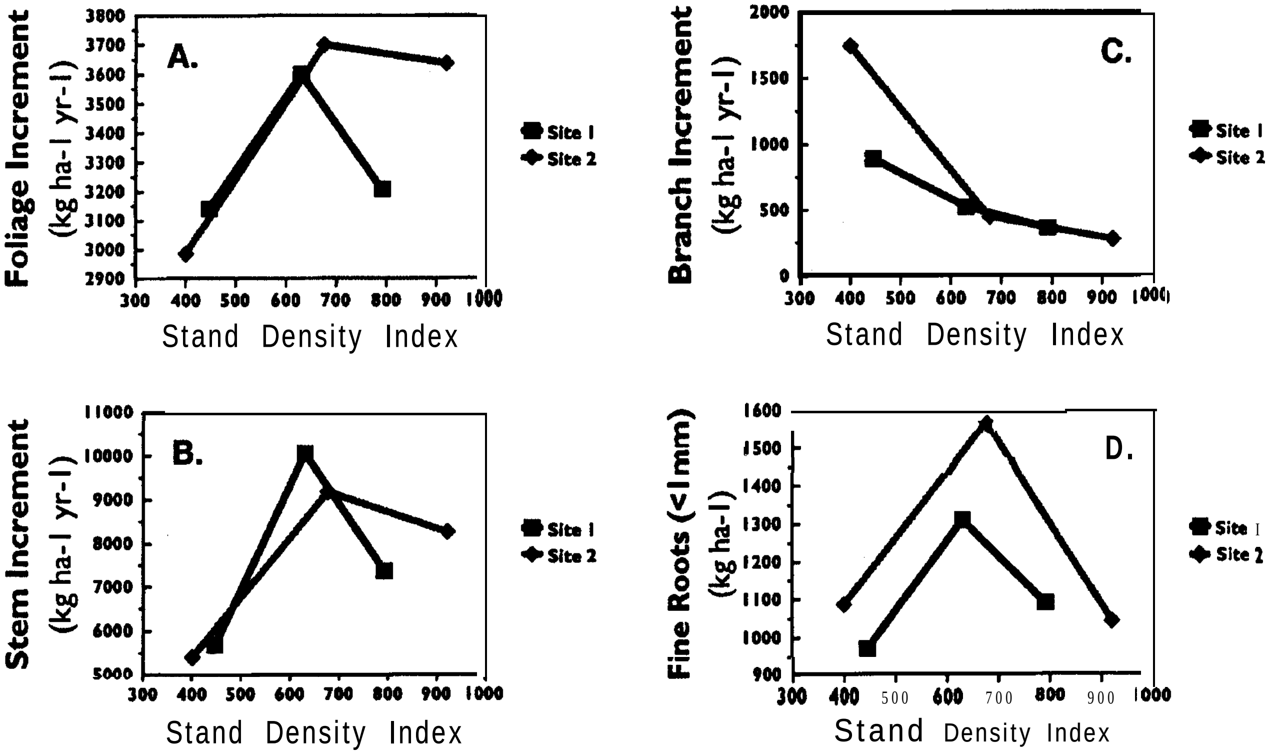

Figure I-Annual stand level biomass increments of loblolly pine (***Pinus taeda*** L.) (A) foliage, (B) stemwood, and (C) branchwood as related to Reineke's stand density index. (D) Loblolly pine fine-roots (**<1** mm) collected in two sampling periods as related to Reineke's stand density index.

Table I--Mean nitrogen concentrations of various loblolly pine (*Pinus taeda* L.) components in low, mid, and high density plots

Component	N concentration		
	Low	Mid	High
	- - - - - - - - *Percent* - - - - - - - - -		
Foliage (year-l)	1.05	1.18	1.12
Foliage (year-2)	.93	1.02	1.08
Foliage (senesced)	.48	.56	.59
Branchwood	.40	.39	.40
Stemwood	.15	.19	.16

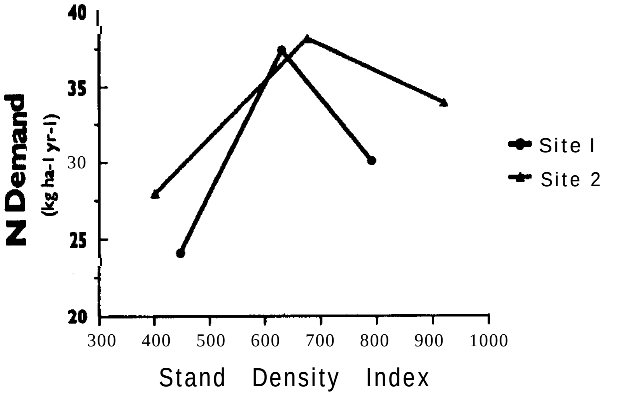

Figure **2—Annual** stand level nitrogen demand in a loblolly pine (***Pinus taeda*** L.) plantation as related to Reineke's stand density index.

CONCLUSION

Stand density appears to affect below-ground biomass production through changes in above-ground N demand, Stand density influenced biomass partitioning to the above-ground components of foliage, stemwood, and branchwood, each of which varied in N concentration. The changes in above-ground partitioning, coupled with varying N concentrations in those components, resulted in changes in above-ground N demand. Differences in above-ground N demand were somewhat related to differences in below-ground biomass production of fine-roots to meet the above-ground needs. The functional balance hypothesis is supported, but additional analyses are necessary because the present study is preliminary in nature. Fine-root turnover, which may have a significant effect on estimates of fine-root production (Vogt 1991), was not considered; this, however, is addressed in an ongoing study on the Lee Memorial Forest. In addition, another site and species is being investigated there. Also, actual estimates of N and P mineralization and uptake are being investigated.

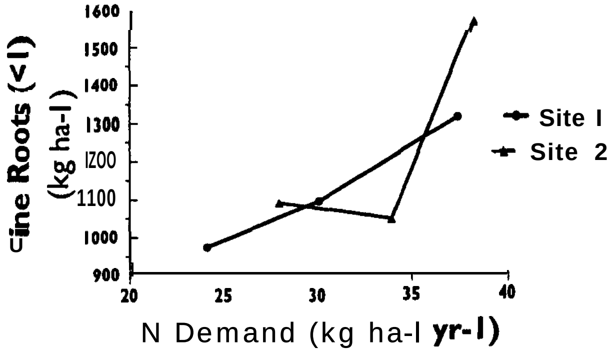

Figure 3—Stand level fine-root biomass as related to annual nitrogen demand in a loblolly pine (*Pinus taeda* L.) plantation.

The analysis of these parameters will provide greater statistical power that may provide more conclusive evidence for the functional balance hypothesis.

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DESCRIPTION OF VEGETATION IN SEVERAL PERIODICALLY BURNED LONGLEAF PINE FORESTS ON THE KISATCHIE NATIONAL FOREST[1]

James D. Haywood and Finis L. Harris[2]

Abstract-In January 1993. the Kisatchie National Forest and Southern Research Station began a cooperative project on two Ranger Districts to monitor how prescribed burning affects tree, shrub, and herbaceous vegetation in upland longleaf pine (*Pinus palustris* Mill.) forests in Louisiana. Longleaf pine is the dominant species on all four sites and represents 81 to 99 percent of the total stand basal area. On all four sites, the most frequently occurring herbaceous plants were pinehill bluestem (*Schizachyrium scoparium* var. *divergens* [Hack.] Gould), swamp sunflower (*Helianthus angustifolius* L.), and grassleaf goldaster (*Heterotheca graminifolia* [Michx.] Shinners). Despite repeated prescribed burning, canopy cover and regrowth of woody vegetation reduced the productivity and occurrence of herbaceous plants.

INTRODUCTION

The reestablishment of longleaf pine (*Pinus palustris* Mill.) on lands historically stocked by this species concerns public land managers in the Southern United States. Longleaf pine is a fire subclimax type, and prescribed burning is considered a necessary management practice, because failure to use fire allows encroachment by hardwood trees and shrubs (Boyer 1995). The formation of a closed tree and shrub canopy creates an unfavorable habitat for plants and animals that require the open and light rich environment found in periodically burned upland longleaf pine landscapes. The net effect is a poorer herbaceous plant community in terms of species richness and productivity.

Prescribed burning is used to obtain a desired future condition in longleaf forests described as open stands of pine with species rich, productive herbaceous plant communities. However, little information exists on how operational prescribed burning influences plant development, structure, and diversity in upland longleaf stands. In January 1993, the USDA Forest Service Kisatchie National Forest and Southern Research Station began a cooperative ecosystem management project on two Ranger Districts (RD) to monitor the effects of their prescribed burning programs. Results from this monitoring effort are presented.

MONITORING SITES

Sites were selected from existing stands of predominately longleaf pine that were repeatedly prescribed burned in the past and would be burned again within several months of selection. Two sites were selected on both the Catahoula and Calcasieu (originally the Vernon) RD's of the Kisatchie National Forest near Alexandria and Leesville, Louisiana, respectively. All sites were within the upland longleaf pine forest type of the humid temperate, subtropical, outer coastal plain mixed forest, and coastal plains and flatwoods Western Gulf Ecoregion of the Southern United States (McNab and Avers 1994).

The mean January and July temperatures are 10 and 28 °C on the Catahoula RD and 9 and 28 °C on the Calcasieu RD, respectively (Louisiana Office of State Climatology 1995). Annual rainfall averages 1433 mm on the Catahoula RD and 1345 mm on the Calcasieu RD and is well distributed throughout the year.

On the Catahoula RD, Stand 71 is a 15-ha stand in Compartment 71, Grant Parish, Louisiana at an average elevation of 76 m. The Ruston and Smithdale (Typic Paleudults) and Malbis (Plinthic Paleudult) sandy loams form a gently rolling upland. The compartment is intermittently prescribed burned. The last burn was in February 1993 and produced almost no crown scorch. Stand 86 is a 30-ha stand in Compartment 86, Grant Parish, Louisiana at an average elevation of 61 m. The Ruston and Smithdale sandy loams form a gently rolling upland. The compartment is prescribed burned every 2 to 3 years. The last two burns were in July 1993 and May 1995 (after the inventory) and both produced almost no crown scorch.

On the Calcasieu RD, Stand 10 is a 1 O-ha stand in Compartment IO, Vernon Parish, Louisiana at an average elevation of 76 m. The Briley (Arenic Paleudult) and Malbis soils form a slightly sloping upland. The compartment is prescribed burned every 2 to 3 years. The last burn was in March 1995 and produced some crown scorch that was concentrated in scattered areas within the stand. Stand 22 is a 16-ha stand in Compartment 22, Vernon Parish, Louisiana at an average elevation of 91 m. The Malbis sandy loam forms a slightly sloping upland. The compartment is intermittently prescribed burned. The last burn was in February 1994 and produced almost no crown scorch.

Vegetative cover is described in detail in the Results and Discussion Section of this paper. The burning techniques historically used in these four stands varied and included back, flank, striphead, and spot fires. The first three kinds of burn were started with either hand carried drip torches or power torches mounted on 4-wheelers. The spot fires were started with helicopter mounted ignition systems. The burns were done to improve wildlife habitat.

PROCEDURES

In each stand, 10 square 0.04-ha plots were established along transects that were laid out perpendicular to the topography. There were three or four plots along each transect. Woody plants with diameters at breast height

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-16, 1999.

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(d.b.h.) >10 cm were individually tagged. Total stem heights were measured with a height instrument to the nearest 30 cm and d.b.h. was measured with a diameter tape to the nearest 3 mm. The tagged vegetation was measured in May 1996 in all four stands. In Stand 71, the last prescribed burn occurred 39 months before these measurements were taken. This period was 34 months in Stand 86, 14 months in Stand 10, and 27 months in Stand 22.

Within the 0.04-ha plots, five circular 4-m^2 subplots were established for identifying and counting trees and shrubs ≤10 cm d.b.h. One subplot was placed in the center of each quarter of the main plot, and the fifth subplot was placed in the main-plot center. Only plants with their pith at groundline within the subplot were counted. Total height and crown cover of the individual stems were measured with a height pole to the nearest 3 cm. Vines were also identified and counted but height and crown spread were not measured. The woody vegetation ≤10 cm d.b.h. was inventoried in August 1995 in Stand 71, April 1995 in Stand 86, and November 1995 in Stands 10 and 22. In Stand 71, the last prescribed burn occurred 30 months before these inventories. This period was 21 months in Stand 86, 8 months in Stand 10, and 21 months in Stand 22.

In each stand, twelve 100-point transects were permanently located to evaluate the soil cover (bareground, litter, and vegetation) and inventory herbaceous plant species (Parker and Harris 1959). Transects were aligned perpendicular to the slope of the terrain. Each transect was 30 m long and readings were made every 30 cm. Readings at each point on the transects were made through a 2-cm diameter circular loop held about 30 cm above the ground and 30 cm from the eye. All herbaceous plants seen through the loop were identified and plant composition by absolute frequency was calculated from these tallies. Canopy cover was measured with a spherical densiometer at the beginning, middle, and end of each transect. The herbaceous vegetation was inventoried and the canopy cover was estimated in August 1995 in Stand 71, April 1995 in Stand 86, and October 1995 in Stands 10 and 22.

Current-year herbaceous biomass was clipped to groundline within seven 0.22-m' quadrants adjacent to each transect. The samples were oven-dried at 80 °C for at least 24 hours before determining aboveground production. Herbage production was sampled in September 1995 in Stands 71 and 86 and November 1995 in Stands 10 and 22.

RESULTS AND DISCUSSION

Woody Vegetation >10 cm d.b.h.

Table 1 displays total stocking, basal area, and canopy cover for woody plants >10 cm d.b.h. Longleaf pine was the dominant species in all stands. Based on basal area, all four stands were classed as pure longleaf pine (Helms 1998). The number of species varied. More species were present on the Catahoula RD than on the Calcasieu RD, and species other than longleaf pine represented a greater portion of the stand basal area on the Catahoula RD than on the Calcasieu RD (table 1).

Stand 71 had the greatest number of species of woody plants >10 cm d.b.h.—longleaf pine, loblolly pine (P. *faeda* L.), mockernut hickory (*Carya fomenfosa* [Poir] Nutt.), flowering dogwood (Comus *florida* L.), sweetgum (*Liquidambar styraciflua* L.), southern red oak *(Quercus falcata* Michx.), post oak (Q. *stellata* Wangenh.), black oak (Q. *velutina* Lam.), and sassafras *(Sassafras albidum* [Nutt.] Nees). In Stand 86, the woody plants > 10 cm d.b.h. were longleaf pine, loblolly pine, mockemut hickory, blackgum (*Nyssa sylvatica* Marsh.), southern red oak, blackjack oak *(Q. marilandica* Muenchh.), post oak, and black oak.

In Stand 10, the only species of woody plants >10 cm d.b.h. were longleaf pine and shortleaf pine *(P. echinafa* Mill.). In Stand 22, the woody plants > 10 cm d.b.h. were longleaf pine, loblolly pine, flowering dogwood, sweetgum, blackgum, southern red oak, blackjack oak, and tree sparkleberry *(Vaccinium arboreum* Marsh.).

Woody Vegetation ≤10 cm d.b.h.

For stems ≤10 cm d.b.h., the Catahoula RD had more tree, shrub, and vine species, more stems per hectare, and a

Table l-Number and basal area of trees and shrubs >10 cm in d.b.h. and the percentage of the stand in longleaf pine

				Basal area		
Ranger districts and stands	Total	Longleaf pine	Total	Longleaf pine	Percent longleaf pine	Total canopy cover
	Stems/hectare		.... *m^2/hectare-*			*Percent*
Catahoula RD					81	
Stand 71	279	124	24.36	19.85	90	77
Stand 86	210	153	24.40	21.89		57
Calcasieu RD						
Stand 10	420	418	22.45	22.35	99	56
Stand 22	472	415	28.51	26.68	94	61

greater average height of hardwood trees and shrubs than the Calcasieu RD (table 2). On the Catahoula RD, there were 16 tree and 16 shrub species in Stand 71 and 12 tree and 16 shrub species in Stand 86. On the Calcasieu RD, there were four tree and six shrub species in Stand 10 and 12 tree and 12 shrub species in Stand 22.

Overall, common tree species with stems ≤10 cm d.b.h. were red maple (*Acer rubrum* L.), flowering dogwood, sweetgum, blackgum, black cherry (*Prunus serotina* Ehrh.), southern red oak, post oak, and sassafras (table 2). Red maple was not in the overstory in any of the stands.

Table 2-Number of stems and average height (ht) of the common trees and shrubs ≤10 cm in d.b.h.—excluding longleaf and loblolly pine

	Catahoula RD stands				Calcasieu RD stands			
	71		86		10		22	
Taxa	Stems	Ht	Stems	Ht	Stems	Ht	Stems	Ht
	Per ha	*m*	*Per ha*	*m*	*Per ha*	*m*	*Per ha*	*m*
Trees								
Acer rubrum	346	1.3	2,323	0.8	—[a]	—	791	0.9
Cornus florida	2,768	.7	9,933	.6	—	—	49	.2
Liquidambar styraciflua	1,433	1.6	148	.3	544	.9	1,779	.9
Nyssa sylvatica	297	.6	2,372	1.1	198	.3	49	.2
Prunus serotina	939	2.1	1,631	.9	—	—	198	.4
Quercus falca ta	2,125	.7	1,631	.6	—	—	1,087	.4
Q. stella ta	198	.3	8,896	.5	—	—	—	—
Sassafras albidum	2,817	.6	4,893	.8	49	.2	—	—
Shrubs								
Callicarpa americana	5,387	1.4	3,805	1.2	—	—	297	.9
Myrica cerifera	9,489	.7	7,611	.3	99	.5	1,878	.4
Rhus copallina	3,212	.9	6,820	.5	—	—	494	.6
Rubus spp.	19,719	.9	9,390	.4	6,128	.4	10,181	.4
Vaccinium arboreum	544	.7	1,631	.6	346	.3	6,820	.6
V. virga turn, elliottii, and *stamineum*	6,870	.6	6,374	.2	2,521	.2	10,378	.3
All trees and shrubs[b]	60,146	.8	74,130	.5	10,873	.4	35,008	.4
Vines								
Berchemia scandens	10,724	—	395	—	—	—	—	—
Gelsemium sempenfirens	15,963	—	10,625	—	—	—	—	—
Lonicera japonica	297	—	17,989	—	—	—	—	—
Rubus trivialis	9,340	—	26,588	—	—	—	692	—
Smilax bona-nox, glauca, rotundifolia, and *smallii*	6,030	—	13,690	—	197	—	1,680	—
Toxicodendron toxicarium	14,282	—	9,093	—	19,916	—	6,820	—
Vitis rotundifolia and *aestivalis*	5,634	—	5,337	—	—	—	1,730	—
All vines[b]	71,117	—	86,632	—	20,113	—	12,849	—

[a] Taxon was not present when inventoried or the heights were not estimated.
[b] Number of stems and average height for all trees and shrubs and number of stems for all vines include all taxa not listed in the table, except for the pines.

This may be directly related to stem die-back produced by prescribed burning because red maple does not tolerate heat injury (Haywood 1995). Other hardwoods are also adversely affected by fire (Chen and others 1975). Prescribed burning normally results in an increase in stem numbers, which are smaller in stature, than not burning because while the tops are killed back by fire the root system is less affected (Silker 1961). However, repeated burning especially on an annual or biennial basis will eventually reduce the number and vigor of woody stems (Chen and others 1975).

Long-term trends in vegetation development may not favor oak and hickory although these taxa are currently in the >10 cm d.b.h. class. For example, in Stand 71 there are large diameter mockernut hickory and black oak but none were found in the <10 cm d.b.h. class. In Stand 86, this same diameter distribution was determined for mockernut hickory, black oak, and blackjack oak. In Stand 22, mockernut hickory was in the >10 cm d.b.h. class but not in the ≤10 cm d.b.h. class. Because oak is generally favored by burning (Barnes and Van Lear 1998), other factors may explain its absence from the ≤10 cm d.b.h. class. The number of oaks with acceptable mast yields on these sites may be insufficient for adequate regeneration: repeated prescribed burning may be causing a gradual decline in the hardwood component; and competition may be keeping oak regeneration from establishing on these sites.

Overall, common shrub taxa were American beautyberry (*Callicarpa americana* L.), southern bayberry (*Myrica cerifera* L.), shining sumac (*Rhus copalina* L.), blackberry (*Rubus* spp.), tree sparkleberry, and other blueberries (*Vaccinium* spp.) (table 2). Stocking and average height of the shrubs varied among stands.

There were 3, 9, 15, and 12 vine species in Stands 10, 22, 71, and 86, respectively. Overall, common vine taxa were rattanvine *(Berchemia scandens* [Hill] K. Koch), Japanese honeysuckle *(Lonicera japonica* Thunb.), Carolina jessamine (*Gelsemium sempervirens* [L.] Ait. f.), dewberry (*Rubus trivia/is* Michx.), greenbrier (*Smilax* spp.), poison oak *(Toxicodendron foxicarium* [Salisb.] Gillis), and grapes (*Vitis* spp.) (table 2). Vines were more common on the Catahoula than Calcasieu RD.

The longleaf and loblolly pine seedlings were poorly developed. The root collar diameters of longleaf seedlings were below 5 mm due to shading and competition for water and nutrients. Because these seedlings were too small to tolerate heat injury, each successive burn reduced the number of pine seedlings. However, the population recovered between burns. The number of longleaf pine seedlings still in the grass stage ranged from 600 per hectare 7 months after prescribed burning in Stand 10 to 13,100 per hectare 21 months after burning in Stand 86. The number of loblolly pine seedlings ranged from none in Stand 10 to 7,400 per hectare 30 months after burning in Stand 71. This regeneration cycle will continue until either natural processes or human intervention disrupts the structure of these stands.

Herbaceous Vegetation

On the Catahoula RD, the total current-year production was 452 kg per hectare (dry matter) in Stand 71 and 753 kg per hectare in Stand 86. On the Calcasieu RD the total current-year production was 1640 kg per hectare in Stand 10 and 1160 kg per hectare in Stand 22. The inventories in Stands 71, 86, and 22 determined that no bare soil was present 21 to 30 months after burning. Following burning in Stand 10, 5 percent of the soil remained exposed 8 months after the last burn. Litter covered most of the soil surface on all sites; coverage was 98 percent in Stand 71, 90 percent in Stand 86, 80 percent in Stand 10, and 94 percent in Stand 22. Vegetative cover was 9 percent in Stand 71, 21 percent in Stand 86, 22 percent in Stand 10, and 16 percent in Stand 22.

Grasses-The grasses were the most numerous group of herbaceous plants in these four upland stands based on the absolute frequency values, i.e., the number of rooted-plant occurrences per 1,200 sampling points per stand (table 3). Species or genera of grasses numbered 24 in Stand 71, 17 in Stand 86, 25 in Stand 10, and 19 in Stand 22. Across all four sites, the two most frequently occurring grass taxa were pinehill bluestem and the low panicums (*Dicanthelium* spp.), with average frequencies of occurrence of 23 and 9 percent, respectively. Pinehill bluestem was more common on the Calcasieu RD (37 percent) than on the Catahoula RD (8 percent).

Table 3-Representative grass taxa (percent frequency of occurrence exceeded 1 percent on at least one site)

	Catahoula RD stands		Calcasieu RD stands	
Taxa	71	86	10	22
	Percent			
Andropogon gerardii	2.67	0.75	0.42	0.33
Andropogon virginicus	.33	.58	.58	1.50
Aristida purpurascens	.08	1.25	1.08	1.25
Axonopus affinis	.08	—[a]	.33	1.67
Chasmanthium laxum and C. sessiliflorum	2.25	2.00	—	—
Coelorachis cylindrica	.08	—	2.42	—
Dichanthelium spp.	1.50	12.67	16.25	5.67
Eragrostis elliottii and *E. spectabilis*	.25	.08	1.92	1.25
Gymnopogon ambiguus	.17	1.42	.33	.17
Muhlenbergia expansa	.08	—	.83	2.83
Panicum anceps	1.83	1 .00	1.08	.17
Panicum virga turn	1.67	.08	—	—
Paspalum setaceum var. *cilia ti folium*	—	.08	1.92	.42
Schizachyrium scoparium var. *divergens*	7.58	8.08	45.42	29.42
Schizachyrium tenerum	—	—	3.92	1.67
Sorghastrum avenaceum	.67	1.08	—	.17
Sporobolus junceus	.33	—	.75	1.42

[a] Taxon was not present when survey was taken.

Table 4-Botanical composition of representative herbaceous plants (percent frequency of occurrence was at least 1 percent on at least one site) excluding the grasses

	Catahoula RD stands		Calcasieu RD stands	
Taxa	71	86	10	22
	Percent			
Grasslike plants				
Scleria spp.	0.42	0.08	1.41	0.17
Composites				
Helianthus angustifolius	.17	4.42	3.67	2.33
Heterotheca graminifolia	1.83	3.83	1.08	2.25
Solidago odora	—[a]	.58	2.08	—
Solidago rugosa var. *rugosa*	—	1.67	—	.17
Vemonia texana	—	.75	1.17	.17
Legumes				
All legumes	1.08	3.68	2.00	1.25
Other forbs				
Diodia teres	—		2.67	—
Euphorbia corollata	—	2.25	.17	.08
Mitchella repens	—	—	—	1.17
Oxalis violacea	—	1.33	—	—
Pycnanthemum tenuifolium	1.50	.17	—	—
Ferns				
Pteridium aquilinum var. *pseudocaudatum*	.17	17.25	1.50	3.08

[a] Taxon was not present when the inventory was taken.

Other herbaceous plants-The most frequently occurring grasslike plant on these four uplands was nutrush *(Scleria* spp.) (table 4). Only four grasslike species or genera were recorded across all four stands.

Across all four stands, the two most frequently occurring composites were swamp sunflower *(Helianthus angustifolius* L.) and grassleaf goldaster *(Heterotheca graminifolia* [Michx.] Shinners) (table 4). Their combined frequency of occurrence averaged 3 percent on the Catahoula RD and 2 percent on the Calcasieu RD. Overall, the species or genera of composites numbered 9 in Stand 71, 22 in Stand 86, 17 in Stand 10, and 9 in Stand 22.

The frequency of occurrence of the legumes averaged only 2 percent on both Ranger Districts (table 4). None of the legumes were numerous but representative species were creeping lespedeza *(Lespedeza repens* [L.] Bar-t.), pencil flower *(Stylosanthes biflora* [L.] BSP.), and Virginia tephrosia *(Tephrosia virginiana* [L.] Pers.). Eight legume taxa were present in Stand 71, fourteen in Stand 86, nine in Stand 10, and five in Stand 22.

Although several species were recorded in the other forbs group, the only species recorded in three of the four stands was flowering spurge *(Euphorbia corollata* L.) (table 4). Taxa of the other forbs numbered 10 in Stand 71, 18 in Stand 86, 17 in Stand 10, and 4 in Stand 22.

Ferns-Bracken fern *(Pteridium aquilinum* var. *pseudocaudatum* [Clute] Heller) represented 94 percent of the total fern population in all four stands and was most common in Stand 86 (table 4). Only two or three taxa of ferns were recorded on each site.

Table 5—Influence of woody plants on current-year herbaceous plant production

Stand description	Woody plants >10 cm in d.b.h. basal area	Trees and shrubs <10 cm d.b.h. Total	Trees and shrubs <10 cm d.b.h. Height	Canopy cover	Current-year herbage production
	m²/ha	*Stems/ha*	*m*	*Percent*	*kg/ha*
Catahoula RD					
Stand 71	24.4	60,146	0.8	77	452
Stand 86	24.4	74,130	.5	57	753
Calcasieu RD					
Stand 10	22.5	10,873	.4	56	1,640
Stand 22	28.5	35,008	.4	61	1,160

Effect of Woody Plants on Herbage Production

Woody plant basal area and canopy cover and the number and stature of trees and shrubs ≤10 cm in d.b.h. affected current-year herbage production on each site (table 5). Stand 71 had intermediate basal area, the greatest canopy cover, the tallest woody plants ≤10 cm d.b.h., and the least current-year production. Stand 10 had the lowest basal area and canopy cover, the fewest and shortest woody plants ≤10 cm d.b.h., and the greatest current-year production of the four sites.

Repeated prescribed burning can reduce understory woody vegetation over a number of years which may renew herbage production (Chen and others 1975, Silker 1961). However, as a pine canopy closes, the ill effects of shading by the overstory and competition for water and nutrients cannot be entirely overcome (Wolters 1982). A decline in the herbaceous community is unfortunate, because the desired future condition may not be reached. Thinning of the overstory to reduce canopy cover and continued prescribed burning to reduce small woody vegetation should improve conditions for herbaceous plant development (Grelen and Lohrey 1978).

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EFFECTS OF CROWN SCORCH ON LONGLEAF PINE FINE ROOTS[1]

Mary Anne Sword and James D. Haywood[2]

Abstract-Photosynthate production is reduced by foliage loss. Thus, scorch-induced decreases in the leaf area of longleaf pine (*Pinus palustris* Mill.) may reduce photosynthate allocation to roots. In this investigation the root carbohydrate concentrations and dynamics of longleaf pine after two intensities of prescribed burning were monitored. In September 1996, 65-year-old longleaf pine were burned. Plots of 10 trees were established in two patches each of nonscorched and scorched trees. Root carbohydrate concentrations and dynamics were monitored May 1997 through December 1998. Root sucrose and starch concentrations were lower on the scorched plots than on the nonscorched plots. One year after burning, fine root mass density and secondary root development were reduced in response to crown scorch. These results indicate that prescribed tires that cause crown scorch may reduce photosynthate allocation to roots. Further research is needed to determine the impact of tire intensity on root system growth and function.

INTRODUCTION

Maintenance of mature longleaf pine (*Pinus palustris* Mill.) ecosystems generally requires recurrent burning at a 2- to 4-year interval (Franklin 1997, Landers and others 1995). Before intensive clearing of the longleaf pine forests, this requirement was met by the natural occurrence of frequent fires (Franklin 1997, Landers and others 1995). However, with the industrial development of the Southeastern U.S., natural forest fires were prevented and prescribed fire was not considered a viable forest management tool (Landers and others 1995).

In the absence of frequent fire, loblolly (*Pinus taeda* L.) and slash pine (*Pinus elliottii* Engelm. var. *elliottii*) grow in association with longleaf pine (Brockway and Lewis 1997, Landers and others 1995). Because the nursery production and establishment of loblolly and slash pine were less difficult and costly than that of longleaf pine, most harvested longleaf pine forests were naturally or artificially regenerated with loblolly and slash pine (Landers and others 1995, Outcalt 1997).

New approaches in seedling culture, site preparation, and release are currently used to successfully regenerate longleaf pine (Barnett and others 1990, Boyer 1989, Hatchell 1987, Loveless and others 1989). With improvements in longleaf pine management tools, this species competes well from a productivity standpoint with loblolly and slash pine (Earley 1997, Franklin 1997, Outcalt 1997).

Comparisons of longleaf pine productivity among stands that are managed with and without prescribed fire have been made (Boyer 1987, Brockway and Lewis 1997). Although it has been reported that routine prescribed fire did not negatively affect longleaf pine productivity (Brockway and Lewis 1997), Boyer found that the growth of longleaf pine was reduced by regular burning (Boyer 1983, 1987; Landers and others 1995).

Decreases in longleaf pine productivity on routinely burned sites may be attributed to the intensity and timing of prescribed burning relative to the seasonal pattern of carbon allocation in trees. Glitzenstein and others (1995) introduce this concept in their discussion of why season of burn affects the dynamics and composition of southeastern forests. At the time of a prescribed fire, branch phenology, the role of existing foliage as a carbon source, and the vulnerability of existing foliage to scorch-induced, premature senescence may be critical factors affecting stand productivity.

In longleaf pine ecosystems with water and mineral nutrient deficits, sufficient energy must be available for the advancement of new roots if soil resource requirements are to be met. On these sites, a chronic reduction in the availability of carbohydrates for root metabolism may limit soil resource uptake, root system expansion, and subsequently, stand productivity. We hypothesize that the scorch-induced, premature senescence of foliage after a prescribed fire reduces the availability of carbohydrates for root metabolism and subsequently alters fine root dynamics and secondary root development.

MATERIALS AND METHODS

Study Location

The study is located in a 65-year-old longleaf pine stand with a basal area of approximately 19.5 m^2 per ha on the Calcasieu Ranger District of the Kisatchie National Forest, Rapides Parish, Louisiana (Section 12, T.2N, R.2W). The study site is characterized by two topographically distinct areas that correspond to the soil series at the location. The soils are a Ruston fine sandy loam (siliceous, thermic, Typic Paleudult) with a 1 to 3 percent slope and a Smithdale fine sandy loam (siliceous thermic, Typic Paleudult) with an 8 to 12 percent slope.

Study Design

In September 1996, the stand was prescribe burned using a series of strip-head fires. At strip interfaces, the crowns of longleaf pine trees were severely scorched. By late fall, the scorched trees were nearly defoliated. The study was established in a randomized complete block design with one plot of 10 trees in a nonscorched and scorched region of two blocks. Blocks were identified based on topography.

Field and Laboratory Procedures

At I- to 2-month intervals May 1997 through May 1998 and in December 1998 one soil core (6.2-cm diameter) was extracted from the O-to 20-cm depth of the soil using a metal coring device. The cores were collected from random locations within 2 m of each tree (Ruark 1985). Within 1.5

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hours of core collection, roots (&-mm diameter) were elutriated from soil cores and cornposited by plot (Smucker and others 1982).

Pine roots, 2 to 5 mm in diameter, were removed from the cornposited root samples and separated into three groups. Two groups consisted of one root each, and the third group consisted of the remaining roots. Roots were placed in paper bags and frozen in dry ice.

Frozen roots were lyophilized and ground (40-mesh). Root sucrose, glucose, and starch concentrations were quantified using a modification of the procedure of Jones and others (1977). Starch and hexose (glucose + fructose) were extracted from 25 mg of ground tissue and enzymatically converted to glucose. Glucose was measured by the glycolytic production of reduced nicotinamide adenine dinucleotide phosphate (NADPH). The NADPH was measured spectrophotometrically at 320 nm. Carbohydrate concentrations are expressed as mg per g ash-free dry weight.

The remaining cornposited fine roots were placed in plastic bags and refrigerated until processing. Initially, these roots were separated into pine and nonpine fractions. The nonpine fraction was discarded. The pine fraction was separated into two categories: (1) live fine roots and (2) dead fine roots. Live fine roots were succulent and pliable and had good adhesion between the stele and cortex. Dead fine roots were dark colored and flaccid or brittle and had poor adhesion between the stele and cortex. Live Rne roots were further separated into two categories: (1) primary roots and (2) secondary roots. Primary roots were characterized as new roots plus roots that were ≤ 1 mm in diameter and nonwoody in appearance. Secondary roots were characterized as either ≤1 mm in diameter and woody in appearance, or >1 but <2 mm in diameter. Roots in each category were dried (70 "C) to equilibrium and weighed. Weights of roots that were 2 to 5 mm in diameter were added to secondary fine root weights to obtain weights of secondary roots ≤5 mm. Data are expressed as either mass density (g per dm^3 soil volume) or percentage of mass density.

In December 1998, foliage from the first flush of 1998 in the upper crown of three randomly selected trees per plot was collected, lyophilized, and ground (20-mesh). After sulfuric acid/cupric sulfate digestion, foliar concentrations of phosphorus (P) were measured by colorimetry (John 1970) and foliar concentrations of potassium (K), calcium (Ca) and magnesium (Mg) were measured by atomic absorption spectrophotometry (Isaac and Kerber 1971). Foliar nitrogen (N) concentrations were quantified using a CNS-2000 Elemental Analyzer (Leco Corporation, St. Joseph, Ml).

Statistical Analysis

Data at each measurement interval were transformed to their natural logarithms as needed to establish normality and evaluated by analysis of variance using a randomized complete block design with two blocks. Main effects were considered statistically significant at probabilities (Pr) ≤0.05 unless noted otherwise.

RESULTS

Root Carbohydrate Concentrations

Root sucrose and glucose concentrations averaged 18.4 and 35.6 mg per g, respectively, and were seasonally variable. Root starch concentration exhibited a seasonal pattern with a maximum in late winter through spring (February-May) (145 mg per g) and a minimum in mid-summer through early winter (August-December) (28 mg per g) (fig. 1).

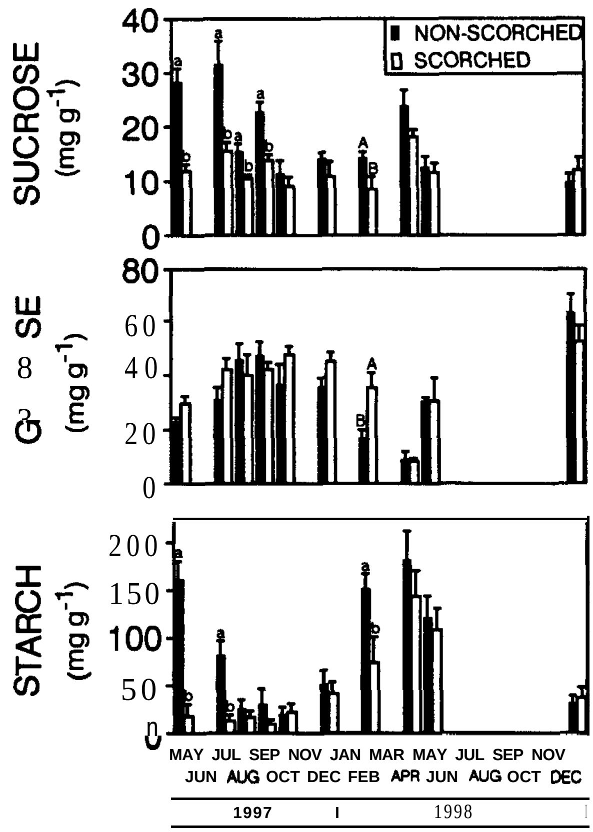

Figure l-Longleaf pine root sucrose, glucose, and starch concentrations (mg per g) 8 to 26 months after a prescribed burn that caused severe crown scorch in September 1996. Means associated with a different lower or upper case letter are significantly different at Pr ≤0.05 or 0.10, respectively.

In May and July 1997, root sucrose and starch concentrations were significantly reduced in response to crown scorch in September 1996 (fig. 1). Root sucrose concentration continued to be significantly less on the scorched plots in August and September 1997 when compared to the nonscorched plots. Root glucose concentration in 1997 was not significantly affected by crown scorch. In February 1998, root sucrose and starch concentrations were significantly lower and root glucose concentration was significantly higher on the scorched plots than on the nonscorched plots.

Root Mass Density

Total (live + dead) pine fine root mass density May 1997 through April 1998 was relatively constant and averaged 2.7 g per dm^3 (fig. 2). During the 8- to 19-month period after the prescribed burn, pine fine root mass density consisted of approximately 28 and 72 percent dead and live roots, respectively. In September 1997, 1 year after prescribed burning, total and live pine fine root mass densities were

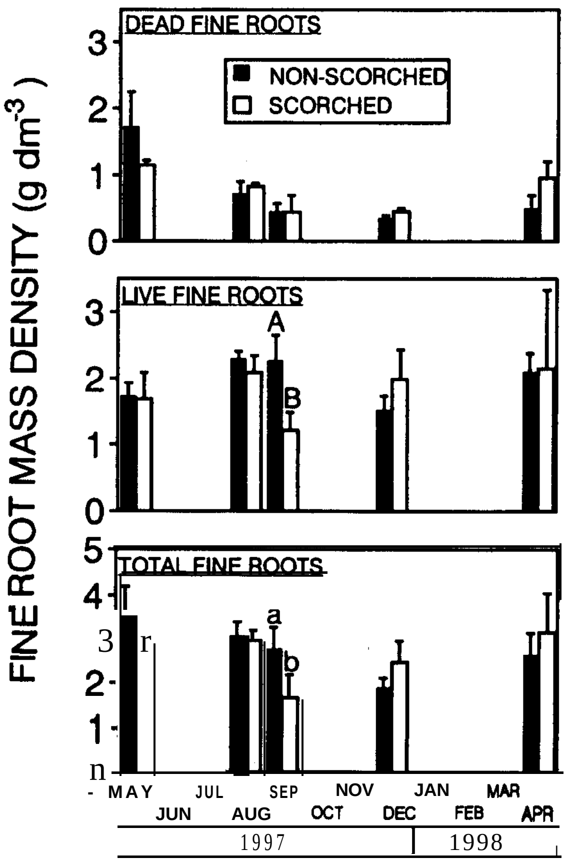

Figure 2—Longleaf pine fine root mass density (g per dm^3) 8 to 19 months after a prescribed burn that caused severe crown scorch in September 1996. Means associated with a different lower or upper case letter are significantly different at Pr ≤0.05 or 0.10, respectively.

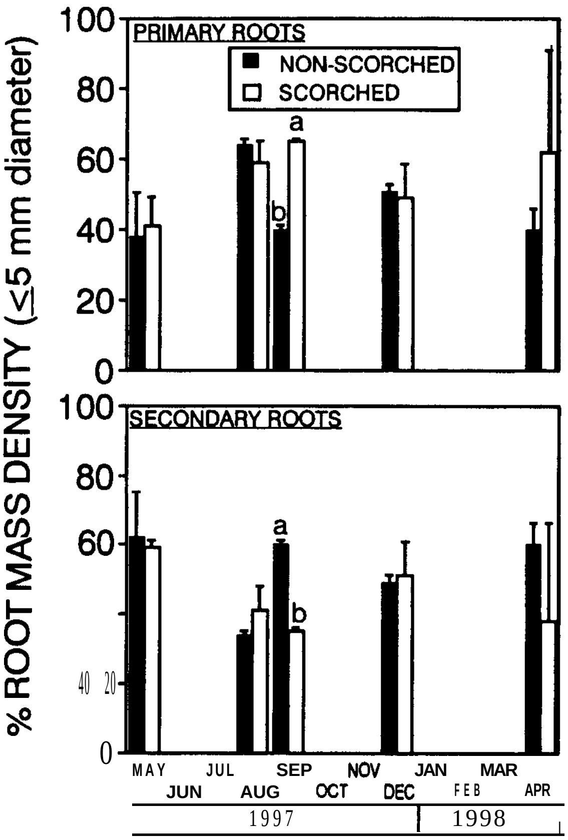

Figure 3-Percentage of longleaf pine root mass density (≤5-mm diameter) that appeared to exhibit primary and secondary development 6 to 19 months after a prescribed burn that caused severe crown scorch in September 1996. Means associated with a different lower case letter are significantly different at Pr ≤0.05.

significantly lower in response to crown scorch. This response did not occur on the other measurement dates in May 1997 through April 1998.

Approximately 51 and 49 percent of the live pine root mass density (≤5-mm diameter) exhibited primary and secondary growth, respectively, during May 1997 through April 1998 (fig. 3). In September 1997, the percentage of live pine root mass density that exhibited secondary growth was significantly reduced in response to crown scorch. This response did not occur on the other measurement dates in May 1997 through April 1998.

Foliar Mineral Nutrient Concentrations

In December 1998, approximately 27 months after prescribed burning, foliar mineral nutrient concentrations were not significantly affected by crown scorch. Foliar concentrations of N, P, K, Ca, and Mg on all plots averaged 8.8, 0.58, 3.8, 1.7, 0.78 g per kg, respectively.

DISCUSSION

Frequent prescribed fire has been associated with a reduction in longleaf pine productivity (Boyer 1983, 1987; Landers and others 1995). Growth reductions could be attributed to fire-induced deterioration of soil quality. However, Boyer and Miller (1994) found that biennial prescribed fire reduced growth in a longleaf pine forest but did not affect soil fertility. Burning did reduce soil pore space and plant-available water holding capacity, but the authors expressed skepticism that this was a major cause of growth reductions.

Perhaps a reduction in mineral nutrient absorption, rather than soil fertility, is the mechanism by which fire decreases longleaf pine productivity. In our study, concentrations of foliar N and P were 10 and 33 percent less, respectively, than the threshold between sufficiency and deficiency for slash pine (Allen 1987). These findings were not unexpected because longleaf pine ecosystems are generally characterized by low soil fertility (Landers and others 1995). In these environments, root system expansion into under-exploited soil is critical for the uptake of nonmobile mineral nutrients such as P. By causing the premature senescence of foliage, prescribed fire may have reduced the amount of photosynthate allocated to the root system and subsequently decreased root growth and soil resource uptake.

Johansen and Wade (1987) found that scorch-induced, premature senescence of 25-year-old slash pine foliage in

January led to a reduction in tree growth for the next two growing seasons. The greatest amount of growth inhibition occurred when the trees were nearly defoliated. However, growth reductions were observed even with the loss of as little as 10 percent of the foliage. Although we did not quantify leaf areas after prescribed burning, we observed a distinct reduction in leaf area in the crowns of the scorched trees when compared to the nonscorched trees within 2 months after burning. Crown scorch in September 1996 accelerated the natural senescence of the remaining 1995 foliage and resulted in the premature senescence of a large portion of the 1996 foliage. In conjunction with premature foliage senescence, we observed a 47 percent decrease in root sucrose concentration May through September 1997 and an 88 percent reduction in root starch concentration May through July 1997.

In addition to decreases in root sucrose and starch concentrations, crown scorch was associated with a 47 percent reduction in live fine root mass density in September 1997. At the same time, a smaller proportion of live root mass density (&-mm diameter) was classified as secondary on the scorched plots when compared to the nonscorched plots. Because root mass density and developmental responses to crown scorch were limited to one of five measurement dates, we question the soundness of this **observation.** Considerable root variability in soil cores, inadequate sample size, and large measurement errors may have negatively affected the accuracy of our results. Continued study of **longleaf** pine fine root dynamics in forest stands will require methods that ensure a larger number of samples are collected and measurement errors are minimized. Nevertheless, our results indicate that **scorch-**induced reductions in leaf area potentially affected **longleaf** pine root system processes by reducing carbohydrate availability for root metabolism.

Reductions in **longleaf** pine stand productivity have occurred in response to prescribed fire without notable crown scorch (Boyer 1987). In these situations, growth reductions may be partly attributed to the negative effects of increased soil temperature on the fine root network in the upper portion of the soil profile. Our results do not address the direct effects of soil heating on fine root mortality because root measurements were not initiated until 8 months after burning. We found that crown scorch affected **longleaf** pine live fine root mass density and secondary root development but did not affect dead fine root mass density 1 year after prescribed burning. Ryan and others (1994) suggested that carbon is preferentially allocated to maintenance respiration rather than to growth. In our study, root sucrose and starch concentrations were reduced but not absent on the scorched plots. Root carbohydrate concentrations on the scorched plots may have been diminished enough 1 year after prescribed burning that root growth ceased, but maintenance respiration was sustained and root mortality was unaffected.

Although the age class of foliage that was directly affected by prescribed burning had naturally senesced by early 1998, reduced concentrations of root sucrose and starch on the scorched plots were still observed in February 1998. In addition to limiting the amount of photosynthate allocated to root growth, scorch-induced, premature senescence of foliage in fall 1996 may have reduced the amount of photosynthate allocated to new flush growth in spring 1997. The consequent reduced photosynthetic capacity of foliage produced in 1997 may have prolonged the period of limited carbohydrate availability for root metabolism beyond 1 year.

Alternatively, reduced concentrations of sucrose and starch in February 1998 may have been caused by more rapid carbohydrate mobilization for root metabolism. In February 1997, lower concentrations of root sucrose and starch on the scorched plots were accompanied by a higher concentration of root glucose. Past research has shown that a greater proportion of fixed carbon is allocated to root system growth than aboveground growth on resource-limited sites (Keyes and Grier 1981, Vogt and others 1983). If the existing root system network on the scorched plots was unable to meet tree-soil resource requirements, rapid transformation of sucrose and starch into glucose may have been a mechanism for accelerated root growth when the soil warmed in spring.

SUMMARY

The restoration of **longleaf** pine ecosystems in the Southern U.S. is underway. Prescribed fire will probably continue to be a valuable tool in managing these forests. We found that a prescribed fire in September that resulted in the premature senescence of foliage reduced the availability of carbohydrates for **longleaf** pine root metabolism. One year after burning, reduced root carbohydrate concentrations were associated with a smaller fine root network and proportion of roots that had undergone secondary development. Frequent recurrence of these responses to prescribed **fire** could reduce the uptake of water and mineral nutrients by roots and subsequently, decrease stand productivity. Further research is needed to determine the regime of prescribed fire that meets forest management goals and minimizes negative effects on leaf area and root system processes.

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STRUCTURE AND COMPOSITION OF VEGETATION ON LONGLEAF PINE (*Pinus palustris*) AND SLASH PINE (*Pinus elliottii*) PLANTATION SITES IN THE HILLY COASTAL PLAIN OF SOUTH CAROLINA[1]

Gregory P. Smith, Victor B. Shelburne, and Joan L. Walker[2]

Abstract-Managers interested in restoring the ground layer vegetation in longleaf pine (*Pinus palustris* Mill.) communities need information about the existing vegetation on the sites, many of which are occupied by 30-40 year old plantations. Numerous studies have reported the short-term effects of plantation establishment on species composition and species diversity, but similar descriptions of older plantations are not available. We sampled fifty-four longleaf/slash pine plantation sites across an environmental gradient at the Savannah River Site in South Carolina. Using the North Carolina Vegetation Survey methodology, a database of information was created on the understory-overstory associations of these disturbed communities. Sites were selected based on criteria of age, bum history, soil moisture, land use, and site preparation methods. Preliminary ordination identified four groups of plantations based on vegetation data. We describe these four groups by species richness, basal area, density and soil texture. These sites will be compared to remnant longleaf sites to evaluate their respective vegetative composition, structure and floristic diversity. The information obtained will be the groundwork for eventual restoration management options of plantation sites to that of remnant conditions.

INTRODUCTION

The South's longleaf pine forests can harbor more species of vascular plants than almost any other forest type in the United States (Peet and Allard 1993), and it is well-known that fire played an essential role in developing and maintaining these diverse systems (Christensen 1988; Haywood and others 1997). Since European settlement, the turpentining industry, harvest, expanding agriculture, and fire suppression have drastically reduced the acres of natural longleaf stands. Longleaf and other pine plantations now occupy much of the land that once supported natural longleaf vegetation types. There is a growing interest in the structure and composition of pine plantations and how they compare to remnant longleaf stands. Such information is needed to assess the potential for restoration and to develop protocols for restoration.

Some information about the distribution of longleaf pine communities along environmental gradients (e.g. Christensen 1988, Harcombe and others, Peet and Allard, Jones and others 1984) is available, but little has been published regarding the composition and structure of plantations relative to the same environmental gradients. The potential existence of distinct plant communities across environmental gradients is important to both forest and restoration ecologists.

In this study, we will describe current vegetation patterns and relationships on disturbed plantation sites at the Savannah River Site. We will use the North Carolina Vegetation Survey (NCVS) method to describe and classify vegetation, interpret vegetation-environment relationships, conduct vegetation inventory, and establish long term monitoring of ecosystem conditions (Peet and others 1997). Using multivariate statistical analysis, we will determine if distinct groupings of vegetation exist along environmental gradients. Finally, we will compare the results from these disturbed plantation sites to results from relatively undisturbed vegetation remnants of the SRS and draw conclusions and make suggestions on management options that will aid in the restoration of these sites.

STUDYAREA

The Savannah River Plant is a 192,323 acre tract of federal land that occupies Aiken, Barnwell, and Allendale Counties, South Carolina (Cooke 1936). It is located northeast of the Savannah River on the upper Atlantic Coastal Plain of South Carolina. The Savannah River Site (SRS) has three major geologic/physiographic regions. These regions are the sandier, excessively drained and droughty areas called the Sandhills Region, the more productive sandy loams and loamy soils of the Upper Loam Hills Region, and the more fertile, well-drained soils of the Red Hills Region (Myers and others 1986). The SRS is drained by five major stream drainages which include: Upper Three Runs, Four Mile Creek, Penn Branch, Steel Creek, and Lower Three Runs (Jones and others 1981). Vegetation at the SRS is distributed across a well-defined moisture gradient extending from xeric, droughty, deep sandy ridges to hydric, flooded marshes and swamps (Van Lear and Jones 1987).

Present vegetation at the SRS largely reflects past disturbance or manipulation by man (Jones and others 1981). These disturbed sites included intensively farmed old fields subsequently replanted with pine, less intensive agricultural sites that were left to regenerate naturally, cutover forests that have had a continuous forest cover of scrub oak/pine, and areas where the natural fire regime has been altered or suppressed.

METHODS

Site Selection

We sampled SRS plantations that were classified as xeric or sub-xeric stands. Soils ranged from excessively drained typic quartzipsamments to well-drained paleudults and hapludults. Potential sample sites included all SRS sites with the following characteristics: artificially regenerated pine plantation, mechanical site preparation, aged 33-43 years

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old, and burned (on average) more than two times per decade. We used Geographic Information Systems software to identify and map potential study sites. We randomly selected sites from among the identified pool of sites.

Sampling

Fifty-four longleaf/slash pine plantation sites were sampled using the North Carolina Vegetation Survey methodology. This methodology provides data for analysis of community structure and composition at multiple scales, and will make it possible to compare results with other vegetation studies ongoing in the region (Peet and others 1997).

Permanent 0.1 ha plots were established at the selected sites. Sites were similar in respect to topographic position, slope gradient, canopy coverage and uniformity of stand. Plots were 20 x 50 meters and consisted of a 2 x 5 array of 10m^2 modules. Within this 2 x 5 array of modules, a block of four focal modules (in a 2 x 2 array) was designated. The four focal modules were intensively sampled for all vegetation and species presence was determined for a series of nested subplots at 5 plot sizes (.001, .1, 1 .0, IO, and 100 m^2). An aggregate count and measure of woody stems by size class was made in all IO modules and all residual species found in the remaining 6 modules were recorded. A coverage class was assigned to each species using the percent cover ranges assigned by the NCVS (Peet and others 1997).

Soils were collected for textural analysis at each plot. Textural soil samples were collected by placing one centrally located auger hole (>200 cm in depth) along midline of plot. Samples of the major diagnostic soil horizons from each plot were collected. Depth to maximum clay and thickness of B/C horizon were also recorded for each sample. Textural samples were analyzed by Brookside Laboratories Inc. (New Knoxville, OH) for particle size distribution.

Data Analysis

A series of multivariate techniques was used for preliminary analysis of data for each plot. Species abundance was analyzed by organizing and displaying data in multidimensional space using the ordination technique Detrended Correspondence Analysis (DCA) (DECORANA, Hill 1979a). The distance between plot locations on the graph relate the relative degree of similarity or difference (fig. 1) (Hutto and others 1997). Species and plots were then simultaneously classified using the main matrix for vegetation data by Two-way Indicator Species Analysis (TWINSPAN) (PC-ORD, McCune and Mefford 1995). Classification by TWINSPAN was also used to separate groups of plots based on vegetation data.

We used SAS programs (Peet and others 1997) to summarize plot data. We determined species richness for each plot size within each sample plot and we calculated mean species richness per 0.1 ha among plots within each classification group. We calculated sapling, tree and total density (# per ha) and basal area (m^2 per ha) of pines and hardwoods for each stand, and compared the stand means for each classification group.

RESULTS

The primary data matrix contained 54 plots and 248 species. Ordination arranged these plots along a soil moisture gradient (axis 1) that showed a beta diversity of 3.5 standard deviations. Based on this preliminary ordination we separated the plots into four groups (fig.1). Plots near the origin of the graph exist on the extreme xeric end of the soil moisture gradient. Each group of plots was reviewed and labeled as groups A, B, C, and D, with group A on the extreme xeric and D on the sub-xeric end of the gradient. Groups A, B, C and D were not assigned a specific soil moisture classification due to the difficulty in classifying four moisture classes for upland pine vegetation. These fifty-four plots all occurred on sites that would be considered xeric and sub-xerlc, most of which were on excessively or well-drained soils. There was also some variation exhibited among plots on the xeric end of Axis 2. This variation has not been determined, and is most likely the result of some disturbance from previous land use.

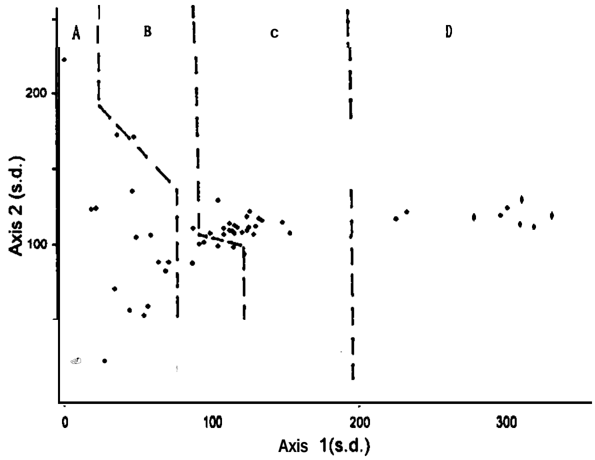

Figure l-Ordination and TWINSPAN classification of fifty-four plantations at the Savannah River Site.

Mean species richness at the five sampling levels and mean species diversity were compared among the four groups (table 1). Mean species diversity among the four groups ranged from a low of 48.0 species per ha to a high of 66.89 species per ha. While there seems to be a fairly consistent species richness level among all four groups of plots at sample scales less than or equal to 0.1 m^2, variation among plots increases with plot sample size.

The mean basal area for pine between the four groups ranged from 15.26 m^2 per ha on extreme xeric sites to 29.61 m^2 per ha on more sub-xeric sites (table 2). Nearly 100 percent of the pine basal area component found on all plots consisted of longleaf, slash and loblolly pine (*Pinus taeda* L.). Due to the dominant nature of the pine component and extremely low hardwood tree component in the sub-canopy and canopy, basal area was not calculated for hardwoods.

Sapling and tree density for classification groups are shown in table 2. Mean pine density ranged from 532.0 to 1287.78 stems per ha among the four groups. Mean hardwood density, composed mostly of saplings, ranged from 216.5 to 2760.63 stems per ha among the four groups. Hardwoods were largely sapling size (O-2.5 cm diameter) and restricted mainly to the midstory and understory. The hardwood component of the plots was largely scrub oak (Quercus *spp.*). Common species present included turkey oak *(Quercus laevis* Walt.), bluejack oak *(Quercus incana* Bart.), sand post oak *(Quercus margaretta* Ashe), and water oak

Table l--Mean species richness at the five sample sizes and mean total species found for all groups of plots

Sample scale	Group A	Group B	Group C	Group D
0.001 m^2	0.29	0.29	0.10	0.18
0.1 m^2	1.26	1.36	.70	.77
1.0 m^2	4.48	5.25	2.83	3.20
10 m^2	12.33	15.45	9.26	11.04
100 m^2	27.42	35.89	25.00	27.33
Total-l 000 m^2	49.19	66.89	56.30	53.44

Table 2-Mean basal area (m^2 per ha) of pines and mean density (number per ha) of pine and hardwood by group

Sample scale	Group A	Group B	Group C	Group D
Basal area pines (m^2/ha)	15.26	20.23	25.27	29.61
Density pines (number stems/ha)	759.38	848.89	532.0	1287.78
Density hardwoods (number stems/ha)	2760.63	2385.56	216.5	535.56

(*Quercus nigra* L.). Other common hardwoods found were sassafras (Sassafras *albidum* (Nutt.) Nees), persimmon (*Diospyros virginiana* L.), hickory (*Carya spp.*), and black cherry (*Prunus serotina* Ehr.). It is also important to note that a large proportion of ericaceous shrubs, mainly sparkleberry (*Vaccinium arboreum* Marshall), had attained a size large enough to be considered a sapling and was included in density counts.

Soil samples were analyzed for particle size distribution. Mean percent clay, silt, and sand were determined for the four groups of plots (table 3). Groups A and B were plots sampled on quartzipsamments, composed mostly of sand with a C horizon greater than 200 cm in depth. Groups C and D occurred mainly on paleudults and hapludults. These plots developed a B horizon anywhere from 50 to 150 cm in depth.

DISCUSSION AND CONCLUSIONS

Using ordination and classification techniques we were able to separate the fifty-four longleaf/slash plantations into four groups. These groups were separated by differences in species composition and abundance, which suggests that there were several distinct communities found along this environmental gradient. The vegetation differences may be related to soil texture, as has been suggested for other studies in the South Carolina coastal plain (Jones 1991). Considering the history of intense mechanical disturbance from agriculture and plantation establishment, it is interesting that the changes in vegetation along a soil texture gradient (assumed to represent differences in site moisture) remains so well defined.

Preliminary analyses suggest that these plantations at age 33-43 years are not the stereotypic pine monocultures with little herbaceous diversity and few native species. Instead at the scale of 0.1 ha, they appear to be as diverse as some natural stands (Peet and Allard 1993). Out of 248 species found on the SRS plantations sampled, roughly 90 percent were judged to be species representative of natural or native longleaf pine sites. The percentage of native species found, however, only indicates species presence. The abundance of these species on plantations versus natural stands must be compared. It is possible that some natives have been reduced by invading exotic species. The diversity and composition results are consistent with results from studies in the Carolina Sandhills National Wildlife Refuge. Walker and Van Eerden (1996) reported that longleaf pine plantations on xeric and sub-xeric sites are remarkably resilient with respect to species composition. The extent to which this finding applies across the longleaf pine ecosystem, however, has yet to be determined. Certainly there will be differences in vegetation based on soil moisture, but factors such as land use history, site preparation techniques, fire suppression and other disturbances must be reviewed before determining the resiliency of native stands to plantation management.

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Table 3-Mean particle size distribution of A, B and C horizons by group

Fraction-horizon	Group A	Group B	Group C	Group D
Percent				
Clay A	3.11	3.81	3.87	5.04
Silt A	3.58	6.52	6.63	4.85
Sand A	93.31	89.67	89.50	90.1
Clay B	—[a]	—[a]	22.57	27.96
Silt B	—	—	5.98	7.04
Sand B	—	—	71.45	65.00
Clay C	5.01	5.36	—[b]	—[b]
Silt C	1.87	2.75	—	—
Sand C	93.13	91.89	—	—

[a] B horizon not present in groups A and B.
[b] C horizon not sampled in groups C and D.

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EARLY DETERIORATION OF COARSE WOODY DEBRIS[1]

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Abstract-Coarse woody debris (CWD) is an important structural component of southern forest ecosystems. CWD loading may be affected by different decomposition rates on sites of varying quality. Bolts of red oak and loblolly pine were placed on plots at each of three (hydric, mesic, and xeric) sites at the Savannah River Site and sampled over a 16-week period. Major changes were in moisture content and nonstructural carbohydrate content (total carbohydrates, reducing sugars, and starch) of sapwood. Early changes in nonstructural carbohydrate levels following placement of the bolts were likely due to reallocation of these materials by sapwood parenchyma cells. These carbohydrates later formed pools increasingly metabolized by bacteria and invading fungi. Most prevalent fungi in sapwood were *Ceratocystis* spp. in pine and *Hypoxylon* spp. in oak. Although pine sapwood became blue stained and oak sapwood exhibited yellow soft decay with black zone lines, estimators of decay (specific gravity, sodium hydroxide solubility, and holocellulose content) were unchanged during the 16-week study period. A small effect of site was detected for starch content of sapwood of both species. Fungal biomass in sapwood of both species, as measured by ergosterol content, was detectable at week zero, increased somewhat by week three and increased significantly by week 16.

INTRODUCTION

Coarse woody debris (CWD) may influence a site for hundreds of years in the form of snags, logs, chunks of wood, large branches, or coarse roots. CWD has many characteristics that contribute to the health of forest ecosystems, such as creating habitats for wildlife, plants, and microorganisms. Through degradation these organisms recycle nutrients to the soil which enhances soil nutrient and energy content, thus creating richer soils for tree growth (Harmon and others 1986, Maser and others 1988, and Spies and Cline 1988). Mortality and breakage of living trees add CWD, as do harvest operations, while fire may remove or transform it (Van Lear 1996). Sporadic disasters such as hurricanes and insect and disease epidemics may also add CWD to the forested ecosystem.

Our understanding of the dynamics of CWD loading in southern forests is limited to one study (Waldrop 1996), which used a forest-succession model to predict loading. That study suggested that CWD dynamics could be strongly influenced if inputs (limbfall or tree mortality) and outputs (decomposition) of CWD vary between different types of forest sites. Little information is available on decomposition rates or the number and types of organisms that cause decay which occur on each site type.

This study examines the populations of bacteria and fungi that occur across three forest types. These sites were defined using the landscape ecosystem classification (LEC) approach developed by Barnes and others (1982) for forests in Michigan and applied to the South Carolina upper coastal plain by Jones (1991). To differentiate among sites there must be interrelationships between vegetation and landform, between vegetation and soils, and between landform and soils (Jones 1991). We previously reported the populations of bacteria that occurred in CWD by site class and species within the first 16 weeks following placement of bolts of red oak (*Quercus* spp.) and loblolly pine (*Pinus taeda* L.) on these sites (Porter and others 1998). In addition, chemical decomposition of the sapwood of both species was monitored during the 16-week period and it is the results of this aspect which are reported here.

METHODS

In April 1995 sample trees between 20-30 cm diameter at 1.4 m above ground were felled and cut into 0.5 m-long bolts. Red oaks were taken from the Clemson Experimental Forest, Pickens County, SC, and the loblolly pines were taken from the Savannah River Site, Aiken County, SC. The freshly cut bolts were placed on the study plots within 2-3 days after the trees were felled. The study sites were on LEC units established on the Savannah River Site and included three sites each of varying moisture availability: xeric, mesic, and hydric. The xeric sites were in pine plantations with little or no undergrowth. The mesic sites were also in pine plantations but there was more undergrowth and organic debris present. The hydric sites were located in mixed-species stands with dense understories. Since hydric sites were also located near streams, the soil was very moist during the study period and usually had some standing water. LEC classifications were used in other CWD studies by Bailey (1994) and Hare (1992).

On each LEC unit, a square plot was established and eleven sample bolts of each species were placed on the ground with the longitudinal axis of the bolt parallel with the ground. The surface of the bolt in contact with the ground was marked for orientation purposes during subsequent sample preparation.

The sample bolts were collected at 3, 6, 10, and 16 weeks after placement, in addition to controls processed immediately after the trees were felled. A randomized system for bolt selection was created by using a time schedule for the collection of two bolts of each species from each site during the different sampling periods. The bolts were taken to Clemson University and broken down for analysis the day following collections.

As the bolts were processed, freshly cut cross-sectional disks were removed and further subdivided into sapwood (upper and lower) and heartwood (upper and lower). After preliminary analyses indicated that there were no differences between upper and lower samples, they were

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combined. Fresh samples were weighed, dried at 105°C to a stable weight, and then reweighed and moisture content determined based on oven dry weight. These samples were then used for extraction and quantification of various chemical components. Duplicate samples were also oven dried as described above and then briefly dipped in melted paraffin and specific gravity determined based on their water displacement and oven dry weight.

Non-Structural Carbohydrates

Non-structural carbohydrates are those components of woody cells that are located in the cytoplasm and are not a part of the cell wall matrix. Subsamples of 20-60 gm of oven-dried wood tissues were ground in a Wiley mill to pass a 40-mesh screen. Soluble sugars were extracted with 60 percent ethyl alcohol for 6 hours in Soxhlet extractors. Aliquants were assayed for total carbohydrate by the phenol-sulfuric acid method (Dubois and others 1965) and for reducing sugars (Nelson 1944). Starch was extracted enzymatically from the sugar-free residue by using Enzyme Method 3 of Rose and others 1991. All determinations were performed in triplicate.

Preparatlon of Extractive-Free Wood

For the subsequent chemical analysis, extractive-free wood was prepared using the procedure of ASTM D1105 (1980b).

One Percent Caustic Soda Solubility

This test measures the degree of decay that has taken place and mainly extracts hemicellulose and degraded cellulose. The procedure outlined in ASTM D1109-56 (198Oc) was utilized.

Holocellulose

This test measures holocellulose plus hemicellulose. Both components are easily degraded by many microorganisms. Each sample consisted of 2.0 g of e&active-free 60-80-mesh wood meal and was analyzed according to the procedure outlined in ASTM D1104 (1980a).

Fungal Biomass

Fungal biomass is difficult to quantify in woody tissues. Ergosterol is produced only by certain higher fungi and has been used as an estimator of fungal biomass. Ergosterol was extracted and saponified with irradiation (Young 1995). Ergosterol was separated from the alkaline methanol irradiation buffer using a lipophilic copolymer. Total ergosterol was measured by HPLC using a 4.6 X 150 mm Sentry Shield RP, 3.5 pm column (Waters Corporation, Milford, MA).

RESULTS AND DISCUSSION

Oak

The initial moisture content did not differ significantly between heartwood and sapwood (81.8/77.6 percent) (table I), but a significant difference was detected by week 3 (72.1/65.5 percent), and both continued to decrease through week 16 (65.4/54.8 percent). Both heartwood and sapwood were drying out but the sapwood dried at a somewhat more

Table I-Chemical composition of oak bolts

		Weeks of exposure			
Attribute	Control	3	6	10	16
Moisture content[a]					
Heartwood	81 .82a[b]	72.08a	70.57a	67.93a	65.35a
Sapwood	77.62a	65.51 b	61.89b	57.221,	54.78b
Specific gravity'					
Heartwood	.673a	.689a	.701a	.701a	.719a
Sapwood	.630b	.625b	.591b	.571b	.554b
Total carbohydrates[d]					
Heartwood	20.66a	13.80a	13.89a	12.17a	11.90a
Sapwood	18.72a	23.28b	10.76b	8.17b	6.36b
Reducing sugars[d]					
Heartwood	29.48a	13.96a	14.84a	9.82a	8.65a
Sapwood	11.15b	16.32a	5.16b	2.74b	3.36b
Starch[d]					
Heartwood	33.55a	35.16a	35.71a	30.34a	30.39a
Sapwood	50.15b	36.36a	34.12a	31.06a	30.74a
Caustic soda solubility[e]					
Heartwood	24.43a	22.66a	22.72a	22.00a	21.32a
Sapwood	23.42a	23.06a	21.79a	21.56a	20.71 b
Holocellulose[e]					
Sapwood	71.24	73.07	71.65	71.56	71.86
Ergosterol'					
Sapwood	2.89	59.88	74.90	48.64	76.52

[a] = (percent), of fresh wood, based on oven-dry weight.
[b] = Means within a column followed by the same letter are not different at p = 0.05.
[c] = Based on oven-dry weight and oven-dry volume.
[d] = (mg/g), of oven-dry weight of unextracted wood.
[e] = (percent), of oven-dry weight of unextracted wood.
[f] = (µg/g), of oven-dry weight of unextracted wood.

Table P-Chemical components of oak sapwood by LEC site

Attribute	Weeks of exposure			
	3	6	10	16
Moisture content[a]				
Hydric	64.49a[b]	65.76a	62.37a	60.52a
Mesic	66.34a	58.45a	56.85b	53.76b
Xeric	65.71 a	61.45a	52.46b	50.08b
Specific gravity'				
Hydric	.622ab	.583a	.574a	.579a
Mesic	.599b	.590a	.563a	.538a
Xeric	.654a	.601a	.574a	.543a
Total carbohydrates[d]				
Hydric	24.63a	11.13a	8.37a	7.09a
Mesic	26.13a	10.77a	8.54a	6.36a
Xeric	19.06b	10.38a	7.60a	5.63a
Reducing sugars[d]				
Hydric	17.26ab	5.24a	2.99a	3.23a
Mesic	19.42a	5.28a	2.51a	3.90a
Xeric	12.28b	4.95a	2.72a	2.96a
Starch[d]				
Hydric	35.13a	32.97a	30.08b	34.50a
Mesic	38.09a	35.92a	34.07a	28.11b
Xeric	35.87a	33.49a	29.02b	29.62b
Caustic soda solubility[e]				
Hydric	23.62a	20.80a	21.34a	21.36a
Mesic	23.48a	22.44a	23.04a	21.15a
Xeric	22.09a	22.12a	20.71a	19.61a
Holocellulose[e]				
Hydric	73.32a	71.82a	71.81a	71.31a
Mesic	72.66a	71.66a	71.26a	71.85a
Xeric	73.24a	71.47a	71.60a	72.43a
Ergosterol'				
Hydric	25.76b	136.67a	26.92a	23.89a
Mesic	130.80a	39.19a	77.94a	124.93a
Xeric	8.91 b	48.84a	51.92a	96.00a

[a] = (percent), of fresh wood, based on oven-dry weight.
[b] = Means within a column followed by the same letter are not different at p = 0.05.
[c] = Based on oven-dry weight and oven-dry volume.
[d] = (mg/g), of oven-dry weight of unextracted wood.
[e] = (percent), of ovendty weight of unextracted wood.
[f] = (μg/g), of oven-dry weight of unextractad wood.

rapid rate. Site differences in moisture content began to show up by week 10 (table 2) with the sapwood of bolts on hydric sites having a higher moisture content (62.37 percent) than on mesic (56.8 percent) and xeric (52.5 percent) sites. By week 16 hydric sites had declined to 60.5 percent, mesic to 53.8 percent and xeric to 50.1 percent. The relative moistness of the three LEC units seems to be accurately reflected in the moisture content of sapwood of the oak bolts placed on those sites.

The initial specific gravity of heartwood and sapwood (0.6728/0.6301) was significantly different, a difference which increased through week 16. Specific gravity increased slightly in heartwood and decreased slightly in sapwood (0.7194/0.5537) over the 16-week period (table 1). There were essentially no differences in specific gravity due to site class (table 2) throughout the 16-week period. These data suggest that there was no major wood decay during this period. The slight, but not significant, declines during the study are probably reflective of internal checking within the wood samples, yielding a somewhat erroneous specific gravity reading, rather than reflecting wood loss due to decay.

Because of their availability, non-structural carbohydrates are the first chemical components to be degraded by invading microorganisms. Nonstructural carbohydrate contents generally decreased throughout the 16-week period (table 1). initially, there was no difference in total carbohydrates between hearlwood and sapwood (20.7/18.7 mg/g), but by week 3 these declined somewhat in hearlwood and then leveled off through week 16. in sapwood there was a slight increase in week 3 to 23.3 mg/g and then a sharp decline to 6.4 mg/g by week 16. in both of these tissues these declines suggest that the pool of total carbohydrates diminished over the 16-week period. There was no effect of site class on total carbohydrate content (table 2).

The reducing sugar contents generally paralleled those of total carbohydrates, from an initial high of 29.5 mg/g in heartwood and 11.2 mg/g in sapwood (table 1). Both tissues declined markedly in reducing sugar contents by week 16 **(8.6/3.4 mg/g).** There was no effect of site class on reducing sugar content (table 2). The decline in total carbohydrates and reducing sugars reflects the declining activity of parenchyma cells in the respective tissues as the increasing populations of bacteria and fungi began to metabolize these readily available carbon sources.

Starch content showed moderate decreases throughout the 16-week period, from a high of 33.6 mg/g in week 0, to 30.4 mg/g by week 16 (table 1). Sapwood had a higher content of starch (50.2 mg/g) than did heartwood and this decreased to 30.7 mg/g by week 16. Site class significantly affected starch decomposition. On the hydric sites there was no change in starch content over the 16-week period (table 2). On the mesic sites starch decreased from 34.1 mg/g at week 10 to 28.1 mg/g at week 16 (table 2). On the xeric sites starch decreased from 33.4 mg/g at week 6 to 29.0 mg/g at week 10 (table 2). It is postulated that on the hydric sites there was sufficient moisture imbibition from the soil to keep the sapwood parenchyma cells alive and this enabled them to resist invasion and colonization by microorganisms.

One percent caustic soda solubility increased only slightly between heartwood and sapwood during the 16-week period (table I), but there was a slight increase in sapwood only at 16 weeks. There were no effects of site class during the study (table 2).

Because the one percent caustic soda solubility test showed little decay loss, holocellulose content was assessed only for sapwood. Holocellulose content, likewise, did not vary over the study period (table I), and was not affected by site class (table 2).

Inspection of the bolts during the course of the study indicated that there were visible stain/decay effects in sapwood but not in heartwood. The sapwood became a light yellowish color with black zone lines. For that reason, fungal biomass was estimated only in the sapwood. Initially, sapwood contained 2.89 µg ergosterol/g, which sharply increased to 59.88 µg/g in week 3, and eventually to 76.52 µg/g in week 16. Although there was quite a bit of variation, the data suggest that ergosterol content may have been greatest on the mesic sites (table 2). Most of this content is believed due to ***Hypoxylon atropunctatum*** (Schwein.:Fr.) Cooke, which is a common invader of oak sapwood of declined or dead trees and also an early invader of freshly milled lumber (Tainter and Baker 1996). It has a unique positional advantage because it colonizes the inner and outer bark of living oak trees as they grow and mature and is never more than a few cells away from the nutrient-rich sapwood of the living trees. The small, but detectable, amount of ergosterol in the control sapwood may reflect invasion of these bolts during the 2-3 days after their preparation before they could be processed.

Pine

The initial moisture content differed significantly between heartwood and sapwood (46.4/105.1 percent) (table 3).

Table 3-Chemical composition of pine bolts

		Weeks of exposure			
Attribute	Control	3	6	10	16
Moisture content[a]					
Heartwood	46.38a[b]	40.07a	41.93a	46.92a	48.45a
Sapwood	105.14b	91.05b	81.46b	75.03b	70.84b
Specific gravity[c]					
Heartwood	.449a	.512a	.482a	.493a	.452a
Sapwood	.554b	.592b	.576b	.582b	.572b
Total carbohydrate&					
Heartwood	8.06a	6.98a	8.03a	10.73a	6.46a
Sapwood	7.03a	4.68b	4.38b	4.59b	4.26b
Reducing sugars[d]					
Heartwood	6.98a	7.36a	8.56a	9.60a	7.14a
Sapwood	3.44a	1.81b	1.60b	1.60b	1.04b
Starch[d]					
Heartwood	11.36a	2.90a	2.06a	2.78a	.78a
Sapwood	12.64a	5.10b	2.69a	3.09a	1.40a
Caustic soda solubility[e]					
Heartwood	19.86a	23.10a	23.31a	27.89a	21.67a
Sapwood	13.51b	13.79b	12.85b	12.71 b	12.80b
Holocellulose[e]					
Sapwood	66.51	67.05	66.98	67.76	67.41
Ergosterol'					
Sapwood	7.15	18.60	23.89	28.01	24.17

[a] = (percent), of fresh wood, based on oven-dry weight.
[b] = Means within a column followed by the same letter are not different at $p = 0.05$.
[c] = Based on oven-dry weight and oven-dry volume.
[d] = (mg/g), of oven-dry weight of unextracted wood.
[e] = (percent), of oven-dry weight of unextracted wood.
[f] = (µg/g), of oven-dry weight of unextracted wood.

The moisture content of heartwood did not decrease through week 16. However, **sapwood** moisture content decreased to 70.8 percent by week 16. The heartwood columns were relatively small in these bolts and were likely protected from drying by the much wetter and thicker **sapwood.** Site differences began to show up by week 3 with the hydric site at 107.7 percent, mesic at 91 .O percent and zeric at 74.5 percent (table **4),** decreasing at week 16 for the hydric site to percent. As with the oak samples, the relative moistness of the three site classes seems to be reflected in the moisture content of **sapwood** of the pine bolts placed on these sites.

The initial specific gravity of heartwood and **sapwood (0.4488/0.5537)** was significantly different, a difference which was maintained through week 16, with no significant change in their relative amounts (table 3). There were no differences in specific gravity among the three site classes (table 4) throughout the **16-week** period. As with the oak data, there were no major chemical effects of wood decay during this time period.

Nonstructural carbohydrate contents generally decreased throughout the **16-week** period (table 3). Initially there was no difference in total carbohydrates between heartwood and 89.9 percent, for mesic to 68.0 percent, and for zeric to 54.6 **sapwood (8.06/7.03 mg/g),** but by week 3 differences were evident **(6.98/4.68 mg/g),** holding steady through week 16 **(6.46/4.26 mg/g)** (table 3). There was no effect of site class on total carbohydrate content (table 4).

The reducing sugar contents generally paralleled those of total carbohydrates in heartwood, from 6.98 **mg/g** to 7.14 **mg/g** in heartwood of control bolts over the **16-week** period (table 3). In **sapwood,** however, the initial reducing sugar content of 3.44 **mg/g** steadily decreased to 1.04 **mg/g** at week 16, but effect of site class on these contents was not clear (table 4).

Table 4—Chemical components of pine sapwood by LEC site

Attribute	Weeks of exposure			
	3	6	10	16
Moisture content[a]				
Hydric	107.68a[b]	92.37a	90.32a	89.92a
Mesic	91 .Olab	84.32a	71.56b	68.01 b
Xeric	74.48b	67.68b	63.21 b	54.58c
Specific gravity'				
Hydric	.601a	.575a	.555a	.578a
Mesic	.569a	.554a	.592a	.559a
Xeric	.605a	.600a	.600a	.578a
Total carbohydrates[d]				
Hydric	3.88b	3.76a	4.34a	3.97a
Mesic	5.32a	4.80a	4.78a	4.62a
Xeric	4.83ab	4.58a	4.63a	4.18a
Reducing sugars[d]				
Hydric	2.21a	2.14a	2.21a	1.37a
Mesic	1.75a	1.57ab	1.63a	.64a
Xeric	1.46a	1.08b	.96b	1.12ab
Starch[d]				
Hydric	4.12a	2.81a	1.30b	.78b
Mesic	5.82a	2.70a	3.81a	1.96a
Xeric	5.38a	2.55a	4.18a	1.46ab
Caustic soda solubility[e]				
Hydric	13.97a	12.94a	13.69a	13.69a
Mesic	13.72a	12.70a	12.70ab	12.06a
Xeric	13.69a	12.90a	11.74b	12.66a
Holocellulose[e]				
Hydric	67.11a	67.1 la	67.34a	67.52a
Mesic	66.96a	66.91a	68.02a	66.59a
Xeric	67.19a	66.91a	67.91a	68.11a
Ergosterol'				
Hydric	3.94b	9.97a	9.11b	13.07b
Mesic	11.20b	24.56a	7.28b	6.65b
Xeric	40.66a	34.81a	67.64a	52.80a

[a] = (percent), of fresh wood, based on oven-dry weight.
[b] = Means within a column followed by the same letter are not different at p = 0.05.
[c] = Based on oven-dry weight and oven-dry volume.
[d] = (mg/g), of oven-dry weight of unextracted wood.
[e] = (percent), of oven-dry weight of unextracted wood.
[f] = (µg/g), of oven-dry weight of unextracted wood.

Starch content showed dramatic decreases throughout the 16-week period, from initial highs in heartwood and sapwood (11.36/12.64 mg/g) (table 3), decreasing to 2.901510 mg/g by week 3 and decreasing even more (0.78/1.40 mg/g) by week 16. Starch decreased more slowly on hydric sites (table 4).

At the beginning of the study, one percent caustic soda solubility was significantly different between heartwood and sapwood (19.86/13.51) and these relative amounts did not change throughout 16 weeks (table 3). Site class had no effect on this measure of decay (table 4).

Holocellulose content of sapwood did not vary over the study period (table 3) or by site class (table 4).

Initially, ergosterol content of sapwood was 7.15 µg/g and this measure of fungal biomass rose to 18.60 µg/g by week 3, and to 24.17 µg/g by week 16 (table 3). Blue stain, caused by *Ceratocystis* spp. or *Ophiostoma* spp., was very evident in these bolts as the study progressed. A detectable amount of ergosterol in sapwood of initial samples likely reflects the rapid invasion and colonization of these bolts during the 2-3 days before they could be taken to the laboratory and processed. Although there was considerable variation in the data, it was clear that ergosterol was most abundant in sapwood of pine bolts placed on the xeric sites (table 4). Since the bolts were randomized before placement, it is unlikely that this is a reflection of pre-existing colonization.

CONCLUSIONS

This study suggests that there are detectable increases in fungal populations during the first 16 weeks when freshly cut bolts of pine and oak are placed on the forest floor and allowed to deteriorate. The bolts begin to dry and the rate of drying is reflective of site class influences. Declines in total nonstructural carbohydrate contents, which also were affected by site class to a limited extent, suggest an increasing utilization of these carbon sources by invading microorganisms. The 16-week period, though, was not sufficiently long enough to allow detectable deterioration of woody cells.

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ROLES OF COARSE WOODY DEBRIS IN THE LOBLOLLY PINE ECOSYSTEM[1]

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Abstract-Coarse woody debris (CWD) plays an important role in forest ecosystems, contributing to habitat, nutrient cycling, and food webs. However, little is known of the function of CWD in the loblolly pine ecosystem on the coastal plain, where a subtropical climate, low soil fertility and water holding capacity, termites, fire ants, and a diverse assemblage of fungi affect the decay rate and relative importance of CWD. The USDA Forest Service has established Long-term Soil Productivity (LTSP) study sites on national forests in Texas, Louisiana, Mississippi, and North Carolina. Treatments on these sites include three levels of compaction and three levels of organic matter removal applied during harvesting and regeneration, and unharvested remnants of the same, mature stand adjacent to the treated area. At one site in each State, we established a CWD study to measure changes in mass, water content, insect and fungal populations, and the physical and chemical characteristics of the wood over a 16-year period. In the mature stand at each CWD study site, we established three replicates consisting of 10 logs (100-cm long and 16- to 37-cm diameter), 6 limbs (50-cm long and 2.5- to 9.4-cm diameter), and 6 twig bundles (4 twigs, each 25-cm long and 0.5- to 1.5-cm diameter). We also established three replicates of the limbs and twigs in the low-impact and severe-impact treatment areas of the LTSP study at each CWD location. The physical appearance of the logs changed more quickly than the limbs and twigs in the first few months, due to attacks by wood and bark boring insects. Such attacks allowed other insects and fungi to penetrate as far as the hearhvood. After 6 months log phloem was completely decomposed and replaced by insect frass, termite mud tubes, and fungal mycelia. At the same time, twigs appeared to change little physically, although they lost 5.3 to 14.5 percent of their mass depending on location. Location did not affect limb rate of mass loss, which was 14.6 percent after 6 months.

INTRODUCTION

Coarse woody debris (CWD) is critically important in forest ecosystems as habitat, in affecting soil transport and sediment storage, in food webs, and in nutrient cycles (Harmon and others 1986). Previous investigators have reported on the production and decomposition of woody debris in forest ecosystems, but most focused on the Northwest U.S. (Edmonds 1987, Harmon 1992, Marra and Edmonds 1994, Means and others 1992) and eastern or northern deciduous forests (Abbott and Crossley 1982, Alban and Pastor 1993, Mattson and others 1987, Onega and Eickmeier 1991). By contrast, little is known about such interactions in loblolly pine (*Pinus taeda* L.) ecosystems, where even information about decay rates is sketchy (Barber and Van Lear 1984).

Loblolly pine is an economically and ecologically important species in the Southeastern U.S., where it is managed on over 47 million acres. Our understanding of the processes governing sustainable forest productivity is rudimentary, and our knowledge of the role of woody material in maintaining long-term carbon and nutrient capital of forest soils is minimal. Few studies have been carried out in managed southern pine stands on the coastal plain, where warm temperatures, an annual wet-dry cycle, active insect and fungal populations, and infertile soils affect the rate and mechanisms of woody decomposition. Due in part to the ubiquity of termites, the decomposition cycle is drastically modified, which affects nutrient transfer, interactions with other organisms, and the rate of wood decay (Lee and Wood 1971). Unlike most other soil animals, termites are able to digest polysaccharides (including cellulose) and transport organic matter and associated nutrients from CWD to a central nesting area. The importance of this movement on nutrient cycling is largely unknown and is usually ignored in nutrient-cycling models.

Experiments in which CWD and site resources are manipulated and quantified are needed to understand its role in the loblolly pine ecosystem. As a joint effort of the USDA Forest Service, National Forest System and Forest Service Research, a Long-Term Soil Productivity (LTSP) study has been established to determine the impact of macroporosity reduction and organic matter removal on long-term soil productivity (Tiarks and others 1993). Nationally, the LTSP study has been installed over a wide range of forest and soil conditions including the mixed conifer type of the California Sierra region, the mixed conifer type of the Intermountain West, the aspen type of the Great Lakes Region, the oak-hickory type of the Central Hardwood Region, and the loblolly pine type of the Southern Region. In the South, LTSP sites constitute a network covering the east- to-west range of loblolly pine. Such a network provides scientists a unique opportunity to study CWD decay processes across a climatic gradient and link the results with other long-term studies.

We overlaid a CWD study onto some of the LTSP installations in Texas (TX), Louisiana (LA), Mississippi (MS), and North Carolina (NC). Our primary objective is to quantify and model the process by which loblolly pine logs, limbs, and twigs decompose. We are measuring wood decomposition rates as well as biotic and abiotic factors governing the decomposition process at each location. This paper summarizes measurements made in the early stages of decomposition, including decay rates of limb- and twig-sized material, the temperature regime in logs, and carbon and nitrogen flux in leachate from the logs. We conclude

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with a preliminary description of the interrelationships among organisms involved in early stages of the decay process.

MATERIALS AND METHODS

General Experimental Approach

In the spring of **1998,** we placed CWD at LTSP locations in LA, TX, MS, and NC, which cover the range of rainfall and potential evapo-transpiration (PET) found on the coastal plain (table 1). Treatments on these sites include three levels of compaction and three levels of organic matter removal applied during harvesting and regeneration, and unharvested remnants of the same, mature stand adjacent to the treated area. In the remnant stand at each site, we established three CWD replicates, each consisting of 10 logs (100-cm long and 16- to 37-cm diameter), 8 limbs (50-cm long and 2.5- to 9.4-cm diameter), and 8 twig bundles (4 twigs, each 25-cm long and 0.5- to 1.5-cm diameter). We distributed the CWD as six sets, each consisting of a log, a limb, and a twig bundle. One set would be destructively sampled after 0.25, 0.50, 1 .0, 1.5, 2.0, and 4.0 years exposure. We also placed two additional log and limb sets for sampling at 6 and 8 years, and two more logs for sampling at 12 and 16 years. At each location we established three replicates of limbs and twigs in the low-impact and severe-impact treatments of the LTSP study. Harvest treatment on the least-impacted plot was "bole only" removal with no soil compaction. Harvest on the severely impacted plot was bole + crown + forest floor removal and severe reduction in macroporosity. We categorized CWD by tree parts and measured the diameter of each sample. All CWD came from freshly felled trees in a 43-year-old loblolly pine stand located in central LA which had been established as a species-selection trial. We cut disks from the end of each log and limb to determine the initial physical and chemical characteristics. We selected four twigs for making a bundle and two additional twigs to represent time zero. We recorded the fresh weight of all twigs and the oven-dry weight of the time-zero twig samples. We calculated the dry weight of twigs in each bundle using the average water content of the time-zero samples. At designated time intervals, we collect designated samples from each replicate to determine mass loss and establish other parameters.

Mass Loss of Limbs and Twigs

After 3 months and 6 months, we retrieved the CWD samples, transporting the materials in containers to reduce loss of bark and water. We oven-dried (70 °C) and weighed all of the twig samples to determine mass loss. We cut a 7- to 8-cm segment from the middle of each limb and measured its length and diameter. After weighing, oven-drying, and re-weighing, we calculated the limb mass loss by changes in density. We also collected bark and wood samples from the logs, although we do not report the results here. Requiring a 95 percent probability level, we tested the statistical significance of changes in twig and limb mass using analysis of variance. The model we tested was:
Mass loss = time + location + harvest treatment + interaction terms + error.

Throughfail and Log Leachate Collection and Analyses

We trapped log leachate and determined the amount of dissolved organic carbon (DOC) and total nitrogen (TN) that were transported from the logs to the soil. We also collected throughfall to subtract DOC and TN leaching from the canopy. To capture throughfall at each site, we used three aluminum channel troughs coated with polyurethane paint and covering an area of 324.4 cm^2. We collected leachate from three logs at each site by placing PVC troughs beneath

Table I-Soil, stand, and climatic characteristics of the CWD study

Attribute	North Carolina	Mississippi	Louisiana	Texas
	Location			
Soil series	Goldsboro	Freest	Malbis	Keltys
Soil classification	Aquic Paleudults	Aquic Paleudalfs	Plinthic Paleudults	Aquic Glossudalfs
Mature stand species	Loblolly	Slash	Loblolly	Loblolly with shortleaf
Preplanted (LTSP) species	Loblolly	Loblolly	Loblolly	Loblolly
Average temperatures:				
Daily max (July), °C	32	33	34	34
Daily min (Jan.), °C	1	2	3	3
Rainfall, mm year'	1385	1430	1450	1050
Potential evapo-transpiration, mm year'	900	995	1028	1035
Water deficit,' mm year'	1	3	82	137

[a] Water deficit is difference between potential and actual evapotranspiration.

the logs. We attached two troughs, each 6.5cm wide around the bottom half of the log and sealed the trough to the log with foam rubber and silica caulking. Throughfall and leachate were trapped in reservoirs buried in the soil. At least monthly we collected and recorded the accumulated water volume. We filtered water samples through 0.7-µm glass microfiber papers (Mattson and others 1987). We evaporated a 25-mL aliquot of the water samples from TX, LA and MS using a metal-lined boat and determined DOC and TN with a Leco 2000 CNS elemental analyzer. We also collected samples from NC, but have not yet determined their DOC and TN.

Log Temperature and Soil Water

At each location, we installed a field-data recorder equipped with a thermocouple reference sensor to record the hourly temperature of one log in the mature stand and an infrared sensor to measure the surface temperature of the log. Thermocouples were used to measure the temperature 1 cm from the top, in the middle, and 1 cm from the bottom of the log. To reduce edge and spatial effects, we inserted the thermocouple sensors 15 cm into both ends of each log and averaged the two readings.

We measured soil water content beneath the log using two Time Domain Reflectometry (TDR) probes placed horizontally at 7.5 cm in the soil and perpendicular to the log. We positioned the probes, which are divided into five 15-cm increments with the middle segment centered on the log. The average diameter of logs above the TDR probes was 29 cm, so the middle segment was covered by the log, the next two segments were under the log's vertical projection, and the outside two segments were in soil unaffected by the log. We manually recorded TDR readings biweekly in the spring and summer and every month in the fall and winter.

Sequence of invasion by Organisms

We made non-destructive field observations during the first 6 months of exposure and destructively sampled logs 3 months and 6 months after placement to develop a preliminary understanding of the function of different organisms in the early stages of decomposition. We noted the presence and location of bark and ambrosia beetle (Coleoptera: Scolytidae), larval wood borer (Coleoptera: Cerambycidae), and termite (Isoptera: Rhinotermitidae) galleries in the wood, phloem, and bark of the logs.

RESULTS AND DISCUSSION

Mass Loss of Limbs and Twigs

The initial mean density of limb segments was 0.48 g per cm^3. The mean density was 0.44 g per cm^3 after 3-months exposure and 0.41 g per cm^3 after 6 months. These changes are equivalent to a mass loss of 8.3 and 14.6 percent, respectively (fig. 1). Time of exposure significantly affected the difference in density of the limbs; but location, harvest treatment, and interaction terms were not significant.

The mass loss from twigs differed by State, as well as by time of exposure (fig. 1). Twigs in NC decayed more rapidly than twigs in the western three States. Harvest treatment did not have a significant effect on the twigs' mass loss. In early stages of decomposition, the more rapid decay of smaller-sized CWD than of larger limbs has been attributed to earlier attack by microbial populations (Barber and Van Lear 1984). Later, as twigs dry and become "case hardened," they are

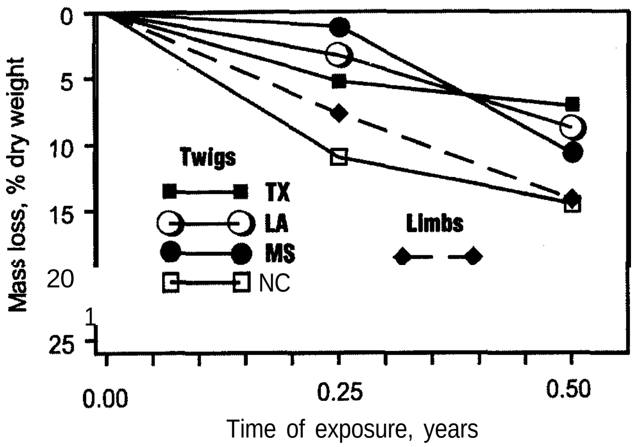

Figure l-Mass loss of twigs and limbs exposed for 3 months and 6 months at four locations. Each point for the twig loss is the average of 36 twigs at each location, and each point for the limb loss is the average of 9 limbs at each location.

thought to be more resistant to decay. In our study, twigs in TX, LA, and MS were exposed to a dry summer and may have hardened, slowing the rate of mass loss. After 6 months exposure, the mass loss of twigs ranged from 5.3 percent in TX to 14.5 percent in NC, which is much greater than the 2.5 percent loss predicted for the same period using the model developed by Barber and Van Lear (1984).

Carbon and Nitrogen in Throughfall and Log Leachate

Both DOC and TN differed significantly by time of sampling, but not by State. To evaluate the trend over time, we plotted the daily equivalents of DOC and TN for the three States (fig.2). The highest amounts of DOC in throughfall and log leachate occurred in September, when the needles were senescent (fig. 2a). DOC in the leachate from logs was much more variable, ranging from periods when log DOC was equal to throughfall DOC, to September when log DOC was the highest and four times greater than throughfall DOC. Because the logs are under a canopy, any DOC in the throughfall would be in the log leachate; therefore, the amount of DOC leached from the log in a given period is the difference between the log leachate and the throughfall.

The amount of nitrogen (TN) in the throughfall varied between 1 and 3 mg per m^2 per day in July and August, but rose in September and October following the pattern observed for DOC (fig. 2b). TN in the log leachate was highly variable, ranging from net absorption by the log in November, to a large peak in late August. Logs have a high carbon to nitrogen ratio, so nitrogen availability often limits decomposition. Thus, the log's net absorption of nitrogen from the throughfall log is expected. Although not expected, the high peaks of TN in July and August may have been the result of nitrogen released by extra-log organisms. By November, rabbit fecal pellets had been deposited on many of the logs. Because rabbits often use logs as territorial markers (Zollner and others 1996), nitrogen wastes may have concentrated on the logs, accounting for the peaks in TN.

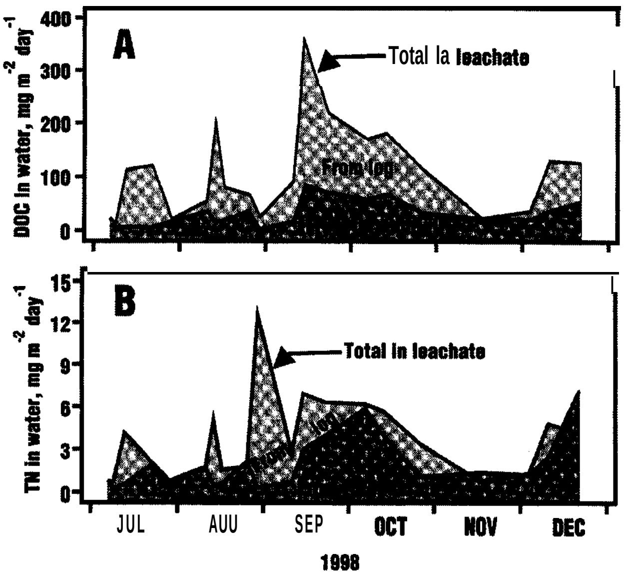

Figure P-Mass of dissolved organic carbon (DOC) and total nitrogen (TN) in throughfall and log leachate averaged for locations in TX, LA, and MS.

The cumulative amount of DOC leached from logs ranged from 16.2 g per m^2 in MS to 20.5 g per m^2 in TX over the 168-day sampling period beginning, which began soon after log placement. In the same period, the amount of DOC accumulated in throughfall was 5.8 g per m^2 in MS and 4.5 g per m^2 in TX. The amount of DOC in the log leachate or throughfall did not differ significantly by State. The average throughfall and log leachate for the three states where measurements had been completed were 5.3 and 18.3 g per m^2, respectively; so the cumulative amount of DOC leached from logs was 13.0 g per m^2.

The cumulative TN in throughfall during the 168-day sampling period ranged from 0.21 g per m^2 in TX to 0.44 g per m^2 in LA, while the cumulative TN in leachate was more consistent, ranging from 0.52 g per m^2 in MS to 0.66 g per m^2 in TX. Like DOC, TN values were highly variable, and differences among the States were not statistically significant. The mean TN accumulated in throughfall was 0.33 g per m^2, and the net TN leached from logs was 0.27 g per m^2.

Effect of Logs on Soil Water Content

The TDR rods we placed under logs measured soil water content within about 3.5 cm of the center of the rod. Thus, the effective depth measured was from 4 to 11 cm below the soil surface. The logs were approximately 30 cm in diameter, so the log drip line was about 15 cm from the center. In TX, the average soil water content for July through December 1998 was not affected by the log (fig. 3). By contrast, the average water content under the log in MS showed a distinct pattern, with volumetric water content beneath the outer edges at 12 percent and directly under the log about 8 percent.

The soil water content outside the log's influence was also about 8 percent. The mean volumetric water content in LA

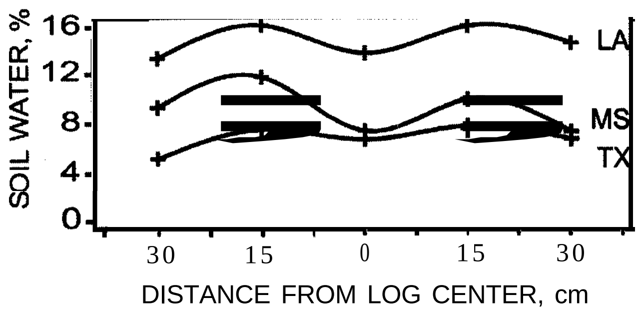

Figure 3-Soil water content (volumetric basis) under the logs in three locations averaged for July through December 1998.

soils was higher than in TX or MS, but the difference in soil water content below the center and outside of the log was only about 2 percent. The log shelters soil from rainfall, but may also reduce evaporation from soil under the log. Although we cannot separate these effects, the soil water content indicates that in LA and MS most water runs off the log, and little leaches through it. In the Pacific Northwest, the amount of runoff and leachate were about the same in the early stages of decomposition (Harmon and Sexton 1995).

Log Temperatures

Between April and December 1998, bark on top of the log reached temperatures of about 50 °C for 1 to 2 hours on several days. These high temperatures occurred on sunny days, even though the logs were under a canopy of older pines. Because bark has a low capacity to store heat, the surface temperature dropped rapidly at night. The diurnal temperature range was about 30 °C in April before the full expansion of new foliage on pines (fig. 4). The range dropped to 20 °C by December. At the same time, the diurnal temperature range in wood nearest the soil was about 3 °C. The log's buffering effect on diurnal temperature ranges may affect colonization by termites and other organisms. Termites use ventilation, site selection, and mound architecture to maintain a temperature range of 3 to 4 °C within the mound (Lee and Wood 1971). Presumably, nearly constant temperatures would be advantageous in the foraging areas as well.

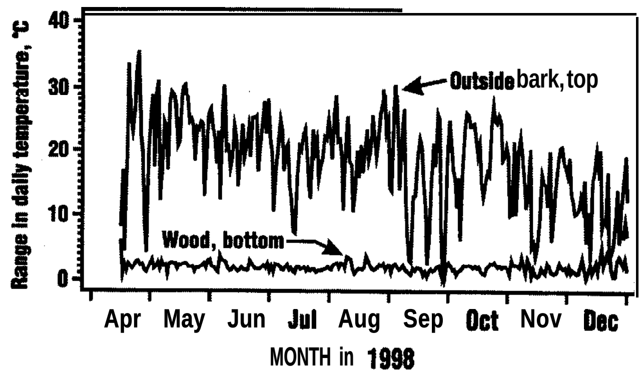

Figure 4-Range in temperature at the bark surface on top of the log and in the wood at the bottom of the log, 1 cm from the soil-log interface at the MS location.

Sequence of Invasion by Organisms

One month after fresh logs were placed on the plots, holes in the bark indicated that bark beetles were feeding and developing in the phloem (fig. 5). Wood-infecting stain fungi associated with bark beetles were introduced and 2 to 3 weeks after log placement, wood borers tunneled into the xylem. After 3 months, the area that had been phloem had become a mixture of wood fiber deposited by wood borers and frass from borers and bark beetles. Termites had colonized the area as well, apparently feeding on the phloem as well as fibers deposited by wood borers. After 6 months, fungi had penetrated to the heartwood via bark beetle and wood borer tunnels. The area between bark and xylem contained frass and termite soil tubes. In some areas, termites had penetrated the wood layers and consumed the early wood portion of the outer two or three growth rings. They had also used wood borer tunnels and fungus-infected wood to enter areas several centimeters into the log. Although our observations are preliminary, they do offer insight into the type of measurements that need to be made in the early stages of decomposition. To understand the impact of early insect attacks on latter stages of log decay, changes in the phloem should be measured using destructive sampling on a monthly basis for the first 6 months. The amount and importance of nitrogen and other nutrients imported into the system could be determined by measuring changes in nitrogen content of the original phloem and the mixture of phloem, frass, wood fibers, and soil that is found between the bark and xylem in later samplings.

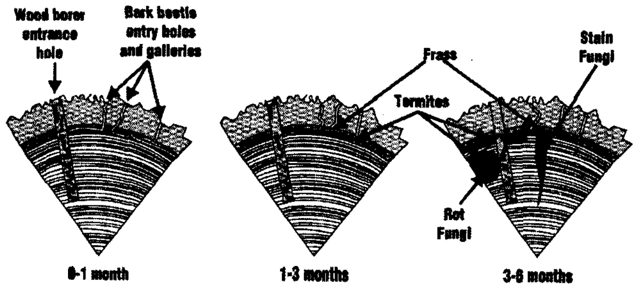

Figure 5—Sequence of invasion by insects and fungi in the early stages of loblolly pine decomposition.

SUMMARY

In the first 6 months, the rate of mass loss from twigs varied by location, e.g. it was greatest in NC and least in TX. After 6 months, the mass loss from limbs was greater than from twigs in TX, LA, and MS; it was about the same as twigs in NC. A long summer dry period in the West Gulf area, may have "case hardened" the twigs, slowing the rate of decomposition. The amount of DOC leached from logs was about 13.0 g per m^2, compared to 5.3 g per m^2 in the throughfall during the same 168-day period. The net amount of TN leached from logs was about equal to the throughfall amount, but the TN was much more variable in log leachate than in throughfall. In MS and LA, runoff from logs was concentrated along the drip line, causing the soil water content under the middle of the log to be lower than along its outer edges. Temperatures of the bark reached 50 °C, with a diurnal range of 30 °C, even though the logs were under a pine canopy. The temperature range just above the log-soil interface was moderated by the insulating effect of the log, with a diurnal range of about 3 °C. In the first 6 months, bark beetles, wood borers, and termites all contributed to the conversion of phloem to a mixture of wood fiber, insect frass, and termite soil tubes. Stain and rot fungi had colonized parts of the wood, especially around holes bored by insects.

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BIRD DIVERSITY AND COMPOSITION IN EVEN-AGED LOBLOLLY PINE STANDS RELATIVE TO EMERGENCE OF IS-YEAR PERIODICAL CICADAS AND VEGETATION STRUCTURE'

Jennifer L. Hestir and Michael D. Cain'

Abstract-In southern Arkansas, 13-year periodical cicadas *(Magicicada* spp.) were expected to emerge in late April and early May of 1998. Presence of a superabundant food source, such as periodical cicadas, may attract greater numbers of birds and more species of birds than is usually present in a particular area. Three even-aged loblolly pine (*Pinus taeda* L.) stands were surveyed for birds by using a fixed-width transect before, during, and after emergence of the periodical cicadas. Emerging cicada nymphs were trapped and counted to obtain an estimate of cicada density. The density of cicadas in these pine stands was considerably lower than densities reported for other forest stands in the Eastern U.S. Bird diversity was variable between months and stands but did not appear to be strongly influenced by the presence of periodical cicadas. Bird composition in these managed loblolly pine stands was similar to that in unmanaged, even-aged pine and pine/hardwood stands of similar ages.

INTRODUCTION

Emergence of periodical cicadas (Homoptera: Cicadidae: Magicicada) is a highly predictable occurrence. The 1 J-year race of periodical cicadas that occurs in Arkansas is a group of three species including Magicicada *tredecim* (Walsh and Riley), *M. tredecassini* (Alexander and Moore), and *M. tredecula* (Alexander and Moore). Adult cicadas synchronously emerge from the ground every 13 years, ascend the nearest tree, and cast their nymphal skin. Adult males aggregate in the forest canopy and form chorusing centers to attract females for mating (Williams and Smith 1991). Adults complete their reproductive cycle and die within 4 to 6 weeks.

Adult populations of periodical cicadas can be very dense. Populations in previous emergences have been estimated at tens of thousands to hundreds of thousands of individuals per acre (Dybas and Davis 1962, Rodenhouse and others 1997, White and others 1982). This type of ephemeral, high density occurrence of insects can provide a superabundance of food that may attract greater numbers and more species of insectivorous birds than is usually present in a particular location. In this study, we investigated the influence of 13-year periodical cicadas on bird diversity in even-aged stands of loblolly pine (*Pinus taeda* L.) in southern Arkansas where periodical cicadas were observed during a previous emergence (personal observation, M.D. Cain, 1985).

The study also provided an opportunity to examine bird composition relative to vegetation structure of loblolly pine stands that were managed to maximize pine development. Others have examined bird composition relative to vegetation structure in unmanaged, even-aged pine and pine/hardwood stands (Childers and others 1986, Conner and others 1979, Conner and others 1983, Dickson and Segelquist 1979, Kellner 1996), but this information is lacking for managed stands. Recent concern over declining populations of neotropical migratory songbirds and an increasing interest in managing forests at the ecosystem level warrants an examination of bird communities inhabiting forests managed for timber production (Finch and Stangel 1993).

METHODS

Study Sites

Three plots were surveyed for birds and cicadas on the Crossett Experimental Forest, Ashley County, Arkansas. Merchantable-sized trees (>3.5 in. d.b.h.) on all plots were primarily loblolly pine, but a few shortleaf pine (*Pinus echinata* Mill.) and assorted hardwood species were present. Plot 5 is a 1 O-acre, 25-year-old stand measuring 1,320 ft long and 330 ft wide. This stand was precommercially and commercially thinned and periodically prescribe burned in winter (Cain 1996). Burning was initiated in the ninth year to control understory vegetation. The most recent burn was conducted in February 1998. Plot 5 also had patches of unmanaged pine and openings that supported grasses and forbs. Plots 37N and 37S are both 15-year-old loblolly pine stands. Plot 37N is 1,000 ft long and 165 ft wide (3.8 acres), and plot 37S is 660 ft long and 330 ft wide (5.0 acres). As part of one ongoing study, plots 37N and 37S have been similarly managed (Cain 1997). Both plots were precommercially and commercially thinned and competing vegetation was controlled with herbicides, manual removal, or both during the first 5 years of pine development. These two plots also had patches of unmanaged pine. All plot boundaries were well-defined by mowed fire lanes.

Bird Survey

Birds were surveyed using a fixed-width transect (Mikol 1980). A transect was established through the center of each plot. Bird surveys were conducted along each transect for 2 days each in early-April, mid-May, and mid-June of 1998. Each 2-day survey was completed within a 4-day period. All birds detected by sight or sound within the plot boundary were recorded and plotted on a map as the observer slowly traversed the transect. In addition, all birds detected within 80 ft outside the plot boundary were recorded and mapped for two reasons. First, birds were not confined to our artificially-defined boundaries. Second, birds in the periphery were observed using the study plots.

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All surveys were performed by one observer within 3 hours after sunrise on days without rain and with minimal wind. On the first sampling day, all plots were surveyed from north to south in the following sequence: plot 5, plot 37N, plot 37S. To diminish the effect of time of day on bird activity, the plots were surveyed in the reverse direction (south to north) and reverse order (37S, 37N, 5) on the second sampling day. Only species that were breeding residents of the Crossett Experimental Forest and were regularly observed in the vicinity of the survey plots were included in the data analyses. Only data on male occurrence were used in the analyses because the majority of the observations were of male birds.

Estimation of bird density (D) from a fixed-width transect was calculated by using the following equation (Mikol 1980):

$$D = n/LW, \qquad (1)$$

where
n = the number of territorial males detected within a strip of a specified transect length (L) and total width (W).

The W is twice the detection width (w) that extends from the central transect to the outer survey boundary (plot boundary + 80 ft). Density is reported as the number of territorial males per 100 acres so plots of different sizes can be compared to each other.

Bird diversity was calculated with the Shannon-Weaver diversity function (Shannon and Weaver 1949):

$$H' = -\sum p_i \log p_i \qquad (2)$$

where
p_i = the proportion of individuals in the ith species.

For calculation of the diversity index, each male was assumed to represent one resident pair of birds (Emlen 1971). A t-test (Hutcheson 1970, as provided in Zar 1984) tested for differences in bird diversity between months and plots.

Cicada Sampling

Thirteen-year periodical cicada nymphs were expected to begin emerging in late April 1998. The bird surveys were timed to coincide with cicada pre-emergence, peak activity, and post-emergence periods. To obtain an estimate of cicada density, wire-mesh traps were systematically placed within each plot (75 traps on plot 5 and 40 traps each on plots 37N and 37S). Traps were checked twice weekly for cicada adults or cast skins beginning April 30, and these checks continued until cicada emergence was complete. Cicada density was estimated by multiplying the average number of cicadas per trap by 20,000 to obtain the number of cicadas per acre for each study site (one trap = 1/20,000 acre).

Vegetation

In accordance with the protocol for ongoing silvicultural studies being conducted in the survey areas, both woody and herbaceous vegetation was measured in the fall of 1998, and the data are presented in this paper to quantitatively describe vegetation on the study plots. On plot 5, five sample points were systematically established within each of fifteen 0.4-acre experimental subplots (75 sample points total). At each point, percent ground cover on I-milacre (3.72-ft radius) quadrats was estimated for herbaceous (vines, forbs, grasses, and semi-woody plants) and woody (all pines, hardwoods, and shrubs) vegetation. In addition, stem counts of sapling-size (I-, 2-, and 3-in. diameter classes) pines, hardwoods, and shrubs were tallied within five O.Ol-acre circular quadrats (11.77-h radius) per subplot. Within each 0.4-acre subplot, a sample of 40 merchantable (>3.5 in. d.b.h.) pines was measured for d.b.h. and 10 of these were also measured for total tree height. On plots 37N and 37S, ten I-milacre circular quadrats were systematically established within each of sixteen 0.25-acre experimental subplots (160 sample points total) to estimate percent ground cover of both herbaceous and woody vegetation and to count sapling-size stems of pines, hardwoods, and shrubs. On each subplot, a sample of 20 merchantable pines was measured for d.b.h. and total height. On plots 5, 37N, and 37S, sample pines were selected for measurement based on crown class, tree quality, and spacing.

RESULTS AND DISCUSSION

Bird Diversity and Periodical Cicadas

The 13-year periodical cicada nymphs began emerging on April 29, 1998 and completed emergence within 2 weeks. As cicada emergence subsided, adult activity increased and peaked during the second week of May, and adults had died by the first week in June. Overall, density of emerging cicadas was low with 13,500 per acre (table 1). By comparison, Williams and others (1993) estimated an average of 164,213 cicadas per acre in an upland hardwood forest in northwestern Arkansas, and Dybas and Davis (1962) estimated an average of 133,000 cicadas per acre in an upland hardwood forest in Illinois. The low densities on plots in the present study may have occurred because Magicicada species are typically more prolific in hardwood forests than in pine forests (Dybas and Lloyd 1974, James and others 1986).

Bird diversity was variable between months (table 2) and plots (table 3). Bird diversity on plot 5 increased ($P<0.001$) from April to May, then decreased ($P<0.001$) from May to June. This peak in bird diversity occurred during maximum cicada activity in May, but plots 37N and 37S did not show a similar trend in bird diversity (fig. 1). In addition, the density of emerging cicadas was highest on plot 37S (table 1) where no change in bird diversity was observed ($P>0.05$) from April to May, although a decrease ($P<0.05$) occurred from May to

Table 1—Summary of results from cicada sampling including total number of cicadas trapped per plot, calculated number of cicadas per square yard, and estimation of cicada density per acre

Plot	Total no. cicadas	No. cicadas per yd^2	No. cicadas per acre
5	12	0.64	3,200
37N	4	0.40	2,000
37s	7	0.72	3,500

Table 2—Comparison of bird species diversity between months for each plot

Comparison of months	Plot number	Bird diversity by month H'	H'	t	P[a]
		April	**May**		
April vs May	5	0.76	1.17	7.26	***
	37N	.83	.96	2.09	*
	37s	.88	.88	,044	ns
		May	**June**		
May vs June	5	1.17	.90	4.61	***
	37N	.96	1.02	1.44	ns
	37s	.88	.73	2.52	*

[a] Probability values are as follows: ns = not significant at a = 0.05, * <0.05, ** <0.01, *** <0.001.

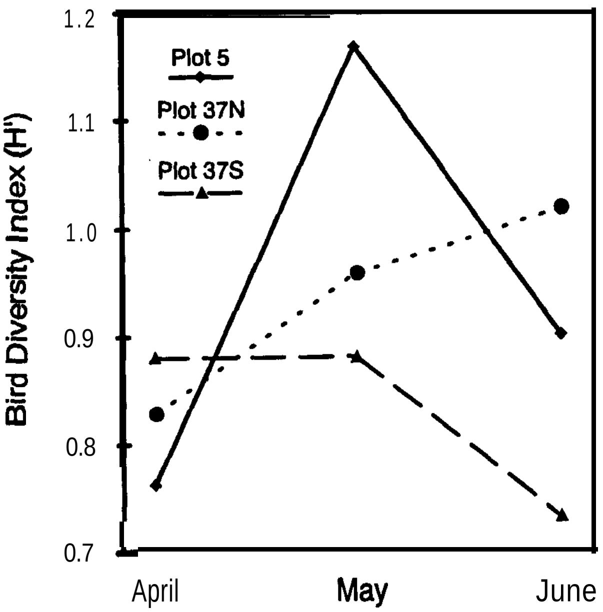

Figure 1—Monthly changes in bird diversity (H') by plot.

Table 3—Comparison of bird species diversity between plots for each month

Comparison of plots	Month	Bird diversity by plot H'	H'	t	P[a]
		5	37N		
5 vs 37N	April	0.76	0.83	**0.93**	ns
	May	1.17	.96	5.18	***
	June	.90	1.02	2.00	*
		5	37s		
5 vs 37s	April	.76	.88	**1.99**	ns
	May	1.17	.88	**6.90**	***
	June	.90	.73	2.30	*
		37N	37s		
37N vs 37S	April	.83	.88	.77	ns
	May	.96	.88	1.79	ns
	June	1.02	.73	5.09	***

[a] Probability values are as follows: ns =not significant at a = 0.05,
* [illegible] * [illegible] < [illegible] *** < [illegible]

June. Furthermore, bird diversity on plot 37N increased **($P<0.05$)** from April to May, as in plot 5, but had the lowest density of emerging cicadas (table I), and bird diversity did not subsequently decrease **($P>0.05$)** in June. Therefore, the monthly variation in bird diversity observed on these plots does not appear to have been strongly influenced by emergence of **13-year** periodical cicadas.

Two factors may account for a lack of cicada influence on bird diversity. First, the density of emerging cicadas in these managed pine stands was considerably lower than densities reported for other forests in the Eastern U.S. (Dybas and Davis 1962, Rodenhouse and others 1997, Williams and others 1993) and therefore, may have been too low to induce a change in bird diversity. However, Karban (1982) failed to find a relationship between density of birds and density of cicadas in eight isolated forest patches in New York where cicada densities were generally higher than in this study. Densities in New York ranged from about 2,500 to 57,200 cicadas per acre, although five of the eight sites had between 12,000 and 25,000 cicadas per acre. Birds were not counted before or after cicada emergence in the Karban (1982) study.

Second, adult cicada chorusing centers were numerous and scattered across the Crossett Experimental Forest. in fact, multiple chorusing centers were located either on or around the study sites. Therefore, birds would not have to travel long distances to forage on cicadas. Williams and Smith (1991) mapped from 29 to 48 chorusing centers within a **40-** acre forest stand in northwest Arkansas and found that the distribution and size of these chorusing centers varied temporally. Given the abundance and dynamic nature of cicada chorusing centers, an examination of the distribution and size of chorusing centers across a larger area in relation to bird distribution and abundance may reveal an influence on bird populations that is not discernable on small forest plots.

Seasonal variation in bird abundance and mating behavior due to spring migration and the progression of the breeding season are additional factors that can affect variation in bird diversity and detectability within forest stands (Ralph and Scott 1981). These factors limited the ability of Kellner and others (1990) to detect any effect of 13-year periodical cicadas' presence on the foraging behavior of four species of birds inhabiting an upland hardwood forest in the Arkansas Ozarks even though over 1 million cicadas emerged on the 40-acre study site (25,000 per acre). Seasonal variation may have influenced bird diversity in the present study given that the survey periods corresponded with early migration, late migration/early breeding, and mid-breeding periods of birds in southern Arkansas. However, only those species that breed in the vicinity of the study area and only data from singing males were used in the data summary and analyses to partially compensate for this variation.

Bird Composition and Stand Characteristics
A total of 21 species of breeding birds-15 neotropical migrants and 8 permanent residents-were recorded in the survey areas (table 4). The density of each species, reported as the number of territorial males per 100 acres, was calculated for each plot (fig. 2).

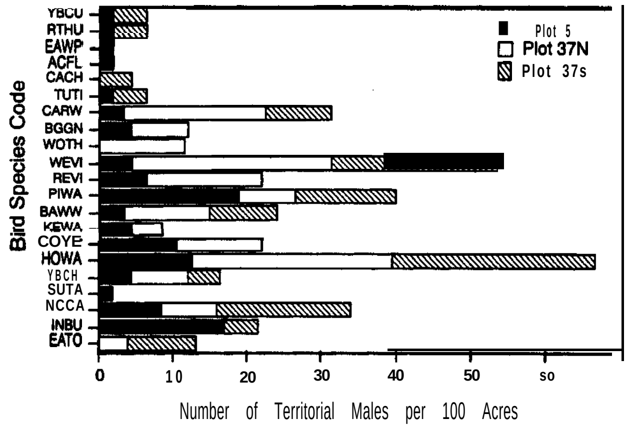

Figure P-Density of bird species by plot (see table 4 to interpret 4-letter species codes).

Overall, plots 37N and 37S had similar vegetation and differed from plot 5 by having three to four times as many hardwood saplings and shrubs in the understory and a greater ground cover of hardwoods (table 5). As expected, plots 37N and 37S generally supported higher densities of bird species that are typically associated with low, shrubby

Table 4-Common and scientific names of bird species present in managed, loblolly pine stands

Common name	Scientific name	4-letter code[a]
Yellow-billed cuckoo	*Coccyzus americanus*	YBCU
Ruby-throated hummingbird	*Archilochus colubris*	RTHU
Eastern wood-pewee	*Contopus virens*	EAWP
Acadian flycatcher	*Empidonax virescens*	ACFL
Carolina chickadee	*Poecile carolinensis*	CACH
Tufted titmouse	*Baeolophus bicolor*	TUTI
Carolina wren	*Thryothorus ludovicianus*	CARW
Blue-gray gnatcatcher	*Polioptila caerulea*	BGGN
Wood thrush	*Hylocichla mustelina*	WOTH
White-eyed vireo	*Vireo griseus*	WEVI
Red-eyed vireo	*Vireo olivaceus*	REVI
Pine warbler	*Dendroica pinus*	PIWA
Black-and-white warbler	*Mniotilta varia*	BAWW
Kentucky warbler	*Oporomis formosus*	KEWA
Common yellowthroat	*Geothlypis trichas*	COYE
Hooded warbler	*Wilsonia citrina*	HOWA
Yellow-breasted chat	*Icteria virens*	YBCH
Summer tanager	*Piranga rubra*	SUTA
Northern cardinal	*Cardinalis cardinalis*	NOCA
Indigo bunting	*Passerina cyanea*	INBU
Eastern towhee	*Pipilo erythrophthalmus*	EATO

[a] Four-letter codes used in figure 2. Birds are listed according to American Ornithologists' Union (1998) sequence.

Table 5—Mean vegetation characteristics

	Plot number		
Vegetation variables	5	37N	37s
Pine overstory			
Tree height (feet)	80.9	49.8	48.3
D.b.h. (inches)	9.2	8.3	8.5
Basal area (ft^2/acre)	87.6	77.1	81.6
Hardwood saplings and shrubs[a]			
Total	145	588	426
1 -inch saplings	80	325	238
2-inch saplings	41	188	125
3-inch saplings	24	75	63
Pine saplings[a]			
Total	28	38	26
1 -inch saplings	0	25	13
P-inch saplings	3	13	13
3-inch saplings	25	0	0
Percent ground cove?			
Pine	74	67	61
Hardwood	3	35	30
Semi-woody	14	2	2
Grass	34	11	10
Forbs	17	9	4
Vines	50	50	47

[a] Values for hardwood saplings and shrubs and for pine saplings are the mean number of stems per acre.
[b] Percent ground cover values are the mean percent coverage on 1-milacre quadrats.

vegetation (Carolina wren, common yellowthroat, northern cardinal, eastern towhee, white-eyed vireo, and yellow-breasted chat) or a deciduous understory with some merchantable-sized hardwood trees (black-and-white warbler, hooded warbler, and wood thrush). All these species, except black-and-white warbler, are dependent upon the presence and amount of deciduous vegetation in the understory for foraging and nesting (Conner and others 1983, Crawford and others 1981, Dickson and Noble 1978, Hamel 1992, Thompson and Capen 1988). Black-and-white warblers depend more on the presence of deciduous vegetation in the midstory and canopy layers (Conner and Dickson 1997, Conner and others 1983, Dickson and Segelquist 1979). Both plots, particularly 37N, had some merchantable-sized hardwoods in the unmanaged areas of the plot.

Compared to plots 37N and 37S, plot 5 generally had larger pines, fewer hardwood saplings and shrubs, and a greater coverage of forbs and grasses (table 5). This plot supported bird species that are typically associated with mature forests such as Acadian flycatcher, blue-gray gnatcatcher, eastern wood-pewee, Kentucky warbler, pine warbler, red-eyed vireo, and summer tanager. All these species, except pine warbler, were present at very low densities and are more commonly associated with hardwood or pine/hardwood forests. These species may have been attracted to the pine/hardwood forest bordering plot 5 on the south and west. In contrast, pine warblers were the most common species in this stand and prefer mature pine forests for nesting and foraging (Conner and others 1983, Hamel 1992). Indigo buntings and common yellowthroats also were fairly common in this 25-year-old stand and were associated with the open, herbaceous areas and the few patches of dense, deciduous understory within the stand. These species usually occur at high densities in the open, shrubby habitat of recent clearcuts and then decrease as the canopy begins to close (Childers and others 1986, Kellner 1996, Thompson and Capen 1988).

In general, bird composition in these managed loblolly pine stands was similar to that found in unmanaged, even-aged pine and pine/hardwood stands of similar ages (Childers and others 1986, Conner and others 1979, Dickson and others 1993, Kellner 1996) and was related to vegetation structure. Therefore, managing stands for maximum development of loblolly pine by precommercial thinning, commercial thinning, and competition control during early development stages does not appear to negatively affect the breeding bird population. Commercial thinning of plots 37N and 37S in December 1997, opened the canopy and stimulated growth of a deciduous understory that was used by the majority of bird species present in those stands. In contrast, a prescribed burn during February 1998 on plot 5, immediately preceding the bird surveys, top-killed most of the shrubs and small sapling hardwoods resulting in an open understory with a greater coverage of grasses and forbs. This type of habitat was more attractive to indigo buntings and less attractive to the other understory species that prefer a dense, deciduous understory. Presence of deciduous vegetation is important for many species of birds (Conner and others 1983, Crawford and others 1981, Dickson and others 1993, Thompson and Capen 1988). Allowing deciduous vegetation to grow after pines have become established will increase vertical foliage diversity and attract more species of birds. More research is needed to clarify the effect of commercial thinning and techniques for controlling competing vegetation on bird populations inhabiting pine stands.

SUMMARY

Emergence of 13-year periodical cicadas did not strongly influence bird diversity within managed loblolly pine stands. Low cicada density and abundant, widely distributed cicada chorusing centers may contribute to the lack of a bird/cicada relationship in this study.

Bird composition in these managed loblolly pine stands was similar to that found in unmanaged, even-aged pine and pine/hardwood stands of similar ages. Managing stands for maximum development of loblolly pine by precommercial/commercial thinning and competition control during early development stages does not appear to negatively affect the breeding bird population. Bird composition could be explained by vegetation structure, and the majority of the bird species present generally depend on some type of deciduous vegetation for nesting and/or foraging.

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A QUANTITATIVE ASSESSMENT OF THE STRUCTURE AND FUNCTIONS OF A MATURE BOTTOMLAND HARDWOOD COMMUNITY: THE IATT CREEK ECOSYSTEM SITE[1]

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Abstract-We report our efforts, initiated in 1995, to quantify ecological processes and functions in a relatively undisturbed, mature hardwood forest. The 320-ha site is located in central Louisiana on the upper reaches of latt Creek, an anastomosing minor stream bottom. The forest is a mature sweetgum (*Liquidambar styraciflua* L.)-cherrybark oak (*Quercus pagoda* Raf.) dominated community with over 70 woody plant species present. Soils are Typic Glossaqualfs. Flooding is flashy, occurring primarily in the dormant season. Initial analyses indicate major overstory species groups do respond to elevational differences within the bottom. Aboveground net primary productivity (NPP) averages 14200 kg per ha per year. Fine litterfall transfers average 8520 kg per ha per year with 63 percent as leaf fall. In contrast to an adjacent pine upland, leaf litter decomposition, as measured by mass loss, was initially greater in the bottomland, but in the second year there was little difference between sites. Pure sweetgum and red oak subgenera (*Erythrobalanus*) decomposed significantly faster than pine needles in both environments. A diverse avian and aquatic population is evident.

INTRODUCTION

The currently estimated 12.5 million ha of forest wetlands in the Southern United States represent less than one-half the original area designated as forested wetlands. Their decline, the growing awareness of their importance, and the efforts to replant or restore wetland (bottomland) forests have increased pressure to understand the structure and functions unique to these communities.

In the early 1990's the Southern Forested Wetlands Initiative was formed. Agencies active in the initiative are the USDA Forest Service, the U.S. Geological Survey, and the U.S. Army Corps of Engineers. In managing, maintaining, or restoring ecosystems the initial need is to identify important functions that characterize undisturbed or stable communities or landscapes. Therefore, an initial objective of the initiative, has been to quantify the physical, chemical, and biological functions of mature bottomland forest communities (Harms and Stanturf 1994).

To address this objective, in 1995, three research areas were established: latt Creek in central Louisiana, Coosawatchie River in South Carolina and Cache River in Arkansas. The Coosawatchie River and Cache River study areas are on major alluvial bottoms, and the latt Creek study area is on a minor alluvial bottom. The Center for Forested Wetlands in Charleston, SC and the Center for Bottomland Hardwood Research in Stoneville, MS are responsible for the Coosawatchie River and latt Creek research study areas, respectively. The U.S. Geological Survey and the U.S. Army Corps of Engineers are responsible for the Cache River study area.

The site types were chosen based on their extent across the South and their probable exposure to management treatments. Selection of specific study areas was based on condition, age, and stability of communities and the area's size and hydrology. Heavily harvested forest communities and dam controlled streams have been avoided. Study areas have at least 300 ha, and nonresearch management activities must be minimal for at least the next 10 years.

A minor alluvial bottom has been selected because the majority of the bottomland hardwood forests remaining in the South are within minor alluvial bottoms (Hodges 1998). Moreover, these bottoms are expected to face some of the highest management pressures. Minor alluvial bottoms primarily differ from those of major streams in two respects: flood characteristics and the influence of immediately surrounding uplands.

Based on published research, gaps are evident in our understanding of the basic processes and components within bottomland forests. These gaps are especially evident for minor bottoms. In this paper we describe the latt Creek Study Area and present some of the preliminary results of this study. In this study area, 11 studies are currently ongoing. This report focuses on initial analysis of the vegetative community, aboveground Net Primary Productivity (NPP), litter-fall transfers, rates of litter-fall decomposition, and observations from avian and aquatic studies.

METHODS

Study Area Description

The latt Creek Study Area is on the upper reaches of latt Creek, on the Winn Ranger District of the Kisatchie National Forest (KNF) located in central Louisiana (31° 43' 30" N; 92" 38' W). The site is a braided stream bottom dominated by latt Creek but laced with secondary streams flowing into and parallel with the primary stream. The approximately 195-km^2 watershed upstream from the research area is primarily forest and pasture. The approximately 320-ha study area varies in width from 550 to 1000 m and has an overall length of 5000 m. The dominant soil series is Guyton, Typic Glossaqualfs. Climate is in the humid temperate domain, subtropical division (Bailey 1998) with a normal annual temperature of 18.1 °C and normal annual precipitation of 1470 mm (Owenby and Ezell 1992).

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Study Area Infrastructure
To provide the information and the organization needed for multiple studies; closed base, perimeter, and transect line surveys were made. Permanent stakes were installed at 61-m intervals on all survey lines and where lines crossed streams. Seven transect lines were located parallel to each other at 500-m intervals (fig. 1). In these surveys the location and elevation of each stake were determined. A separate point grid at 250-m x 250-m intervals was established for the avian study. The starting points of all surveys were randomly selected. Two meteorological stations were established, one in the forested bottom and the other in an adjacent clearcut opening.

Geographic Information System (GIS) coverages of latt Creek are provided by the KNF. Coverages include soils, topographic, vegetation and land use, roads, land ownership, and aerial photographs. Geographic Positioning System (GPS) and elevational surveys were used to greatly refine the coverages especially location and extent of sloughs, stream channels, and other features within the study area (fig. 1).

Vegetation Dynamics-Ordination
Study design and installation-Beginning at a random starting point, 47 ordination plots were established at systematically located points 122 m apart on the seven transect lines. The plots were 0.1 ha (20 m x 50 m) and were subdivided into ten 10-m x 10-m subplots to facilitate data collection and analysis.

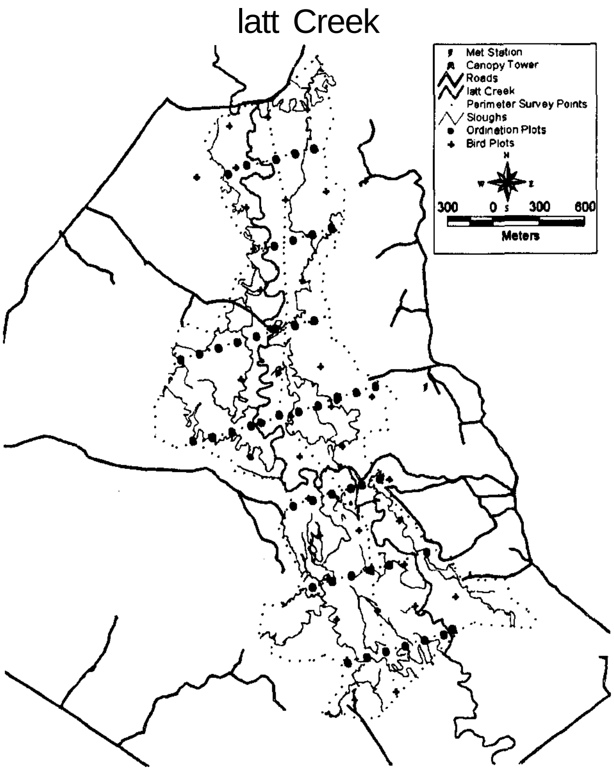

Figure I-The latt Creek Study Area, Winn Ranger District, Kisatchie National Forest.

Overstory and **midstory** plants in each plot were inventoried, and species and diameter at breast height (d.b.h.) for each stem ≥ 7.6 cm d.b.h. were recorded for each O.Ol-ha subplot. Elevation above sea level of each subplot corner and maximum elevation of the soil surface at the base of each of the measured trees were calculated.

Sapling and low shrub/herbaceous layers were also measured. In the sapling layer, the d.b.h. and species of every tree > 2.5cm and < 7.6-cm d.b.h. were determined. On each subplot all trees < 2.5cm d.b.h and > 1.4-m in height were counted by species and two d.b.h. size classes: ≤ 2.5 cm and ≥ 1 cm and < 1 cm. To measure the low shrub (height < 1.4 m) and herbaceous layer, ten 1-m^2 sample plots were randomly located within each O.l-ha plot. For each sample plot, percent cover by plant species was calculated.

Data summary and analysis-Initial analysis efforts focused on tree layer (> 7.6-cm d.b.h.) composition and species dominance. Basal area (BA, m^2 per plot), density, and importance value were calculated for each species. These variables were summarized by species for all trees, for all dominant and codominant trees, and for all intermediate and suppressed trees. Data for each tree species were aggregated into five data sets: the full data set representing all 10 subplots of each ordination plot, two non-overlapping 0.04-ha square plots (S1 and S2), and two non-overlapping 0.04-ha rectangular plots (L1 and L2). The S and L subplots are composites of the smaller 0.0%ha subplots initially established as the subdivisions of the 0.1-ha study plots. Data were summarized into total BA and total density by plot and subplot for each species, and into importance values for each species on each plot and subplot. Importance value was calculated as (species relative BA as proportion of total BA on plot) + (species relative density as proportion of total density on plot) + (species relative frequency as proportion of 10 (or 4) subplots on which the species occurred). Environmental variables for each of these data sets include the elevation, to the nearest 0.1 m, of all the trees and all the plot corners that belong to that data set.

Analysis of this data set is ongoing and a complete discussion of approach is beyond the scope of this paper. For this paper, data analyses were conducted using SAS (Anonymous 1988), CANOCO (Ter Braak 1988), and TWINSPAN (Hill 1979). We used SAS for data manipulations and for hypothesis testing. We used CANOCO to conduct a detrended correspondence analysis of the species BA values and TWINSPAN to conduct a two-way analysis of species and plots to produce a hypothesis of plot and species groupings for visual and nonparametric analysis.

Aboveground Net Primary Productivity
Annual aboveground NPP per unit area is calculated as the sum of annual net biomass increment and detritus production or litter-fall (leaf and branch) (Binkley and Arthur 1993, Waring and Schlesinger 1985).

Initial cluster analyses indicated that **sweetgum** (*Liquidambar styraciflua*) and sweetgum-cherrybark oak(*Quercus* pagoda) are the two dominant communities in the bottom, accounting for 70 percent of the 47 ordination plots (Gardiner and others 1996). From these dominant communities, 10 ordination plots were randomly selected for estimation of NPP. The tree, sapling, and herbaceous vegetation layers were defined like those in the ordination study.

Biomass increment is the increase in plant biomass produced during the measurement period. It is estimated as the annual change in standing woody biomass plus mortality. For each tree in the tree layer within each plot, d.b.h. was measured annually and height in alternate years beginning in the winter of 1995-96. Using published biomass equations aboveground biomass was estimated for each tree and summed on a per area basis for each year (Megonigal and others 1997, Schlaegel 1984).

Similarly, beginning in 1996 all saplings have been identified and measured annually (basal diameter and height). Sapling biomass also has been estimated by using published equations (Williams and McClenahen 1984).

Mortality occurring between measurements is not measured as biomass in the second measurement year. Therefore, the mass of the mortality occurring between measurements is added to the change in living biomass between years to provide a valid estimate of biomass increment. Adding the biomass of tree(s) that died during the measurement period to the change in aboveground tree biomass increases the biomass increment of dead tree(s) to zero for the measurement period (Binkley and Arthur 1993).

To measure aboveground herbaceous production within each productivity plot, 10 points were randomly selected and sampled in August 1996 at the peak of standing biomass. All low vegetation was collected from a 1-m^2 plot at each sample point. Vegetation was separated into grasses, sedges, broadleaf, current growth of woody perennials (< 1.4 m), vines, ferns, and other materials. All vegetation, except woody perennials, was clipped at ground level, sorted by categories in the field, and placed in paper bags. For woody perennials, leaves and current years twig growth were collected. All materials were ovendried at 70 °C with mass reported on an ovendried weight basis.

Litterfall-Annual Detritus Production

Fine litterfall—Litterfall was measured using litter traps—open mesh baskets supported about 1.5 m above the ground by poles. Within each of the ten O.l-ha plots used to estimated aboveground NPP, five litter traps were randomly placed. Collections were made monthly. Contents were sorted into leaf tissue, fruits and flowers, bark and fine wood (< 1 cm diameter), and other; ovendried (70 °C), and weighed.

Coarse branchfall—Five 50-m' subplots (5 m x 10 m) were randomly located within each of the ten O.l-ha study plots. Initially, all coarse woody branchfall (wood > 1 cm in diameter) was marked or removed from each sample subplot. Since 1996, coarse branchfall has been collected on a quarterly basis and processed in a manner similar to fine litterfall.

interaction of litter species and forest community in decomposition processes-Litter decomposition and nutrient mineralization reflect the leaf litter composition and micro-environment in which they occur. The objective of this study was to evaluate the influence of leaf litter species and community type on leaf litter decomposition and nutrient mineralization. The mass loss rates of three litter species or species groups were evaluated in latt Creek's bottomland hardwood community and the adjacent upland pine community. Nutrient analyses are in process.

This study used the litterbag method to follow mass and nutrient loss over time. In this method, mesh bags, filled with a known mass of litter, are placed in the study environment. Changes over time are determined by periodically collecting and weighing a subset of litterbags. In this study the litterbag was a flat nylon net bag, 20 cm x 30 cm , Delta (15.9-kg test), with l-mm mesh openings. The litterbags were filled with 20 g of the leaf litter, sewn shut, and placed on the surface of the existing forest floor. Bags were individually numbered and secured in place with wire pins.

The three litter species were sweetgum, red oak subgenera (*Erythrobalanus*) and loblolly pine (*Pinus taeda* L.). Litter materials were freshly fallen senescent leaves collected within the study communities and sorted by species or species group.

Within each community, five permanent plots were randomly selected. The five bottomland hardwood plots were selected from the 10 plots used in determining NPP, and the five pine plots were selected from a pool of nine O.l-ha pine plots in the adjacent upland.

On each plot, three sets of 14 litterbags were randomly placed for each of the three species of litter. At approximately bimonthly intervals over the next 2.5 years, collections of three litterbags for each species were made from each of the 10 plots. A total of 1,260 litterbags were installed and collected.

Collected samples were returned to the laboratory in individual paper bags, cleaned of foreign materials and soil (as practical), ovendried (70 "C), and weighed. Because mineral contamination was significant and variable, a subsample from each collected bag was then ashed at 450 °C for 4 hours in a muffle furnace to allow reporting of mass loss on an ash-free basis.

Avian and Aquatic Populations

Avian surveys were conducted by means of IO-minute point counts in winter and summer at all study area grid points (Hamel and others 1996). Aquatic populations were surveyed by using standard electro-shocking and netting techniques in the case of fish and hand probing of habitat in the case of fresh water mussels. Results are reported on a per unit effort basis.

RESULTS AND DISCUSSION

The mature hardwood forest is tall, multi-sized, and dominated by large diameter sweetgum, cherrybark oak, and water oak (*Quercus nigra* L.). Some 73 species appear in the woody vegetation layers. The age of the co-dominant/dominant trees (mean height 33 m) is 66 to 75 years at 0.6-m above soil surface. Total tree age may be from 5 to over 20 years greater. Basal area averages 35 m^2 per ha with a mean stand density of 462 stems per ha ≥ 7.6 cm d.b.h.; 1,037 stems per ha ≥ 2.5 cm d.b.h.; and 1,610 stems per ha < 2.5 cm d.b.h. Quadratic mean diameter of all trees ≥ 7.6 cm d.b.h. is 30.4 cm with a quadratic mean diameter of 20.5 cm for all trees ≥ 2.5 cm d.b.h.

Ordination-Vegetation Dynamics

Figure 2 presents an example of initial ordination analyses. The CANOCO and TWINSPAN programs were applied to data on BA of all trees on a 10-m x40-m subset of the full vegetation sample plots. The analysis produced a combined ordination of plots and species to a six-level hierarchy. Analysis of the elevations of the plot corners from the groups of plots distinguished in the ordination revealed a very great variability of species occurrence at the latt Creek site. Analysis of variance of elevations indicated that significant differences existed among mean elevations of plots at all six levels of the hierarchy (R^2 for level 6 = 0.504, where $F_{(15, 452\ df)}$ = 30.71, P = 0.0001). However, the differences among means were distinct and ordered in sequence by elevation for only the two highest levels of the hierarchy (R^2 for level 2 = 0.326, $F_{(2, 465\ df)}$ = 112.44, P = 0.0001). A simultaneous plot of the species and plots indicated a substantial variation among species in the minor stream bottom. Because the variation in elevation within plots is relatively large compared to the variation in elevation across the entire study site, efforts to distinguish gradients defined by elevation will be difficult.

Aboveground Net Primary Productivity

Initial estimates of aboveground NPP show that the single dominant component is fine litterfall (leaf production) which accounts for about 60 percent of the total NPP as follows:

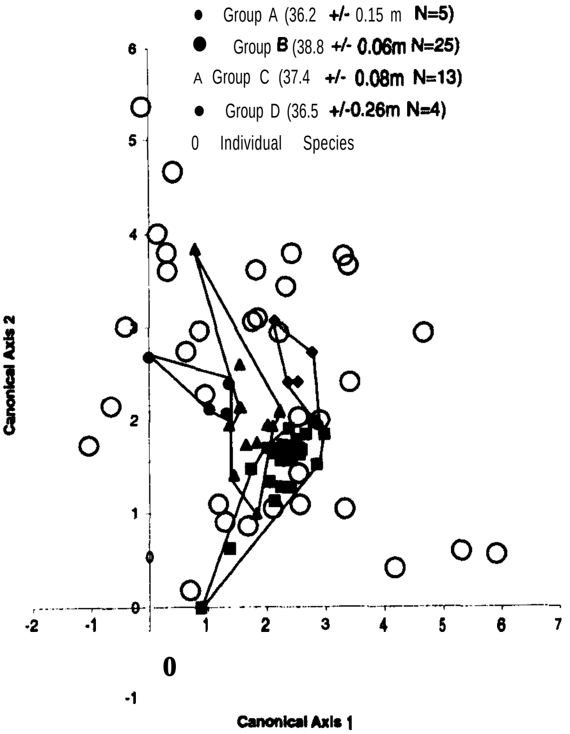

Figure P-Initial Canonical analysis plot of one data subset from the overstory (> 7.6 cm d.b.h.) vegetation data set.

Component	kg per ha per year
Tree layer wood biomass increment	3,880
Sapling layer wood biomass increment	30
Finelitter-fall	8,520
Coarse Branchfall	1,530
Herbaceous annual production	160
Total aboveground NPP	14,120

Wood increment accounts for about 28 percent of total NPP with coarse branchfall accounting for about 11 percent. Both sapling biomass increment and herbaceous understory production appear relatively minimal.

The distribution of productivity reflects the maturity of the forest and the multi-layered nature of the forest vegetation. Due to mesic conditions, the study area supports a large leaf surface area. The large diameter branchfall reflects natural pruning associated with a mature, closed canopy forest. The aboveground NPP is high but within the range reported for southeastern wetland forests (Megonigal and others 1997). The NPP is among the highest for the world's forests outside the tropics. The relationship and responsiveness of annual aboveground NPP to yearly and across site variation in site parameters is being investigated.

Litterfall

Consideration of seasonal litterfall patterns is beyond the scope of this report. Based upon 3 years of data, mean total litterfall is 8520 kg per ha per year with leaves accounting for 63 percent, fruiting structures and seeds 15 percent, fine wood 12 percent, and other fines 9 percent. Total fine litterfall is near the upper limit of the litterfall range (1380 - 8550 kg per ha per year) reported by Megonigal and others (1997) for an array of southeastern wetland forests. Indeed, the latt Creek litterfall is among the highest reported in world forests (Bray and Gorham 1964, Meentemeyer and others 1982, Vogt and others 1986) as a group, exceeded only by tropical rainforests.

Fine Litterfall Decomposition Rates

We compared the rates of mass loss for senescent leaf tissue from cherrybark oak, sweetgum, and loblolly pine in the bottomland and adjacent uplands (table 1). Changes in mass remaining were fit to the negative exponential model of Jenny and others (1949). Rates of decompositions are reported as k values (table 1). In forests, k values commonly range from 0.01 in boreal coniferous to 1 or 1.2 in temperate deciduous forests and as high as 4 to 6 in tropical rainforests.

After 13 months, litter in the pine community exhibited lower k values than in the bottomland (table 1). Within both communities the k values for pine litter are lower than those for deciduous litter. Moreover, within the pine community, sweetgum mass loss is somewhat greater than for red oak leaves while in the hardwood community, the k values are almost identical for the two deciduous broadleaf species.

After 27 months, the k values show a lack of significant differences between communities; the primary difference being the much slower rate of decomposition for the pine needles. As expected, mass loss rates for pine needles were significantly lower than those for deciduous broadleaf species. The impact of substrate quality differences between pine and deciduous broadleaf species has been frequently noted (Heal and others 1997, Swift and other 1979). Decomposition constants for the deciduous broadleaf

Table l-Jenny k values for two sites and three leaf species, where percentage remaining = e^{-kt} (t = time in years) (Jenny and others 1949)

Leaf species	Bottomland hardwoods	Upland pine
	- - *k* values *based on initial 13 months* - -	
Lobloliy pine	0.43	0.28
Red oak	.77	.58
Sweetgum	.76	.63
	- - *k values based on entire 27 months* - -	
Loblolly pine	.51	.44
Red oak	.76	.76
Sweetgum	.77	.78

species are within the range of wetland forests. For forested wetlands, our k values for single deciduous species are lower than the 1 .01 reported by Lockaby and Walbridge (1998) and the 0.83 by Conner and Day (1991) in a natural forested wetland. However, they are slightly higher than the 0.667 reported by Day (1982). Regardless of variation, the k values for the dominant deciduous broadleaf species are indicative of a forest with a high rate of decomposition and nutrient mineralization (Swift and others 1979).

Wildlife Populations

Avian populations-Repeated winter and summer counts revealed more than 75 bird species. Of these species, 23 were Neotropical migrants and 17 were North temperate or short distance migrants. These surveys continue.

Aquatic populations-in September 1997, the fishes and freshwater mussels were quantitatively surveyed at two sites along the latt Creek mainstem and at four sites in the floodplain (e.g., beaver-dammed tributaries, overflow depressions). One mainstem site was located at the northern boundary and the second in the southern section of the study area. The mainstem of iatt Creek yielded a total of 21 fish species, and the shallower floodplain habitats yielded from 6 to 16 fish species. With few exceptions, the fish fauna found in the isolated pools on the floodplain represented a subset of the fauna in the mainstem. Further analysis of catch-per-unit-effort and relative abundances of fishes may provide additional information on the composition of the fauna between mainstem sites and between mainstem and floodplain sites.

The main stream sites yielded six total freshwater mussel species, but no freshwater mussels were found in the floodplain habitats. Freshwater mussels were most common in the shallow riffles and pools at the mainstem site on the northern boundary where catch per unit effort was 80 mussels-per-person-hour searched. in the middle section, catch per unit effort was lower (24 mussels-per-person-hour searched): however, ail six freshwater mussel species were present at both mainstem sites.

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LONGLEAF PINE CONE CROPS AND CLIMATE: A POSSIBLE LINK[1]

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Abstract-The physiological development of longleaf pine seed extends over three calendar years. The duration of this process may explain the reason for infrequent seed crops. Infrequent crops cause problems for those interested in natural regeneration. Longleaf pine cone crops have been monitored on the Escambia Experimental Forest (EEF) in Brewton, AL since 1958. Weather data was lagged up to 4 years prior to seedfall to determine if a relationship exists between climate and cone crops. Correlation analyses indicated precipitation explained 48.8 percent of annual cone crop variation while average monthly temperatures explained 33.7 percent. With knowledge of important months for cone production, it seems likely that mangers would be able to prepare for large crops to reduce management costs. We suggest managers capture as much reproduction as possible in preparation for a reproductive drought similar to the 1969-1975 interval at EEF.

INTRODUCTION

The longleaf pine (*Pinus palustris* Mill.) forest covered an estimated 33-37 million hectares distributed in a broad arc from southeast Virginia to east Texas (Vance 1895, Frost 1993). This forest is now listed as critically endangered ecosystem (Noss and others 1995). Noss (1989) estimated that in pre-settlement times this ecosystem comprised 40 percent of the southern coastal plain. By 1995, the longleaf pine forest, containing one of the most species-rich understory in temperate North America (Peet and Allard 1993), occupied an estimated 1.2 million hectares or 3.2 percent of its former range (Outcalt and Sheffield 1996). Consequently, interest has escalated in the recovery and management of the longleaf pine ecosystem.

One of the major concerns in longleaf pine restoration, regeneration, and management is its sporadic seed production. Excellent mast years occur once every 4-7 years, but with wide variations geographically (Wahlenberg 1946, Boyer 1990) and interannually (Boyer 1987). Maki (1952) reported heavy seed crops might occur over much of the longleaf range once in 8 to 10 years. The minimum size of a cone crop for successful regeneration is considered 750 cones/acre or roughly, 30 cones per tree (Boyer and White 1989). From 1966-l 996 in the longleaf range, five of the eight cone crops considered adequate for natural regeneration have occurred since 1990 (Boyer 1998). The 1996 cone crop was one of the largest recorded in many regions (Boyer 1998). The increase in crop size and frequency, locally and regionally, leads to the hypothesis that climate most likely plays a role in cone crop production (Boyer 1998).

To date the relationship between longleaf pine seed crops and climate remains obscure. Using a 40-year time series (1958-1997) of cone production from the Escambia Experimental Forest (EEF), located in Brewton, Alabama, the influence of temperature and precipitation on cone crops will be explored.

METHODS

Development of Longleaf Pine Cone and Seed

The visual development of longleaf pine seed extends over three calendar years. Male and female flower buds are set during the growing season before the flowers appear. Male flowers typically occur in the lower crown while females are often located in the upper crown. Development of both flowers is weather dependent (Boyer 1990). Table 1 is a guideline of stages for the seed development process from Mathews (1932), Croker and Boyer (1975), and Boyer (1990) and using terminology proposed by Croker (1971).

Site Description

The study was conducted at the Escambia Experimental Forest in south central Escambia County, Alabama. The forest is maintained by the U.S. Department of Agriculture, Forest Service, Southern Research Station in cooperation with T.R. Miller Mill Company.

The climate is humid and mild with rainfall well distributed throughout the year. The warmest months are July and August with average daily minimum and maximum temperatures of 20 and 33 °C, respectively. The coldest months are December and January with average daily temperatures of 3 and 18 °C, respectively. The growing season is approximately 250 days. Annual precipitation averages 156 cm with October being the driest month.

Climate Data

Climate data were obtained from the National Climatic Data Center (NCDC) in Asheville, NC. These data were for Alabama Climatic Division 7, which is the region surrounding EEF. Regional data was used because it tends to reduce the noise of individual station data (Blasing and others 1981). This is important for the southeastern United States, since summer precipitation is characterized by convective rainstorms.

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Table I--Development of longleaf pine seed (adapted from Croker and Boyer 1971 and Boyer 1990)

Year and stage	Usual start
Bud year	
Male catkin initiation	July
Female conelet initiation	August
Male catkins appear	November-December
Flower year	
Male catkins growth begins	January
Female conelet buds appear	January-February
Pollination	Late winter-spring
Conelet, early	June
Conelet, late	October
Seed year	
Fertilization	Spring
Rapid cone growth	February-June
Cone ripens	Mid-September-mid-October
Cone opens	Late October

Seed Crop Data

All crop data from the 1950's were collected from seed traps. Cone counts from 1960-I 996 were made by binocular counts and described in Boyer (1998). The number of trees sampled per year up to 1971 was 235, except for the small cone crop of 1966 when only 41 trees were sampled. After 1971, a new set of 217 trees, older than 55 years, were sampled at the EEF (Boyer 1974). No change in the number of cones per tree was observed after this shift (fig. 1). Trees from this set, which were cut or died, were not replaced. By 1996, the number of trees sampled equaled 205.

The number of cones counted per tree was averaged to establish a time-series of cones per tree per year (CPT) for EEF.

Determining Climate Factors Important for Cone Production

Since the development of cones extends over several years, linear regression analysis was lagged four years to identify the months of influence on cone production. The CPT was compared to monthly precipitation and average temperature.

RESULTS

Cone Crop Production

On the Escambia Experimental Forest cone crops greater than one CPT were produced every year except 1963 and 1989 (fig. 1). Average CPT for EEF from 1958-1997 was 24.7. When divided into three equal periods the number of times a crop equaled 30 or more CPT was four for 1958-71, zero for 1972-84, and five for 1985-97. Average CPT was 20.4 for 1958-71, 13.1 for 1972-84 and 41 .O for 1985-97. All of the crops larger than 100 CPT occurred between 1987 and 1996.

Relation to Climate

The regional climate data were strongly related to crop production. Precipitation explained 48.6 percent of annual variation while temperature explained 33.7 percent. Several months of average temperature were significantly related to important stages of cone development (fig. 2). August and December average temperatures prior to the bud year are positively, significantly correlated with cone crops. The positive correlations continue through the winter and spring of the bud year. This is just prior to differentiation of male and female flowers. During differentiation, July temperature is significant and negatively correlated to cone crops. October temperature of the bud year is positive and significantly correlated. This is just prior to the appearance of male flowers in December. The positive correlation

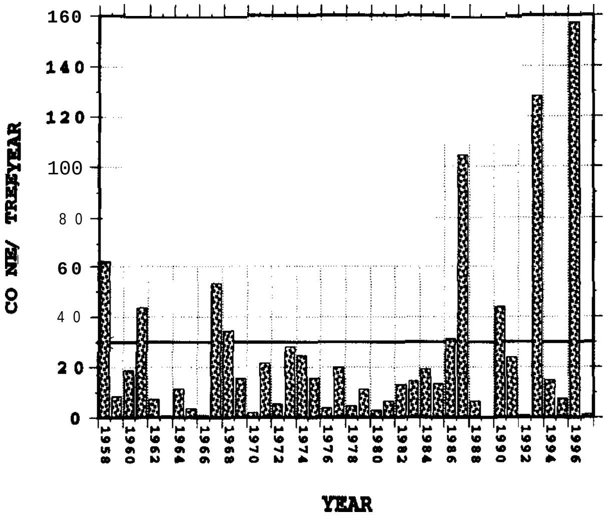

Figure I-Average number of cones per tree per year at the Escambia Experimental Forest, AL from 1958-1997. The line at 30 cones per tree represents the level considered adequate for natural regeneration (Boyer and White, 1989).

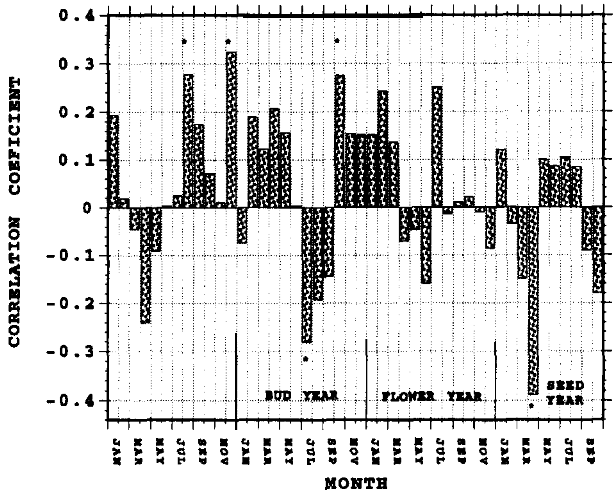

Figure 2—Correlation of monthly precipitation from AL Climate Division 7 and annual cone crops. Bud Year, Flower Year and Seed Year represent the years of development of a longleaf pine seed; * = significant correlation level p=0.10.

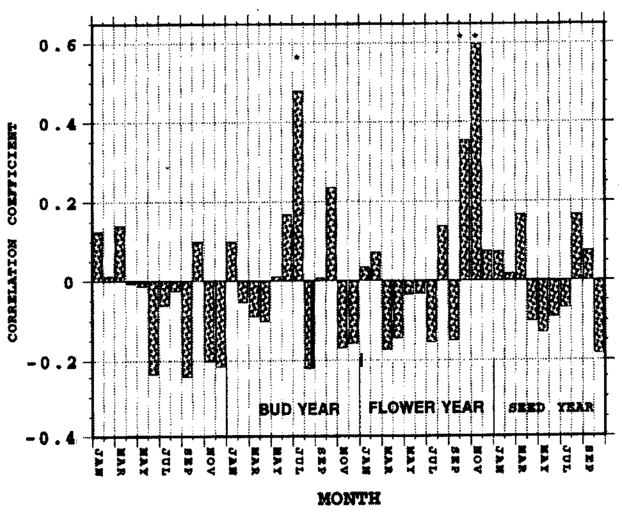

Figure 3-Correlation of monthly temperature from AL Climate Division 7 and annual cone crops. Bud Year, Flower Year and Seed Year represent the years of development of a longleaf pine seed; * = significant correlation level p=0.10.

extends through the winter months. April temperatures of the seed year were significant and negatively correlated with cone production.

Regional monthly precipitation explained 48.6 percent of annual variation and shows important timing with crop development (fig. 3). July of the bud year is significant and positively correlated to cone crops. This marks the beginning of differentiation of male and female flowers (table 1) and is consistent with earlier findings by Shoulders (1967). Precipitation is strongly correlated with October and November of the flower year and coincides with the commencement of the late conelet stage.

DISCUSSION

Factors Influencing Cone Crop Production

This study has revealed the importance of climate and longleaf pine cone production. Many phases in the physical development of a longleaf pine cone are correlated with or preceded by significant climate variables (table 1, fig. 2 and 3). The significance of climate just before many development stages suggests that the health of the tree determine whether energy investments should be made before commencement of the next stage. Significant months at the end of the growing season (warmer August and December before the bud year, warmer October of the bud year, and a wetter October and November of the flower year) suggests that extended growing seasons are important. Extended growing seasons may allow luxuriant or non-essential nutrient uptake to improve the health of the tree, feed the cone buds and conelets, or stores extra photosynthate.

One of the largest contributions of climate was seen prior to the flower year. Flower development and pollination occurs early in the flower year. This suggests that healthy buds might be very important to cone development. A recent study found an increase in the production of female flowers plus a higher percentage of survival (Boyer 1998). Therefore, it may possible to conclude that better climatic conditions aid bud survival and health which leads to increased female flower development, survival, and pollination at EEF.

The strongest climate factor correlated to cone development at EEF is precipitation during fall of the flower year. This period is the beginning of the late conelet stage. This stage marks the end of conelet losses, is when fertilization occurs, and may be when seed viability is determined (Croker and Boyer 1975). Perhaps this late-growing season precipitation helps to provide better tree health for the large energy demand during fertilization, cone enlargement, and seed ripening the following year.

Other factors beside climate have influence on longleaf cone production. One possible reason for the increase in cone crops could be stand density. Changes in stand density would alter the competitive environment and the availability of resources like nutrients and water. For example, increased stand density reduces cone production while lower stand densities increases it (Croker 1973). However, the goal of forest management on the EEF was to maintain a constant stand density. Therefore, management does not seem to be a likely cause in the increased activity of the reproductive cycle.

Climate, Climate Change and Future Work

From the above line of reasoning, climate appears to be the primary factor in the changing cone crop production at EEF. The increased survival of female flowers (Boyer 1998) suggests that environmental conditions are improving during recent reproductive cycles. How future climate change will effect these interactions is uncertain. There is growing consensus that climate will warm in the long-term (Houghton and others 1996). The warming observed in the last century has been primarily through nighttime temperatures (T_{min}) (Houghton and others 1996). There is no reason to expect that maximum daily temperatures (T_{max}) have the same effect as T_{min} (Alward and others 1999). Future work calls for understanding the effect of T_{min} and T_{max} on cone development and production as well as better understanding of the causes of increased survival of female flowers.

November precipitation increased 53.2 percent from 1985-1997 when compared to 1958-l 971. This change may be the primary cause for change in the reproductive cycle at EEF. The reason for the increased precipitation could be the observed changes in the Pacific Ocean. The southeastern U.S. is teleconnected to the Pacific Ocean (e.g. Ropelewski and Halpert 1986). The major 1976 step change of the Pacific (Ebbesmeyer and others 1991), recent anomalous El Nino/Southern Oscillations (ENSO) (Latif and others 1997) or the possible change of ENS0 from 3-4 year mode to a decadal oscillatory mode (Zhang and others 1997, Villalba and others 1999) could provide a small, but important change in cone production. Winter is the primary season of influence of ENS0 on the southeast USA (Ropelewski and Halpert 1986). Several months during the fall and winter were significantly correlated with cone production in this investigation. It is also expected that global warming will change precipitation regimes (Houghton and others 1996). Future work requires the investigation of the influence of the Pacific Ocean and precipitation indices on longleaf pine

Pacific Ocean and precipitation indices on longleaf pine cone production.

SUMMARY

We have shown significant correlation between climate and longleaf pine cone production at the Escambia Experimental Forest. Several months of temperature and precipitation during different stages of the three-year cone development process contribute to total cone production. How different aspects of climate change will impact these relationships is unknown, but will be pursued in future work.

It seems reasonable than an observant manager will be able to plan for regeneration well in advance of a substantial cone crop (Boyer 1974). By observing flower development and climate variables during important months, cone crop abundance could be anticipated a year in advance. This would extend the window of opportunity for timber and fire management plans to enhance longleaf pine regeneration and reduce costs. Finally, in the face of an uncertain future climate, we suggest that managers capture as much reproduction as possible in preparation for a potential reproductive drought like 1969-l 985 at EEF. The long-lived and persistent nature of longleaf pine makes this type of reproduction management possible.

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RELATIONSHIPS OF SELECTED SOIL PROPERTIES AND COMMUNITY SPECIES COMPOSITION IN TURKEY HILL WILDERNESS AREA IN EAST TEXAS[1]

Kenneth W. Farrish and Brian P. Oswald[2]

Abstract-Sixty-nine different stands within 15 different previously managed communities were sampled in what is now the Turkey Hill Wilderness of the Angelina National Forest. Within each stand, 0.04 ha plots were randomly located, and the height, diameter, crown class and species of each tree recorded. Soil samples were collected in two locations within each plot, and the soil type confirmed at plot center. Soil samples were analyzed for selected soil chemical and physical properties. Due to the low occurrence (less than 4 times) of some communities, only six community types were analyzed in-depth. Analysis of the vegetation and soil data using Cluster, Principle Component and Pearson's Correlation Analyses showed some relationships between vegetation communities, species and the soil properties. This information may be useful toward development of better understanding about plant community relationships.

INTRODUCTION

Designated wilderness areas within National Forests in the eastern United States were commonly established on forestlands that had been managed for a number of years. Since wilderness designation, these areas have had no management in the traditional forestry sense. They provide an excellent laboratory to observe and quantify successional trends and soil/vegetation relationships.

The region known as the Piney Woods of East Texas is dominated by pine, pine-hardwood and bottomland hardwood forests. Dominant tree species may include Loblolly pine (*Pinus taeda*), Shortleaf pine (*Pinus enchinata*), Longleaf pine (*Pinus palustris*), Sweetgum (*Liquidambar styraciflua*), a number of elms (*Ulmus* spp.) and a wide variety of oaks (*Quercus* spp.). These forests are found over a wide range of soil types and landforms.

The objective of this study was to correlate vegetation communities and species within them to selected soil chemical and physical properties.

METHODS

Using color IR aerial photographs (nominal scale 1 :1 5,840) the 2140 ha Turkey Hill Wilderness was delineated into 69 stands of apparently different communities. Randomly located 0.04 ha plots were established within each stand, and vegetative data (species, height, d.b.h.) were collected. Cluster analysis was used to group the 69 stands into 15 overstory community types. Because some of these communities were only found a few times (less than 4), only 6 (table 1) were used for further study. These six communities covered 1605 ha (75 percent of Turkey Hill Wilderness area).

In two corners of each plot, soils were sampled from each of the surface horizons and the first B horizon and composited by horizon. Various soil chemical physical and chemical parameters were analyzed (table 2). Soil data was converted to a weighted mean for the profile. A soil profile description was also made at each plot center and each soil was classified (table 3) using an established soils legend for the area (USDA SCS 1980).

Principle Component Analysis was used to identify which soil parameters accounted for the variability among communities. Pearson's correlation was performed to correlate soil parameters to a species relative importance within a community, using Relative Basal Area (RBS) as reflecting importance. All statistical tests were performed using SAS (SAS Institute 1990).

RESULTS

Because of the large number of correlations found, we reduced these to those with a correlation of positive or negative > 0.80 and a p-value of less than or equal 0.05 (table 4).

On the more mesic sites (loblolly pine-hardwood and hardwood communities), a variety of soil-hardwood species correlations were observed.

Those communities we classified as shortleaf pine had a large number of shortleaf pine correlations with soil parameters, while the loblolly pine sites and shortleaf pine-loblolly pine sites showed hardwood species correlations, but not with pines.

Those old loblolly pine sites that were decimated by the Southern Pine Beetle (SPB) showed a few insignificant dogwood and red maple correlations. Five of the six areas were found on fine-textured Ultisols (Cuthbert, Kirvin, Sacul soils), while the other was found on a loamy textured Ultisol (Lilbert soil) (table 2).

DISCUSSION

In the shortleaf pine communities, the measured soil parameters appear to have little effect on other species other than shortleaf pine. When site conditions become

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

[2] Associate Professor and Assistant Professor, Arthur Temple College of Forestry, Stephen F. Austin State University, Nacogdoches, TX 75962-6109, respectively.

Table l-The vegetative communities, area, and number of plots found on Turkey Hill Wilderness Area

Cover type	Area	Number of plots
	ha	
Mixed hardwood'	*700*	*20*
P. ***taeda*-hardwood**[a]	*305*	*10*
P. ***taeda***[a]	*214*	*7*
Pinus echinata[a]	*206*	**6**
No **overstory**[a]	*102*	**6**
P. echinata-P. ***taeda***[a]	**78**	*4*
P. ***palustris-P. taeda***	**80**	**3**
P. ***taeda-Liquidambar styraciflua***	*76*	**2**
P. echinata-Quercus sp.	*50*	**2**
Q. ***alba-Q.*** *pagoda*	*14*	**2**
Q. ***falcata***	80	**1**
Q. ***alba***	*67*	**2**
Q. spp.	*91*	**2**
Fagus grandifolia -hardwood	*40*	**1**
Q. michauxii-Q. pagoda	*35*	**1**

'Only the communities in bold type were used for statistical analysis.

Table P-Selected soil chemical and physical parameters analyzed

Parameters		
pH	Manganese	Bulk density
Total nitrogen	iron	Texture (percent sand, silt, clay)
Extractable phosphorus	Nickel	Magnesium
Potassium	Zinc	Depth of horizons
Calcium	Organic matter	**Copper**
Available soil water holding capacity		

more **mesic** and lobloiiy pine becomes **a** co-dominant species, a few of the soil parameters have negatively correlated to **sweetgum** (table 4).

The iobiolly pine communities in this study appear to be climax white oak types. These sites will continue to reflect the successional pressure of white oak on the lobioily pine. Similar **NIPL** stands across the region should be expected to exhibit the same type of successional pressures.

A mixed iobiolly pine-hardwood community in this area has **a** number of soil parameters that favor the hardwood components. Loblolly pine on these sites (and on the **loblolly** pine sites above) have greater plasticity in site requirements, and is hence not highly correlated to any on the soil parameters we measured.

Table **3—Soils** used in the correlations

Soil series	Taxonomic classification
Cuthbert	Clayey, mixed, thermic typic hapludults
Sacul	Clayey, mixed, thermic aquic hapludults
Kirvin	Clayey, mixed, thermic typic hapludults
Lilbert	Loamy, siliceous, thermic arenic plinthic paleudults
Woodtell	Fine, montmorillonitic, thermic vertic hapludults
Keltys	Coarse-loamy, siliceous, thermic aquic glossudalfs
Darco	Loamy, siliceous, thermic grossarenic paleudults
Tenaha	Loamy, siliceous, thermic arenic hapludults
Joiner	Siliceous, thermic psammentic paleustalfs
luka	Coarse-loamy, siliceous, acid, thermic aquic udifluvents
Rentzel	Loamy, siliceous, thermic arenic plinthaquic paleudults
Tuscosso	Fine, mixed, thermic, dystric fluvaquentic eutochrepts

Table 4-Correlations between soil properties and species' within communities. Species proceeded by a "–" have negative correlation with the soil property

Soil variable	No overstory	Shortleaf/ loblolly	Shortleaf	Loblolly	Loblolly/ hardwood	Hardwood
Slope				-R maple	R maple	-Elm
Sand (percent)			-Shortleaf	-Wh oak	Dogwd	SR oak
Silt (percent)			Shortleaf	Wh oak	Wh. oak	Bjk. oak
Clay (percent)			Shortleaf	Wh oak	Bk oak	
AWC			Post oak			Hickory
P			Shortleaf			Hickory
Na		-Swtgum				
K	-Dogwd					
Ca	R maple		Shortleaf	-Bk gum	-R maple	
Mg	-Dogwd	-Swtgum	Shortleaf	Wh oak	-R maple	
Ni	-Dogwd		Shortleaf	Wh oak		
Mn				Wh oak		
Fe	-R maple			Wh oak	Bk Gum	Hickory
cu				Wh oak		
Zn					-Beech	
Sb[b]	R maple		Shortleaf	Wh oak	Bjk oak	
PH						Mix
OM						-Oaks
TN[c]	-Dogwd		Shortleaf			Hickory

[a] R maple = *Acer rubrum*; Elm = *Ulmus* spp.; Shortleaf = *Pinus echinata;* Wh oak = *Quercus alba*; SR oak = *Q. falcata;* Dogwd = *Comus florida;* Bk oak = *Q. velutina*; Bjk oak = *Q. marilandica*; Hickory = *Carya* spp.; Swtgum = *Liquidambar styraciflua*; Bk gum = *Nyssa sylvatica*; Beech = *Fagus grandifolia;* Mix = large mix of hardwood species; Oaks = *Quercus* spp.
[b] Sb = Sum of bases.
[c] TN = Total nitrogen.

Table !&Occurrence of soil series by community type

Soil series	No overstory	Shortleaf/ loblolly	Shortleaf	Loblolly	Loblolly/ hardwood	Hardwood
Cuthbert	3				1	3
Sacul	1	2		2	1	2
Kirvin	1				1	3
Lilbert	1					1
Woodtell		1	3	3	1	7
Keltys		1		1	2	
Darco			2			
Tenaha			1		2	
Joiner				1		1
Iuka					1	
Rentzel					1	
Tuscosso						3

All but one of the pine beetle spots occurred on fine-textured Ultisols, not on other fine-textured soils in the study **area.** The other beetle site occurred on a loamy Ultisol (table 5). The lack of management on these sites, combined with the increased competition from hardwoods, may pre-dispose these sites to loblolly mortality from beetle outbreak. The low nutrient status of these soils may be an additional stress factor influencing beetle susceptibility.

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Water and Soil Hydrology

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STREAM CHEMISTRY AFTER AN OPERATIONAL FERTILIZER APPLICATION IN THE OUACHITA MOUNTAINS[1]

Hal 0. Liechty, Jami Nettles, Daniel A. Marion, and Donald J. Turton[2]

Abstract-The amount of forested land annually fertilized in the southern United States has increased rapidly in the past 10 years. Although forest growth responses to fertilizer are fairly well understood, knowledge concerning the effects of fertilization on stream chemistry and health in this region is limited. To better understand the potential changes in stream chemistry after operational forest fertilization in the Ouachita Mountains of Arkansas, levels of N were monitored in a stream after application of 437 kg ha" of urea and 140 kg ha^{-1} of diammonium-phosphate to a 150 ha watershed. Baseflow and stormflow concentrations of NO;-N, NH,-N, and Total Kjeldahl N were measured at the outlet of the fertilized subwatershed, the outlet of a reference subwatershed, and downstream of both in the main watershed prior and up to three months after fertilization application. Maximum NO_3^--N and NH,-N concentrations prior to fertilization were respectively 0.3 and <0.01 mg L^{-1}. Nitrate-N concentrations peaked at 3.58 mg L^{-1} during a storm event 50 days after urea application while NH,-N levels peaked at 4.91 mg L^{-1} 24 hours after urea fertilization. Concentrations of total organic nitrogen (Total Kjeldahl N - NH,-N) peaked at 44.5 mg L^{-1} five hours after urea application. Nitrate-N concentrations remained elevated for 78 days after urea fertilization. The unexpectedly rapid increase and high levels of N afler application appear to be related to an extremely large precipitation event which occurred within 24 hours of fertilizer application and to direct application of fertilizer to intermittent and ephemeral stream channels.

INTRODUCTION

In the past 10 years the use of fertilizer to increase productivity of southern pine forests has increased dramatically. The reported area of fertilized loblolly has increased from approximately 128,000 acres in 1988 to 890,000 acres in 1997 (North Carolina State 1998). Although there has been a rapid growth in fertilizer use, information documenting the potential changes in stream chemistry resulting from forest fertilization in the southern United States is minimal. The available research, much of it from the 1970's, indicates that application of fertilizer typically causes a short-lived peak in several constituents followed by low-level alterations in stream chemistry for two to three years after application. Aubertin and others (1973) documented a sevenfold increase in average NO_3^--N concentrations during the first 9 months and an 18 percent increase in total N discharged in the first year following application of 225 kg ha^{-1} of urea to a West Virginia watershed dominated by second growth hardwood. Patric and Smith (1978) reported that in this same watershed NO;-N and Ca^{2+} concentrations were significantly elevated above pre-fertilization concentrations for respectively, two and three years after fertilization application. Helvey and others (1989) reported similar changes in stream chemistry after application of 336 kg ha-' N as ammonia nitrate and 224 kg ha^{-1} P_2O_5 in another pair of watersheds dominated by second growth hardwoods located in this same area of Western Virginia. Stream water concentrations of NO_3^--N rapidly increased and at times were above drinking water standards but concentrations of P were unaltered (Helvey and others 1989). Nitrate-N concentrations after this fertilizer application were still higher in the treatment than control watersheds nine to ten years after the application. Edwards and others (1991) reported that the outputs of NO_3^--N, Ca^{2+}, and Mg^{2+} from these treated watersheds were significantly greater than predicted by control watersheds for the first three years after application.

These studies generally demonstrated that while urea-N and NH,-N concentrations rise immediately after fertilization and quickly return to pre-fertilization levels, NO_3^--N levels remain elevated for extended periods of time after fertilization. Peak concentrations of ionic N occur during stormflow events and storm characteristics such as size and intensity influence peak concentrations to a greater degree than absolute fertilization rates. However, cumulative effects of fertilization, both temporally and spatially, have not been considered.

Forest fertilization in the Ouachita Mountains of Arkansas primarily occurs in watersheds dominated by loblolly (*Pinus taeda* L.) and shortleaf pine (*Pinus enchinata* Mill.). Streams in this region supply much of the drinking water for local urban centers and are valued for their recreational use. To better understand the potential effects of operational fertilization on these streams, water chemistry was monitored during and after an operational fertilization of a 150 ha watershed in the Ouachita Mountains. The objectives of the study were: 1) to quantify changes in NO;-N, NH,-N, and Total N concentrations in the fertilized watershed 2) to determine the duration of the changes in N concentrations, 3) evaluate whether these changes in N chemistry persists downstream from the area of fertilizer application, and 4) gather information for further fertilization and analysis of cumulative effects.

METHODS

Study Site

Research was done in the Little Glazypeau watershed located approximately 20 km from Hot Springs, Arkansas (fig. 1). The watershed encompasses 2,273 ha, has an elevation between 209-381 m, has a southwest aspect, and contains 33 km of perennial streams. Approximately 50 percent of the watershed contains loblolly pine plantations while the remaining 50 percent of the watershed contains mixed pine-hardwood stands, natural short-leaf pine stands,

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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precipitation amounts, and used the stage measurement to initiate and control timing of the water sample collections by the ISCO 3700 samplers beginning in December of 1997. Historical stage data was used to design a unique sampling scheme for each outlet. A critical stage measurement initiated hourly storm event sampling and a critical increase in stage between successive 1 O-minute stage measurements was used to collect additional samples during rapid increases in discharge. Baseflow sampling ranged from hourly to weekly with the most intensive sampling occurring just prior to, during, and shortly after fertilization application.

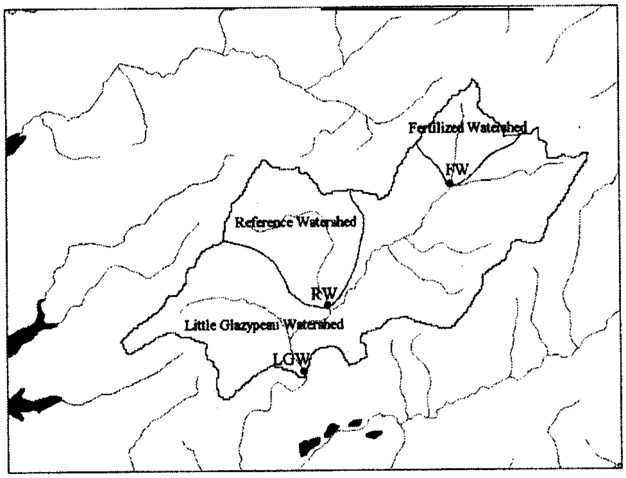

Figure 1—Study watersheds and outlet monitoring stations.

cleared land, or land dominated by shrubs and brush. Two subwatersheds as well as the outlet of the basin were the focus of the study. The subwatershed that was fertilized (FW) is 150 ha in size (fig. 1). Loblolly pine plantations occupy 138 ha while mixed hardwood-pine stands occupy 12 ha of the FW. The second subwatershed which is 325 ha in size was used as a reference (RW). The RW contains 104 ha of pine plantations. Mixed hardwoods, natural pine stands, and shrub/bush vegetation dominates the remaining 221 ha. The 150 ha basin had not been previously fertilized, but a 76 ha pine plantation in the reference basin had been fertilized the year before the study. Stream water was monitored at the outlets of the FW, RW, and larger Little Glazypeau watershed (LGW). The monitoring station in the LGW is approximately 6.5 km below the FW station.

Fertilizer Application

A total of 437 kg ha^{-1} urea was applied to the FW on February 9, 1998 and another 140 kg ha-' of diammonium phosphate (DAP) was applied 77 days later. Delivery of N was 201 kg ha" and 25 kg ha^{-1} from the urea and DAP applications respectively. Application of the fertilizer was by helicopter using a bucket spreader. It took four hours to apply the urea and two hours to apply the DAP. Perennial stream channels and streamside management zones surrounding these stream channels were avoided during application. However, non-perennial channels and the associated surrounding riparian areas did receive the same fertilizer application as the upland portions of the watershed.

Sample Collection and Stream Measurements

Stream stage and velocity were measured every 10 minutes at each of the three outlets, with data collection beginning in the summer of 1996 at the FW and LGW outlets and shortly before fertilization in the RW. Stream stage and velocity was monitored using Starflow Ultrasonic Doppler #6526 Instruments. Stream stage was also measured in stilling wells using Belfort water level recorders equipped with FW1 potentiometers. Precipitation was measured using tipping rain gages at each station and stream water samples were collected using ISCO 3700 pump samplers. A Campbell CR1 OX Data logger recorded potentiometer stage as well as

Sample Analysis

Nitrate-N and NH,-N concentrations were determined for every water sample but to reduce analysis costs Total Kjeldahl N (TKN) concentrations were only determined for every other water sample. Since N measured as TKN includes NH,-N, urea-N, and other forms of organic N, total organic N (TON) was computed by subtracting NH,-N from TKN. Nitrate-N concentrations were determined using ion chromatography. Ammonia-N concentrations were determined colormetrically using a Latchat 2000 flow injection system. TKN was determined in the same manner after digestion with sulfuric acid. All concentrations were determined after filtration with 2.0 pm filter paper. To calculate mean concentrations over a given time period, concentration below detection limits (<0.01 mg L^{-1}) were given a value of 0.005 mg L^{-1}. All mean concentrations were calculated from concentrations unadjusted for discharges.

RESULTS AND DISCUSSION

Precipitation During the Study

A total of six storm events were sampled prior to fertilization. Average recorded precipitation amounts for these events at the LGW outlet was 8.19 cm (3.23 in). Within IO-12 hours after urea application, a storm event began that produced 29.0 cm (11.43 in) of precipitation during a 26-hour period at the maximum point recorded in the watershed. At the outlet, the rainfall measured 24.6 cm (9.68 in). The maximum point 24-hour rainfall was 10.64 inches, well above the 100-year, 24-hour rainfall of around 9 inches (USDA Dept. of Commerce, 1961). Stream stage at the RW outlet increased from 0.21 to 3.54 feet in less than eight hours. This no doubt represents a potential worst-case scenario for fertilizer movement due to overland and channelized flow. Another seven precipitation events occurred after the February 10"' event before the end of the study on April 9.

Urea Application

Only 17 to 19 percent of the samples collected prior to fertilization application had detectable NH,-N concentrations (<0.01 mg L^{-1}). Mean NH,-N concentrations prior to fertilization were below detection limits at all outlets as well (table 1). TON concentrations were generally between 0.5 and 0.8 mg L^{-1} prior to fertilization. No discernable difference in TON concentrations were evident among stations in pre-fertilized stream samples shown in Table 1. However, prior to fertilization NO_3^--N concentrations were consistently greater at the RW outlet than at FW or LGW outlets. Mean pre-fertilization concentration at the RW outlet was approximately 0.19 mg L^{-1} and 0.26 mg L^{-1} greater than NO_3^--N concentrations at the LGW and FW outlets, respectively (table 1). Differences in pre-fertilization NO_3^--N may reflect prior fertilization application in the reference subwatershed or differences in vegetation and soils within the Little Glazypeau watershed.

Table I-Mean (standard deviations in parenthesis) N concentrations (mg L^{-1}) and number of samples (n) of stream water prior to urea fertilization (12/7/1997-1/26/98) and prior to DAP fertilization (3131198426198) at each watershed outlet

	NH,-N		NO_3^--N		TON	
Watershed	Mean	n	Mean	n	Mean	n
			Pre-urea fertilization (mg L^{-1})			
FW	co.01 (<0.01)	82	0.03(0.04)	105	0.47(0.12)	53
RW	co.01 (<0.01)	90	0.29(0.05)	108	0.43(0.09)	54
LGW	co.01 (<0.01)	114	0.10(0.03)	142	0.46(0.14)	71
			Pre-DAP fertilization (mg L^{-1})			
FW	co.01 (<0.01)	38	2.22(0.96)	40	0.46(0.14)	20
RW	<0.01(<0.01)	26	0.14(0.01)	26	0.34(0.11)	12
LGW	<0.01(<0.01)	14	0.24(0.16)	14	0.31(0.18)	8

Concentrations of TON dramatically increased after urea fertilization (fig. 2). TON concentrations increased from approximately 0.3 mg L^{-1} to 44.5 mg L^{-1}, its maximum level, five hours after completing urea application. The dominant N constituent measured as TON during this time period was undoubtedly urea-N. As the urea began to hydrolyze, levels of NH,-N also rapidly increased in the fertilized subwatershed. However, the highest concentration of NH,-N measured within the first 11 hours after urea application and prior to a storm event was only 1.5 mg L^{-1}. Due to the microbial mediated mechanisms involved with the conversion of NH, to NO;, NO;-N concentrations also increased but more slowly than TON or NH,-N (fig. 2).

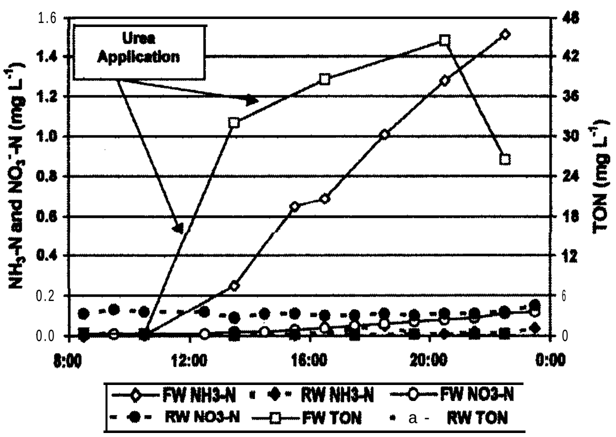

Figure 2—NH_3-N, NO,-N, and TON concentrations prior and within 12 hours of initiation of urea application at the outlets of the fertilized (FW) and reference (RW) subwatersheds.

The cold temperatures during this period may have contributed to the slow microbial conversion of NH,. Assuming that the majority of the TON is urea-N, transient levels found in the FW outlet are much higher than urea-N levels observed in six fertilization studies from northwestern United States summarized by Fredriksen and others (1975). However, Bisson (1982) measured a short-lived Total-N peak of 37.5 mg L^{-1} after application of 224 kg ha^{-1} urea to a watershed located in the state of Washington. This high level of N was attributed the direct application of the urea to the stream and snow covered soil, both practices currently avoided. As in this study, the peak occurred the day of fertilization, immediately dropped, and was down to 1.5 mg L^{-1} 72 hours later.

TON concentrations decreased from a maximum of 44.5 mg L^{-1} to 11.6 mg L^{-1} 21 hours after application. Concentrations continued to decrease but were still greater than concentrations of TON in the RW on March 17, 39 days after application (fig. 3). However, maximum concentrations of TON occurred immediately after fertilization and then decreased during the rising limb of the storm hydrograph. Elevated concentrations of TON after the February IO" storm event were most pronounced at peak flows (fig. 3). Rainfall records suggest that peak concentrations occurred just prior or shortly after the initiation of the February 10^{th} storm event. The peak in TON concentrations almost immediately after fertilization indicate that the urea was reaching the outlet through channeiized streamflow. Whether it reached the stream by both overland flow, caused by the heavy rainstorm, and direct application to non-perennial channels, or only by direct application to channels could not be determined. Aubertin and others (1973) also reported immediate rises in NH,-N concentrations after fertilization and attributed this response to urea application directly into the stream channel.

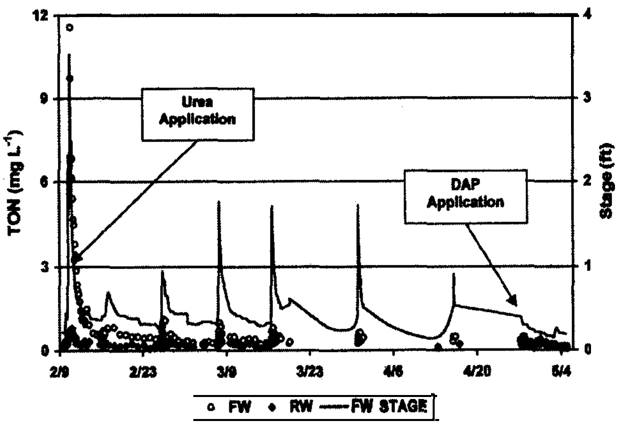

Figure 3-TON concentrations measured at the outlets of the fertilized **(FW)** and reference (RW) subwatersheds and stage at the outlet of the FW after urea fertilization (Values greater than 12 mg L^{-1} were not included in graph to better represent later trends in **concentrations).**

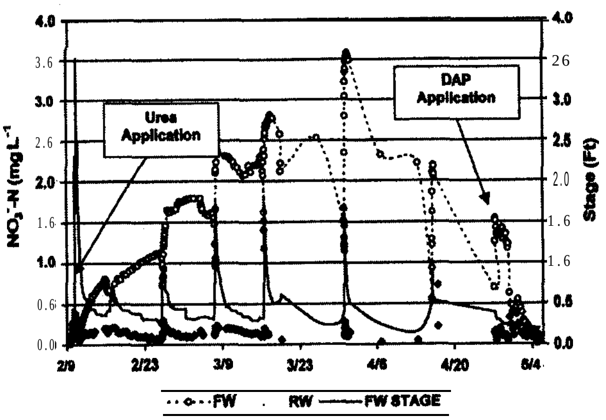

Figure **5—NO_3-N** concentrations at outlet of the fertilized **(FW)** and reference (RW) subwatershed and stage at outlet of FW after urea fertilization.

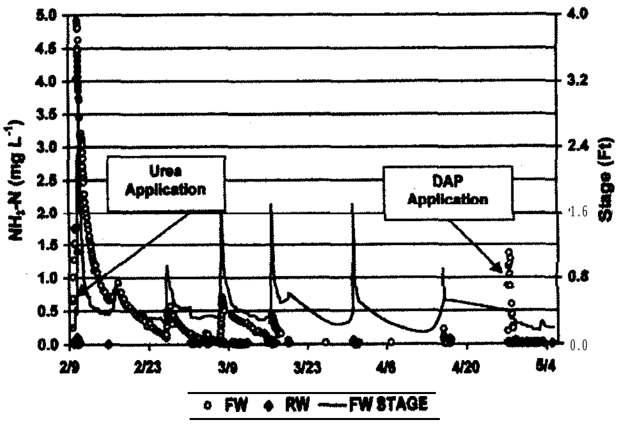

Figure **4—NH_3-N** concentration at the outlets of the fertilized (FW) and referenda (RW) subwatersheds and stage at outlet of the FW after urea fertilization.

As the hydrolization of the urea occurred, levels of NH,-N increased. Concentrations of NH,-N peaked at 4.91 mg L^{-1} approximately 24 hours after application during the February 10^{th} storm event, corresponding closely to peak discharge. Concentrations continued to fall during base flow but rose during storms and generally followed the storm hydrograph. Ammonia-N concentrations at the FW outlet were elevated above those at the RW outlet until the middle of March, when TON levels had returned to pre-fertilization levels. Prior to the end of March, differences in NH,-N levels between the FW and the RW were only discemable during storm runoff (fig. 4).

Nitrate-N concentrations showed a much different response to urea fertilization than did TON or NH,-N (fig. 5). Concentrations rose slowly as nitrification occurred. The peak concentration of 3.58 mg L^{-1} did not occur until 31 March, 50 days after urea application. Concentrations were still elevated when DAP was applied in April. Changes in NO;-N concentrations in response to storm events were also much different from those observed for TON and NH,-N. Nitrate concentrations decreased during the rising limb and reached their minimal levels during peak storm discharges. Concentrations then increased rapidly during the falling limb of a storm hydrograph (fig. 5). Ammonia-N and TON concentrations generally increased during the rising limb, reached their maximum during or shortly **after** peak discharge, but then decrease during the falling limb. These results suggest that **NO_3^--N** concentrations during storms reflect a complex relationship between storm dilution of **NO_3^--N,** loss of **NO_3^--N** from soils, and alteration of nitrification rates due to changes in NH, availability or edaphic factors limiting nitrification.

Nitrate-N concentrations at the FW outlet were elevated beyond background levels for at least 77 days after urea fertilization. Mean concentrations prior to urea fertilization compared to mean concentrations during an approximate three week period prior to DAP fertilization in late April indicate that NO;-N concentrations were still 1 O-l 5 fold higher in the fertilized subwatershed than in the reference subwatershed (table 1). Low flow concentrations during the four hours just prior to DAP fertilization on April 27 averaged 1.25 mg L^{-1} at the FW outlet but only 0.13 at the RW outlet. As the result of the N contributed by the DAP fertilization, the potential alteration of NO,-N levels by the urea fertilization in FW could not be quantified after this period. Ammonia-N and TON concentrations appeared to have returned to background values by the first of April prior to DAP application.

Increases in NH,-N and **NO_3^--N** after urea fertilization were of a similar magnitude to those found by Abubertin and others (1973). However, the increases were greater than those reported after urea fertilization in the northwestern United States (Fredriksen and others 1975, Bisson 1982, 1988). The extremely severe rainstorm after application may have contributed to the high levels of NH,-N and NO_3^--N in the FW. However, differences in soils or vegetation among regions may also in part be responsible for these differences in N concentrations after fertilization.

DAP Application

Alteration of nitrogen concentrations in the FW as a result of DAP fertilization was less severe and of shorter duration than those found after urea fertilization (fig. 3-5). Elevated levels of NH,-N were only evident for a 48 hour period after DAP fertilization. The maximum concentration was 1.37 mg L^{-1} and occurred approximately six hours after application. NH,-N concentrations were again below detection limits as early as 30 hours after DAP application. TON concentrations also increased but were a result of the elevated concentrations of NH,-N in the stream. Nitrate-N concentrations in the FW were not visibly increased after DAP application and remained constant or decreased during the interval between DAP application and the end of the study period.

The lack of any pronounced changes in N levels after the DAP application no doubt reflects the lower application rates of N. However, the storm-free period minimized off-site movement, while seasonal increases in temperatures and biological activity created greater uptake by plants and microbes. These factors may have decreased the percentage of total N export, further reducing in-stream N concentrations below those observed after the urea application.

Downstream Changes in N Concentrations

Application of fertilization in the FW did increase N levels at the outlet of the LGW. Increases beyond background levels were generally limited to periods when N was at its highest concentrations in the FW. Concentrations of NH,-N and TON were greater at the outlet of LGW than the RW up to 3 days after urea application. Maximum concentrations of NH,-N and TON at the outlet of the LGW were respectively 0.70 and 4.21 mg L^{-1} 24-28 hours after urea application.

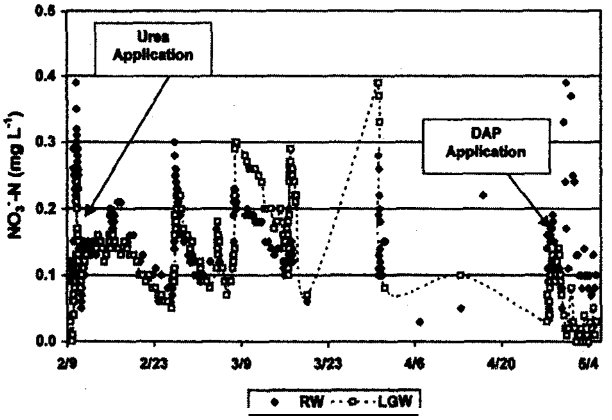

Figure 6—NO_3-N concentrations measured at the outlets of the reference subwatershed (RW) and the Little Glazypeau (LGW) watershed after urea fertilization.

Elevated concentrations of NO_3^--N at the LGW outlet were also evident (fig. 6). Elevated NO,-N concentrations occurred later and over a greater time period than did NH,-N and TON. Nitrate-N concentrations at the LGW were consistently lower than at the RW outlet prior to urea fertilization (table 1). Twenty-six days after urea fertilization, NO,-N concentrations at the LGW outlet had risen and were greater than those measured at the RW outlet. Concentrations remained higher at the LGW than RW until March 31. Mean NO_3^--N concentrations during this time period were 0.24, 0.15, and 2.28 mg L^{-1} at the LGW, RW, and FW outlets respectively. These results suggest that NO;-N levels at the LGW outlet may have increased by as much as three or four fold after urea fertilization. There was no evidence of any alteration of NO;-N, NH,-N, or TON concentrations (fig. 6) at the LGW outlet after DAP fertilization.

SUMMARY

Application of 437 kg ha^{-1} of urea significantly increased stream water N concentrations both within and downstream of the fertilized subwatershed. Ammonia-N and TON concentrations increased rapidly during and just after application and peaked within 24 hours of application at concentrations of 44.5 and 4.91 mg L^{-1} respectively. These increases, although dramatic, were relatively short-lived. It appeared that the elevated NH,-N and TON concentrations in stream water shortly after urea application were due to the direct application of fertilizer on non-perennial stream channels and a 100-year storm event which occurred shortly after application. Increases of NO_3^--N concentrations as much as 10 times above background levels were observed. increases were not as great as those for NH,-N or TON but occurred over a greater duration of time. Nitrate-N concentrations in the fertilized subwatershed were still greater than background concentrations 77 days after urea application. Application of 140 kg ha-' of DAP following urea application had minimal effects on N concentrations in the watershed. The lack of response was attributed to the lower amounts of applied N, lack of any significant storm events, and higher biologic activity during and following the DAP application.

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EFFECTIVENESS OF BEST MANAGEMENT PRACTICES TO PROTECT WATER QUALITY IN THE SOUTH CAROLINA PIEDMONT[1]

Thomas M. Williams, Donal D. Hook, Donald J. Lipscomb, Xiaoyan Zeng, and Joseph W. Albiston[2]

Abstract-The South Carolina Forestry Commission published the most recent edition of Forestry Best Management Practices (BMP) in 1994. The Commission has been doing compliance monitoring since 1990 and has generally found compliance near 90 percent. In 1995 we installed a study to measure effectiveness of these BMP's on four experimental watersheds on the Clemson Experimental Forest, in the Piedmont of South Carolina. After 15 months of pre-treatment monitoring three watersheds were cut and site prepared using all appropriate BMP's. Following logging, site preparation treatments were: natural regeneration; shear, rake and pile; and herbicide and burn. Suspended sediment, nitrate, phosphate, pH, and water temperature were measured throughout the pre treatment period and for 12 months post treatment. Suspended sediments were ten fold less than logging without BMP's and near to those measured due to increased flow due to tree removal. All other parameters were similar to pre-treatment levels.

INTRODUCTION

The Southeastern States have depended on voluntary Best Management Practices for water quality protection in application of forestry practice. The program in South Carolina has been typical. The first publication of silvicultural guidelines by the South Carolina Forestry Association occurred in 1976. These were updated in 1969 to include practices on forested wetlands (SCFC 1989). Both publications were revised and included into a single booklet of Best Management Practices in 1994 (SCFC 1994).

In order to protect water quality, voluntary BMP's must be effective and implemented. South Carolina has had a program to examine compliance with the published BMP's since 1990. Compliance has been very high and increasing slightly, from 84.9 percent in 1990 to 89.5 percent in 1994 (Hook and others 1991, Adams and Hook 1994, Adams 1994). These surveys initially focused on roads and harvesting, but with the 1994 manual site preparation was included. A survey of site preparation sites in 1996 showed 86.4 percent compliance with site preparation BMP's (Adams 1997). Through a vigorous educational program for landowners, loggers, and professional foresters the South Carolina Forestry Commission has achieved compliance with voluntary guidelines similar to that of mandatory statutes used in other regions.

South Carolina BMP's are primarily based on research conducted during the 1960's and 70's (Dickerson, 1975, Beasley 1979, Hewlett and Douglass 1964, Hewlett 1979, Ursic 1975). The main findings were that forest practices were most likely to impair water quality with suspended sediment (Yoho 1980). The most common cause of sediment movement were road building and operation of heavy equipment in or near stream channels. A major portion of the BMP manual is devoted to road building practices and to streamside protection.

Streamside protection is afforded by a 40 foot (12.2 m) primary zone on each side of the stream channel, or an 80 foot (24.4 m) zone on trout streams where side slopes exceed 5 percent. On perennial streams individual stems can be removed as long as a minimum 50 sq ft/ac (11.5 m2/ha) of overstory trees are left. Soil disturbance is to be minimized and mechanical site preparation and planting are prohibited, as are landings, portable sawmills, or the using toxic liquids, including oil and gasoline. On intermittent streams the primary SMZ can be clearcut as long as the channel is protected and all other practices are used. A secondary SMZ is also required on streams where side slopes are greater then 5 percent. On slopes from 5 to 20 percent the secondary SMZ is to be 40 feet (12.2 m), 80 feet (24.4 m) on slopes of 21 to 40 percent, and 120 (36.6 m) feet on slopes greater then 40 percent. In this zone, clearcutting and mechanical operations are permitted but soil disturbance is limited to less than 15 percent of the surface. Decks roads, and handling or storing toxic materials are also to be avoided.

The study reported here was a test of the South Carolina Forestry BMP's applied in the Piedmont. Since it is characterized by relatively steep slopes, erodible soils, and a history of severe erosion, the Piedmont was considered to be the most critical physiographic province. Hewlett (1979) found that forested Piedmont watersheds in Georgia naturally lost 80 kg/ha/yr and that logging without BMP's resulted in a loss of 7500 kg/ha for each of the first two years after logging. Van Lear and others (1985) characterized very small (<3 ha) watersheds in the South Carolina Piedmont and found natural suspended concentrations of 35 mg/l which increased to 72 mg/l following careful logging. Sediment yields were 30 kg/ha/yr under natural conditions and 151 kg/ha the first year after logging. Since logging was done without roads or landings in the watershed and skidding was done with small tractors that minimized soil disturbance, these values can be considered to be due to increased channel scour that is an unavoidable consequence of increased flow associated with forest removal.

METHODS

Four watersheds were chosen in the Seneca River watershed on the Clemson Experimental Forest approximately five km northeast of Seneca, SC. The four

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watersheds varied in size from 37 to 67 hectares and were primarily Madison and Pacolet soils (table 1.) and were significantly steeper than those used by Hewlett (1979) and Van Lear and others(1985) Vegetation was similar on all four watersheds with upland oak-hickory stands with mixture of loblolly pine (*Pinus taeda* L.) and shortleaf pine (*Pinus echinata* Mill.). Coves included yellow poplar (*Lirodendron tulipifera* L.) with oak and hickory. Ramsey Bridge, Kenamore One and Kenamore Two also had loblolly pine plantations.

Logging treatments were applied to three watersheds to test three common types of site preparation practiced in the South Carolina Piedmont. All areas and site preparation plans were based on silvicultural prescription and resulted in the portions of each watershed treated as listed in table 1. The Holley Springs watershed hardwood stand was clearcut and regenerated by stump sprouts. A 13.8 ha pine plantation on the Ramsey Bridge watershed was clearcut and regenerated by an herbicide and burn treatment. Following logging of the pine, all non-merchantable hardwoods were treated with Velpar and burned with the slash. On the Kenamore Two watershed a 5.3 ha pine plantation was thinned, and 10.9 ha of hardwood was clearcut. Five hectares of this clearcut was then site prepared by shearing all non-merchantable material and root raking all slash and non-merchantable stems into windrows.

Each watershed was instrumented with a two foot (60.9 cm) H flume, with an ISCO Model 4230 flow recorder and Model 3700 automatic water sampler. Each flume was calibrated in the field by timed volumetric measurements to assure flow rate errors of less than three percent. Flow was measured continuously from February 1996 to June 1998. Flow rates were averaged hourly and data was transferred to Hewlett Packard model 540 palmtop computers and later to Excel spreadsheets where calibration regressions were applied. Water quality parameters were determined on one stormflow sampling and two baseflow samples each month. Stormflow samples were taken by the ISCO automated samplers.

Samplers were triggered when the flow recorders detected a stage rise greater than a predetermined amount. Since base flow varied between seasons and watersheds the triggering stage rise varied also, usually between two and ten millimeters. One-liter samples were collected each hour for the first 12 hours, then a 250 ml sample was collected each hour with four samples aggregated into a single bottle. Samples were collected for 60 hours. Also two, one-liter samples were taken during baseflow by manual triggering of the automated samplers.

Samples were preserved with sulfuric acid. Samples were first filtered with .45 pm pre-weighed filters. For most samples the entire liter was filtered through a single filter although 100 ml aliquots were used for samples with high sediment concentration. Filters were then dried to 100 C and re-weighed to the nearest 0.1 mg. Aliquots of filtrate were then analyzed for NO,-N by cadmium reduction, PO,-P by stannous chloride, and Ca, K and Mg by atomic adsorption

Table l-Characteristics of experimental watersheds, soils, slopes, and treatments

Watershed	Size	Madison	Pacolet	Saluda	Starr	Worsham
	Hectare					
Holley Springs	67.0	33.6	28.7			1.1
Ramsey Bridge	58.4	37.4	16.0		4.8	
Kenamore One	45.9	17.2	23.8	2.9	.5	
Kenamore Two	36.8	27	4.2	8.3	1.0	

Watershed	Slopes 0-5	5-20	20-40	>40	Treatment	Portion treated
	Percent					*Percent*
Holley Springs	12.3	26.7	46.5	9.3	Logged	22
Ramsey Bridge	16.8	12.4	53.8	17.0	Herbicide	22.5
Kenamore One	9.4	17.1	55.1	18.4	Control	0
Kenamore Two	10.2	9.7	47.7	32.4	Mechanical	29.9
					and thin	14.4

MADISON SERIES: Clayey, kaolinitic, thermic Typic Kanhapludults. The Madison series consists of well drained, moderately permeable soils that formed in residuum weathered from felsic and intermediate, micaceous high grade metamorphic rock. PACOLET SERIES: Clayey, kaolinitic, thermic Typic Kanhapludults. The Pacolet series consists of very deep, well drained, moderately permeable soils that formed in material weathered mostly from acid crystalline rocks of the Piedmont uplands. Slopes commonly are 15 to 25 percent but range from 2 to 80 percent. SALUDA SERIES: Loamy, mixed, mesic, shallow Typic Hapludults. The Saluda series consists of shallow, well drained, moderately permeable soils that formed in weathered granite, gneiss, or schist. Slopes range from 8 to 90 percent. STARR SERIES: Fine-loamy, mixed, thermic Fluventic Dystrochrepts. The Starr series consists of deep, well drained, moderately permeable, loamy soils that formed in Piedmont alluvium. Slopes range from 0 to 8 percent. WORSHAM SERIES: Clayey, mixed, thermic Typic Ochraquults. Soils of the Worsham series are deep and poorly drained. They formed in local alluvium at the heads of drainage ways in the Piedmont uplands.

spectrophotometry (Greenberg and others 1992). Water quality sampling began in April of 1996 and continued until June 1998.

Sediment and elemental loss were estimated using flow records and a flow volume to nutrient concentration relation determined from the storm flow sampling in that particular month. For each month, the flow rates and elemental concentrations were used to determine 60 hourly estimates of elemental loss. A regression was then calculated between flow rate and elemental loss. That regression was then used on the hourly flow rates for that element and that month to produce elemental loss estimates for each hour during the month. Separate regression equations were used for each element and each month on each watershed. Regression estimates were used for all hourly flow rates where the regression estimate exceeded the product of the flow rate and the average base flow concentration. In no case was a regression equation used to estimate elemental loss for flow rates below the lowest rate measured during the 60 hour stormflow sample. In general the regression equation predicted elemental loss similar to the base flow concentration at the end of the 60 hour stormflow sampling period.

Statistical analysis was conducted as paired watersheds with each of the three treated watersheds compared to the control in separate analyses. For sediment and each element a monthly export amount and flow weighted mean concentration were calculated. A paired T-test was used to compare differences between each watershed values and the control during the pre-treatment period to those obtained during the post-treatment period. Since the post-treatment period occurred during the El Nino weather pattern post-treatment values in each watershed were also compared to pre-treatment with a simple two tailed T - test.

RESULTS

Instrument installation was completed in March 1996 and data collection began in April 1996. Logging was begun in June 1997 and completed by July, site preparation treatment were applied in August-September 1997 and post-treatment measurements continued until June 1998. For analysis April 1996 to June 1997 was considered pre-treatment and July 1997 until June 1998 was considered post-treatment. During the fifteen month pre-treatment period 153 cm of rain fell while 166 cm fell during the post-treatment year (fig. 1).

Holley Springs and Kenamore Two watersheds produced more runoff and Holley Springs and Ramsey Bridge produced slightly less sediment but for most other elements the watersheds were similar (table 2). Pre-treatment regressions were made based on hourly flows from each watershed. Kenamore One was intermediate in most values and well correlated to the other three watersheds and became the control. Hourly flows were best predicted by the equations

Holly Springs flow = 0.921 Kenamore One flow + 0.414 $r^2 = 0.74$ (1)

Ramsey Bridge flow = 0.872 Kenamore One flow + 0.198 $r^2 = 0.88$ (2)

Kenamore Two flow = 0.970 Kenamore One flow + 0.006 $r^2 = 0.91$ (3)

These equations were used to predict post-treatment flows of the three treated watersheds. The post-treatment period contained substantially higher rainfall due to the El Nino weather pattern. The combination of this weather pattern and the extent of treatment on the steepest watershed, post-treatment flows in the Kenamore Two watershed were substantially increased (table 3).

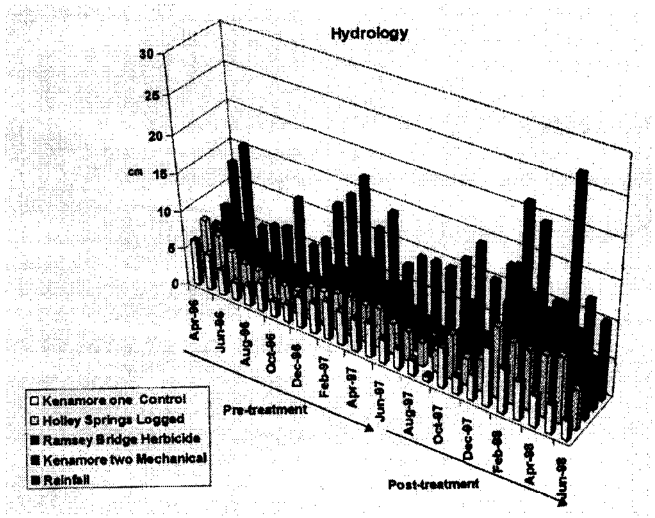

Figure l-Rainfall and runoff from four experimental watersheds from April 1996 through June 1996.

DISCUSSION AND CONCLUSION

There are a number of clear results of this experimental application of logging and site preparation using Best Management Practices. Increased rainfall during the post-treatment period had a number of impacts. Concentrations of suspended sediment, phosphate and all cations were increased in all watersheds, many of these increases were also highly significant. Channel erosion is generally found when streams must accommodate larger peak flows. Suspended sediment increased in all streams, with concentrations increases relatively proportional in all watersheds. Nitrate concentrations declined in three of the watersheds with higher rainfall, which may be due to wetter soils. Soluble phosphate concentrations were correlated to both flow rate and suspended sediment concentration.

As one might expect, cutting of portions of these watersheds resulted in significantly higher rates of runoff. Cutting the largest portion of the steepest watershed resulted in the greatest increase in runoff. The two watersheds with site preparation also showed significant small increases in nitrate concentration. The increases were greater on the watershed with the greatest proportion of vegetation disturbance. Total losses of sediment and cations were also significantly increased on the two site-prepared watersheds. This was due to increased runoff since neither watershed showed significant concentration increases.

However, the point of this study was not to define small differences between the site preparation options but to determine how well BMP's protected water quality. This can best be determined by examining these results in relation to the prior research on Piedmont logging. Hewlett presented

Table 2—Pre-treatment total flows, per year flows, flow weighted concentrations, and estimated annual material exports from the four experimental watersheds

Watershed	Mean flow	Sediment	NO3-N	PO4-P	Ca	K	Mg
	m³m	*mg/l*	*mg/l*	*µg/l*	*mg/l*	*mg/l*	*mg/l*
Hoiley Springs	0.810	44.0	0.109	11	0.89	0.91	1.18
Ramsey Bridge	.574	39.2	.069	13	1.36	.82	1.06
Kenamore One	.426	71.5	.068	12	1.78	.92	1.10
Kenamore Two	.411	66.1	.044	12	1.53	.91	1.16
	Flow	Sediment	NO3-N	PO4-P	Ca	K	Mg
	Cm/yr			*Kg/ha/yr*			
Holiey Springs	58.6	249	.61	.061	5.11	5.58	5.70
Ramsey Bridge	46.9	184	.31	.059	5.62	4.09	5.00
Kenamore One	46.5	332	.30	.053	5.88	4.29	5.12
Kenamore Two	52.8	377	.32	.064	7.97	5.21	8.64

Table 3-Post-treatment total flow, flow weighted nutrient concentrations, and estimated annual material exports from the four treated watersheds

Watershed	Mean flow	Sediment	NO3-N	PO4-P	Ca	K	Mg
	m³m	*mg/l*	*mg/l*	*µg/l*	*mg/l*	*mg/l*	*mg/l*
				9			
Holiey Springs	0.907	97.8	0.081	27[d]	1.37"	0.93	0.97[b]
Ramsey Bridge	.800	95.1	.087[c]		1.79[a]	1.15[d]	1.43"
Kenamore One	.422	114	.034	20	2.04[a]	1.17[d]	1.34
Kenamore Two	.631	89.6	.143[bd]	17	1.83[a]	1.23[a]	1.25
	Flow	Sediment	NO3-N	PO4-P	Ca	K	Mg
	cm/yr			*kg/ha/yr*			
Holiey Springs	70.9[b]	894	.58	.067	9.74[d]	6.64	6.88
Ramsey Bridge	67.7[b]	647	.60	.182[d]	12.2[bd]	7.80[bd]	9.73[ba]
Kenamore One	45.8	522	.16	.091	9.35[d]	5.35	6.14
Kenamore Two	90.2[b]	802	.81[b]	.095	10.32[ba]	6.99"	7.03[ba]

[a] Post-treatment significantly different from pre-treatment, a = .Ol.
[b] Difference due to treatment significant a = .01.
[c] Difference due to treatment significant a = .05.
[d] Post-treatment significantly different from pre-treatment, a = .05.

results of logging without BMP's while Van Lear and others presented unavoidable changes in water quality associated with tree removal. Figures 2 present results of this study in relation to those two studies.

Runoff results (fig. 2a) are similar to Hewlett for the mechanical site preparation treatment. Van Lear measured very small watersheds near tributary heads that only produced runoff for short periods after rain. The larger watersheds used by Hewlett and this study capture subsurface flow and result in larger flows during both pre-treatment and post-treatment. One might expect higher runoff amounts in this study since the watersheds were considerably steeper than those used by either other study.

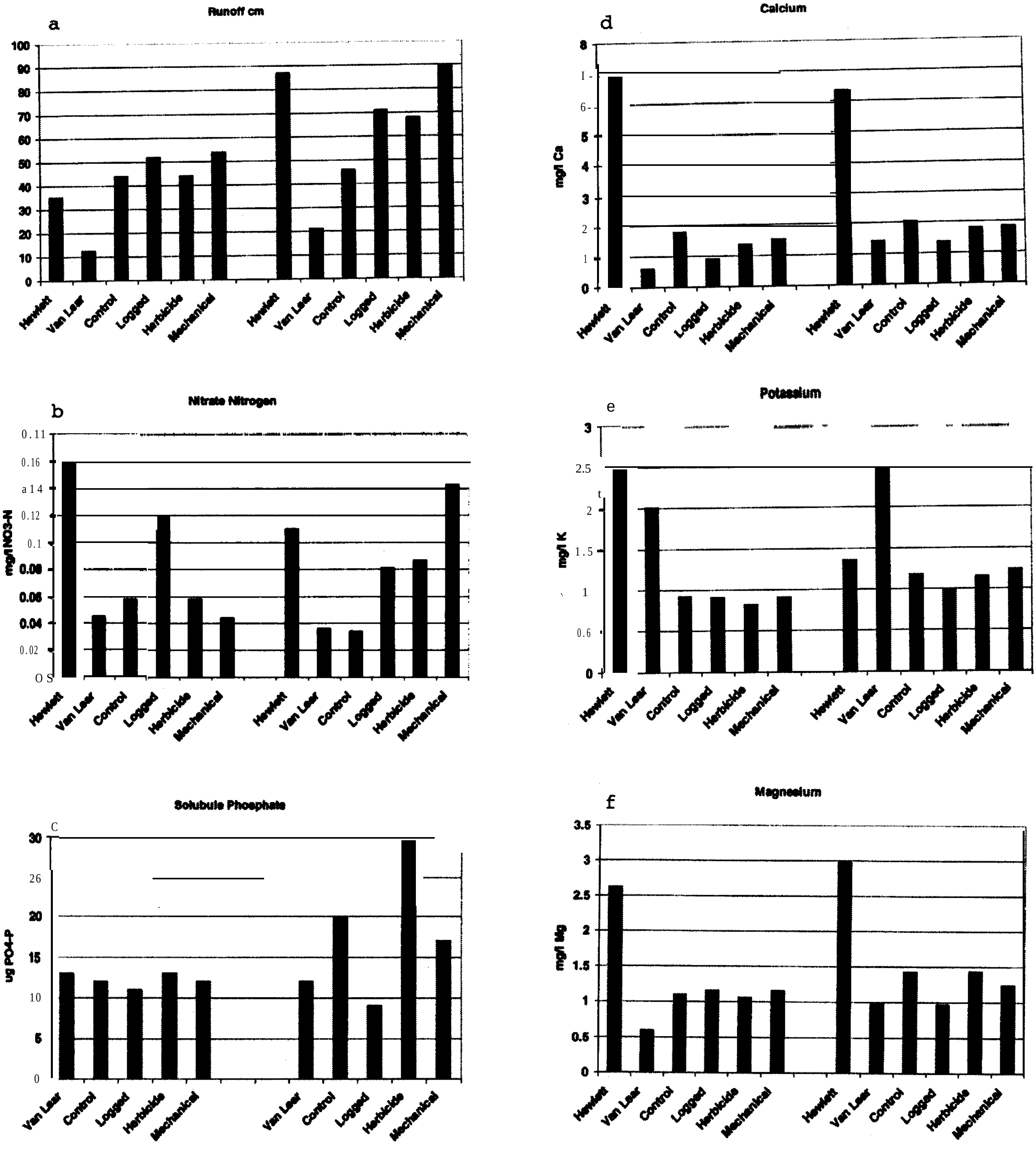

Figure 2-A comparison of this study compared to previous studies of logging impacts in the Piedmont: (a) Runoff, (b) Nitrate nitrogen, (c) Soluble Phosphate, **(d)** Calcium, (e) Potassium, and **(9** Magnesium.

Nitrate nitrogen (fig. 2b) shows increases for the two site preparation treatments. Neither other study found an increase in nitrate nitrogen. Soluble phosphorus (fig. **2c)** also increased on the site preparation treatments in contrast to Van Lear's data. Hewlett did not measure soluble phosphorus. Calcium (fig. **2d),** Potassium (fig. **2e),** and Magnesium (fig. **2f)** show results very similar to Van Lear but considerably less than Hewlett for both pm-treatment and post-treatment. It seems that Hewlett's experiment was done on soils that were derived from more basic bedrock or that were not as severely weathered or eroded.

Sediment concentration (fig. 3) shows the most important aspect of this study. All of the other measures in Figure 2 show that all three studies behaved relatively similarly and resulted in high quality water. Forested Piedmont watersheds have relatively high average sediment concentrations (30-70 **mg/l)** compared to other physiographic regions. Severe erosion from previous land use has resulted in streams which are actively eroding channel banks. In this experiment sediment concentrations were higher on the steepest watersheds.

Cutting trees increase the rate of stream flow and result in increased channel erosion. Van Lear's careful experiment found an increase from 40 to 70 **mg/l** due to this increased flow Logging with BMP's increases these values to roughly 100 **mg/l.** This value is roughly ten fold less than occurred with logging prior use of BMP's. Increased storm activity associated with the El Nino weather pattern also resulted in concentrations of 100 **mg/l.** Sediment yield did increase more substantially with logging and site preparation since flow increased considerably. Yields from very careful logging on upper slopes resulted in yields of 150 **kg/ha/yr** while the most severe treatment in this study yielded 800 **kg/ha/yr** (fig. 3). Although the change in yield is more pronounced than in concentration it is still ten fold below that produced prior to BMP's.

This study applied South Carolina's latest BMP's on the most difficult physiographic province in the state. The test was done with commercial loggers using normal silvicultural practice subject only to careful adherence to the BMP's. The experiment placed the most severe treatment on the smallest steepest watershed in the experiment. The results of this severe test were sediment concentrations and yields ten fold below those found when BMP's were not used.

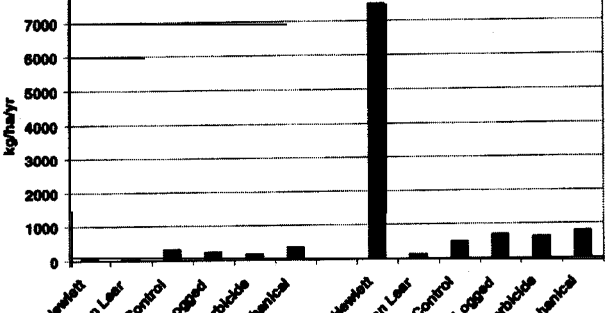

Figure **3—Sediment** yields for this study in comparison to two others in the Piedmont.

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TIMBER HARVESTING AT THE BANNISTER HISTORIC SITE: A COOPERATIVE EXPERIMENT IN MULTI-RESOURCE MANAGEMENT[1]

Elaine P. Sherman[2]

Abstract-The Bannister Historic Site is a 130 acre multi-component archaeological site located on the Angelina National Forest. In 1996 a pine timber thinning harvest for the enhancement of red cockaded woodpecker (RCW) habitat was proposed for the forest management compartments encompassing the site. Past experience had raised concerns about the environmental and archaeological consequences of the forest policy which excluded land management activities from archaeological sites. On larger sites this practice has resulted in the development of dense overgrown conditions creating stress within the ecosystem and threatening the stability of the cultural resources. To avoid the development of such problems at Bannister, harvesting was allowed within the site under a strict mitigation and monitoring plan. Harvest at Bannister was conducted between 16 July and 1 August 1997. Disturbance to the site was successfully kept to a minimum, while overall site stability, forest health and RCW habitat were significantly improved.

INTRODUCTION

When the land making up the Angelina National Forest was acquired by the U.S. Department of Agriculture in 1935, most of it was cut over and suffering from various levels of erosion. The forest was regenerated through a combination of natural seeding, extensive hand planting and human manipulation of the environment. As a result the forest as it exists today is still relatively young and not yet in full equilibrium.

For approximately the last twenty years, forest policies have prohibited all potentially ground disturbing activities, and in some cases prescribed burning, on various tracts in order to protect cultural resources. This policy is intended to protect both prehistoric and historic sites by a method known as preservation in situ (in place) by means of avoidance. As most sites tend to be small, often less than one acre in size, this method has caused little environmental impact. However for the few larger sites, and especially for the large historic sites, the withholding of timber harvests and other ground disturbing land management practices has begun to cause some serious concerns both for the health of the ecosystem and for the stability of the sites themselves. Overgrown conditions on large sites have stressed the forest ecosystem making these tracts more susceptible to wind-throw and Southern Pine Beetle (SPB) infestations, and increasing the threat of wildfire. Wind-throw, for example, can be especially damaging to cultural resource sites, as the uprooting of the trees dislodges artifacts, sometimes damaging them and disturbing their provenience (relative location within the original deposit), thereby compromising the integrity of the site itself.

In 1996 an opportunity arose to address these concerns by implementing an experimental timber harvest at Bannister, a 130 acre historic site on the Angelina National Forest. This harvest was initially designed as part of a 1200 meter pine timber thinning for the enhancement of red cockaded woodpecker (RCW) habitat. But with careful mitigation and monitoring, it also helped to preserve the historic site by improving site stability and overall forest health.

Site Description and Environmental Setting

The Bannister Site (41 SA214) is located on the north side of the Angelina National Forest in San Augustine County, TX. It is situated on the upper slopes and broad ridge top of an upland formation between Scott Creek and the upper reaches of Harvey Creek. The ridge line runs roughly north-south and ends south of the site at the confluence of the two creeks. The core area of the site ("downtown" Bannister) is centered around the junction of old Highway 147 (FS 300F) and First Street (FS 3069).

Three soil types occur in the vicinity, all of which are found at Bannister. The soil in and along the creek channels is a dark gray fine sand with a light gray fine sandy or silty loam subsoil over a reddish brown clay base. The soil on the lower slopes is a grayish brown to dark brown fine to very fine sandy loam over a light yellowish brown clay. The broad ridgelines and hill tops consist of a brown to yellowish brown very fine sandy loam over a grayish brown to reddish brown subsoil over a brown to reddish brown clay (Freeouf 1977). The vegetation is primarily mixed pine and hardwoods with a longleaf pine component and an understory of mixed brush, forbs, briars, and grasses.

Site History

Bannister is a multi-component site consisting of four historic occupations and one prehistoric element. The prehistoric element consists of a small lithic scatter located on a terrace of a small tributary branch of Scott Creek on the northwest boundary of the larger historic site. It is uncertain which prehistoric period this lithic scatter belongs to, as no ceramic or other diagnostic materials have yet been recovered from the area.

The earliest known historic occupation at Bannister began circa 1898. The site was initially a turpentine camp which, by

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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1902 had evolved into a logging camp, and then into a small community. The logging community reached its peak between 1918 and 1922, at which time it boasted a population of approximately 2,500 people.[3 4] There was no sawmill at Bannister itself, instead the timber cut in the local area was sent by rail via the Texas & Louisiana Railroad to the Kelty's mill in Lufkin, TX, for processing. By the 1920's most of the pine timber had been cut out of the area. In 1926 the town was closed and the houses and other structures were moved to new logging locations at Donovan and Prickett (Long-Bell Lumber Company 1926). The railroad tracks that ran through Bannister were removed circa 1932. In 1933 the location became the site of a Civilian Conservation Corps (CCC) facility known officially as Camp Broaddus (F-22-T), but 'also occasionally referred to as Camp Bannister[5 6] (Civilian Conservation Corps 1936). The camp housed CCC Company 2878, who's members worked on reforestation projects, built roads and fences, fought wildfires, and constructed campground facilities in the area. In 1935 the lands in and adjacent to the camp were acquired by the U.S. Forest Service. The CCC camp remained in operation until early in 1942. In September that same year the camp facility was modified and reopened as a German prisoner of war camp. The P.O.W. camp closed in late 1944 at which time the facilities were removed and the area reverted to a forest ecosystem.

As each occupation of the site progressed, the archaeological evidence of the prior occupations became more disturbed. The final removal of the P.O.W. facility appears to have caused some heavy localized disturbance at the site. Since the closure of the P.O.W. camp, the site has also incurred some disturbance from routine road maintenance, off road vehicle usage, and hunting camps. Most of the information available on the site has come from archival research and oral history interviews. No systematic archaeological investigation of the site has yet been undertaken.

PROJECT HISTORY

In 1996 the boundaries were laid out for the Compartment 11, 12 and 17 timber sale. The Bannister site, located in compartment 12, lies near the center of this area. The site was originally recorded and flagged for avoidance prior to the sale, but only the central core area was initially located. It was only later, with the initiation of an oral history program on the forest that the actual extent of the site was revealed. Informants were able to describe and pin-point on the ground the locations for many of the original facilities and residential areas from the various occupations. This lead to an expansion of the known boundaries of the site into adjacent areas that were, by this time, already marked and under contract for harvest. As a result, discussions were held between the heritage and timber resource specialists to develop alternatives and determine a solution to this problem.

Experience gained at the Old Aldridge Sawmill Site (41 JP82) had raised serious concerns about the environmental and archaeological consequences of excluding land management practices from cultural resource sites. There has been no active land management practiced within the 650 acre Aldridge site since the late 1970's. As a result dense vegetation has grown up in and around the remaining structures and foundations threatening the stability of these features. In recent years, the possibility of wind-throw and wildfire has become a tangible threat to the site, and several SPB spots have already occurred within the site boundaries. In hopes of avoiding the development of similar conditions at Bannister, the heritage resource staff recommended that the timber harvest be allowed to proceed under a strict mitigation and monitoring plan. This plan was drafted and submitted to the State Historic Preservation Officer (SHPO) at the Texas Historical Commission on 9 June of 1997, and concurrence for the project was received on 26 June 1997.

Project Activities

The timber harvest project took place at Bannister between 16 July and 1 August 1997. Forest service personnel monitoring the project were Elaine Sherman (Zone Archaeologist), Sharon McHale (Archaeological Technician), Faye Green (Archivist/Oral Historian), and Lamar Smith (Timber Sale Administrator). The purchaser of this sale was Temple Inland Inc., and their contractor for the project was the Doyle Davis Logging Company. The contractor and his crew were very cooperative, and accepted the challenge of this experimental project with enthusiasm. A meeting was held with Mr. Davis and his crew prior to beginning operations on the first day. They were informed of the history and archaeological value of the site, and mitigation measures were discussed.

Mitigation Methods

Because no project of this size and nature had been attempted before on the National Forests and Grasslands in Texas, the mitigation plan had to be drawn up as much from theory as from professional experience. In writing the plan professional foresters and silviculturists as well as archaeologists and soils scientists were consulted. Ideas were gathered and the resulting mitigation plan was a compendium of those ideas. Consequently, most of these measures incorporated into the plan were experimental rather than proven, and as such were implemented with caution.

The mitigation plan submitted to SHPO included 12 measures designed to protect the site by limiting soil disturbance. The proposed mitigation methods included the stipulations that the Zone Archaeologist or other member of the heritage resources staff be present at all times during operations: that the contractor and his crew would be briefed on the history of the site as well as on the mitigation methods to be used and on the locations of any sensitive areas: that the logging equipment used would be limited to rubber tired (low PSI) vehicles; that sensitive areas would be flagged for avoidance or special treatment: and that the log sets, temporary haul roads, and main skid routes would be

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[3] Holbrook, A.K. 1996. Taped oral history interview. On file with: U.S. Department of Agriculture, Forest Service, Angelina Ranger District, Lufkin, TX 75901.

[4] Lacy, CR. 1996. Taped oral history interview. On file with: U.S. Department of Agriculture, Forest Service, Angelina Ranger District, Lufkin, TX 75901.

[5] Canton, E. 1997. Taped oral history interview. On file with: U.S. Department of Agriculture, Forest Service, Angelina Ranger District, Lufkin, TX 75901.

[6] Johnson, J.E. 1996. Taped oral history interview. On file with: U.S. Department of Agriculture, Forest Service, Angelina Ranger District, Lufkin, TX 75901.

located in previously disturbed areas such as old road right-of-ways.

As the first day of operations progressed it became apparent that some of the planned mitigation methods were not working under the conditions existent at the site, and changes to the mitigation plan were made on site as needed. By the end of the third day of the project two of the originally proposed mitigation methods had been abandoned, and one more had been modified. The first to be abandoned was the proposal that "A feller-buncher should be used where feasible, to cut and carry the trees to an appropriate area where they can be safely put on the ground.'" However, with the first two tries at this it became evident that this method would not work. While we were assured by a forester that the method worked with smaller timber, the large trees being cut on the site were too tall and heavy for the equipment to carry upright for any distance. These large trees had a tendency to make the feller-buncher "buck up" at the rear. This caused substantial ground disturbance from the digging in of the front tires. Another problem with this method, also related to the size of the timber, was that as the feller-buncher attempted to manipulate the upright cut trees through the surrounding forest the action tended to break limbs out of both the cut and standing trees. This process exposed the standing trees to an unacceptable amount of damage which could have resulted in additional tree mortality. It was therefore decided that this method would be abandoned and the trees would be dropped where they were cut and carefully skidded to the log decks.

The second mitigation method to be abandoned was the condition that "trees may be cut and skidded to a log deck .....so long as ..... the trees are skidded with the branches on to minimize ground disturbance"(Sherman 1997). Again, because of the age and size of the trees being removed, it quickly became apparent that this method would cause much more ground disturbance that it would prevent. The branches on the larger trees, instead of being limber and acting as a springbed for the bole of the tree, were stiff and solid and plowed up the ground surface. (The contractor indicated that this method does work with smaller, younger trees and was sometimes used during "first thinning" and "precommercial" thinnings). Trees were therefore limbed with a chainsaw prior to being skidded. This also had the effect of providing additional ground cover in the form of the scattered branches, which helped to stabilize the surface and protect it from disturbance.

Finally, one mitigation method was modified during project activities. This was the stipulation that "Logging operations will be conducted only when dry ground and weather conditions exist" (Sherman 1997). Dry conditions were present on the first day of the project, but on the second day rain showers temporarily shut down operations. The third day was clear, so in order to expedite completion of the project, the decision was made to continue operations despite damp ground conditions. It was then discovered that the moist (but not soggy) conditions actually favored ground stability and surface integrity better than the dry conditions of the first day. The moisture in the soil helped to keep the dust down, limited the horizontal movement of soil along the skid routes, and generally seemed to limit the overall compaction and surface disturbance. For the remainder of the project work continued on moist soils and was stopped only when the ground became saturated to the point where signs of rutting or other movement became evident. Soil moisture was monitored by frequent surface inspection and by the occasional use of a soil probe.

To minimize ground disturbance from the skidding, the primary skid routes (dubbed "Feeder Skids") were given a thorough surface examination and metal detector sweeps prior to use. During use, these feeder skid routes were visually monitored for evidence of archaeological materials or features. As long as no cultural materials appeared in the routes the location was considered "safe" and continued to be used. Individual skid routes leading from the location where the trees were cut to the feeder skid routes were normally only used for one or two passes of the skidder and caused little to no ground disturbance.

Careful visual monitoring of the site during project activities and surface inspections after completion of the harvest indicated that little to no damage had occurred to the integrity of the site. The amount of disturbance present at any given location appeared to be related to five primary factors. These factors were soil texture, soil moisture content, the speed at which the equipment operated, tightness of the turns, and number of passes on a given route. In order to minimize the disturbance we operated as much as possible on damp soils. The skidder operators were asked to slow down, to make broad sweeping turns where possible, and to avoid quick sharp turns. They were also asked to limit repeated use of the outermost skid routes as much as possible, making broad use of the general forest area but treading lightly on it.

Soil Disturbance Patterns

Observed levels of disturbance from various project activities were as follows:

Felling-The actual felling operation caused little ground disturbance. There was some crushing of vegetation where the feller had passed. Minor soil disturbance occurred at the base of the stumps where the skid-like feet on the base of the cutter head occasionally rutted the surface. After the cut was made the front tires of the feller sometimes dug into the soil a bit, especially when maneuvering the tree to where it could be safely laid down. Soil disturbance was seldom more than 3 inches deep and was limited to the area immediately adjacent to the stump. Usually less than 20 percent of the effected ground surface was exposed or disturbed.

Individual skids-These usually supported 1 to 3 passes of the skidder as it gathered the cut logs and brought them to the feeder skid routes. Disturbance was generally limited to flattening (crushing or breaking) of the vegetation and scraping aside the duff. Log ends slid primarily on the duff and crushed vegetation, causing little disturbance below the surface. Usually no more than 1 O-20 percent of the utilized surface was exposed.

Push backs or kick backs-These were large divots made by reversing the skidder during a drag and pushing backward on the log(s). This caused the end of the log to dig

[7] Sherman, E.P. 1997. Proposal for methodology and mitigation for logging operations at the Bannister Historic Site **(41SA214).** 3 p. Unpublished report. On file with: U.S. Department of Agriculture, Forest Service, Angelina Ranger District, Lufkin, TX 75901.

in, producing a shallow (l-4 inch deep) trench with a pushed up pile of dirt at one end. Size depended on size of log and the distance it moves backward. These usually occurred when a skidder was trying to maneuver around in a tight spot. The surface soil was exposed only in the trench itself.

Outer feeder skids-These were used to gather together the individual skids and bring them in toward the log set. These were more heavily used than the "Individual Skids", but less than the "Near Feeder Skids". Two or more outer skids would come together into a near skid. Disturbance on these routes included flattening (crushing) of vegetation with some uprooting of grasses and brush. Churning of the surface occasionally occurred (especially on tight turns) to a depth of about 4 inches. Approximately 30-50 percent of the utilized surface was exposed. These skid routes were monitored for evidence of artifacts or features. Use was continued as long as no cultural materials appeared.

Near feeder skids-These were the primary skid routes immediately adjacent to the log set, and extending outward 30-50 meters from the set. These received the heaviest skidding use and were laid out and surveyed by visual surface inspection and metal detector sweeps prior to use. Soil disturbance was usually between 3 and 6 inches deep. Disturbance consisted of churning up of the soil, but created little lateral movement. Most of the utilized surface was effected. These skid routes received the heaviest monitoring and also continued in use as long as no cultural materials surfaced.

Log sets-Log sets created small islands of high disturbance. Disturbance consisted of churning of the soil with some lateral movement across the set. This broad and deep disturbance was related to the factors previously discussed. Because of the limited size of the log sets the skidders were forced to maneuver in a small area, making very tight turns and increasing their speed in order to swing the logs around into position. This, combined with the high number of passes made, was primarily responsible for the depth of the disturbance. Because these activities could not be avoided, mitigation for the log sets consisted of placing them in previously disturbed areas along existing road corridors and surveying the area by means of visual inspection and metal detector sweeps prior to construction. Where possible the log sets were place outside of the site boundaries. The disturbance in the log sets averaged between 4 and 8 inches deep across the entire area.

CONCLUSIONS AND REMARKS

One unexpected bonus of the timber harvest at Bannister was the discovery of two additional trash dump areas, one water well location, and one ceramic steam pipeline location. While these materials were uncovered by project activities, they did not appear to be damaged or displaced by the operation. In fact, it was noted that the combination of the moist soft soils and the wide low PSI tires used on the heavy equipment was sufficient to protect most artifacts even those were located on or near the surface. For example, after three days of constant use on one near feeder skid route, a brief rain shower exposed several artifacts in the heavily used corridor. The artifacts included large fragments of a white stoneware plate and soup bowl, and a complete 1920's ketchup bottle. Despite evidence that these artifacts had been directly run over by the heavy equipment, they did not appear to have suffered any damage. The bottle was intact, and the broken edges of the stoneware were heavily stained, indicating the fractures were not recent. The only known damage to an artifact from project activities was to one white glass saucer fragment. This was shattered as it lay at the edge of the road where it was inadvertently run over by a dual wheeled service bed pick-up truck.

Another bonus for the site was the selective removal of a number of small pines from around an old oak tree. The oak is known to have stood in front of the Doctor's house at Bannister during the early to mid 1920's. Over time it had become thickly enclosed by the pines, some of which were actually growing up through its branches. As this oak is itself considered to be a living feature of the site, its protection was a major benefit to the preservation efforts at Bannister.

Overall, the project was very successful. Disturbance to the site was kept to a minimum with no notable loss of site integrity. The health of the forest ecosystem was improved and the stands can now be primarily maintained by occasional prescribed burning. During this project a great deal was learned about harvesting techniques and mitigation methods. Of the 12 mitigation methods originally proposed, 2 were dropped as unfeasible, one was modified, and three additional measures were adopted. The final mitigation methods that were used successfully at Bannister were as follows:

1. The Zone Archaeologist and/or other heritage staff members were on site during all operations to monitor and direct the activities.

2. The Purchaser's Representative, Field Supervisor, and Field Crew Members were all briefed by the Zone Archaeologist prior to beginning work at the site. The briefing covered the historic significance of the site, the mitigation methods to be used, and the need for limiting ground disturbance.

3. The Archaeologist and Timber Sale Administrator held brief pre-work conferences each day to ensure that the Field Supervisor and Crew Members knew the location of any sensitive areas or special conditions that may be encountered that day.

4. Harvest activities were performed by only one crew over the entire site. This helped to ensure the site **was** treated the same throughout, and aided in monitoring of the operations.

5. Harvest activities were conducted only when ground and weather conditions were favorable. Originally dry ground conditions were specified, but experience revealed that moist (but not wet) conditions provided better site protection.

6. Vehicles used off-road were limited to those equipped with large, low PSI, rubber tires.

7. Log sets and temporary roads were located on previously disturbed corridors such as old woods roads and previously treated SPB spots. Where feasible they were located outside of the site boundaries.

8. Main skidding routes (feeder skids), temporary roads, and log sets were surveyed by visual surface inspection and metal detector sweeps prior to use, and were monitored during use.

9. Sensitive locations such as foundations, earthen features, and areas with high density surface artifact deposits were flagged off for avoidance or special treatment during project activities.

10. Harvest operations began in the least sensitive area of the site in order to work out any procedural problems before moving into the more sensitive areas.

11. At the discretion/request of the Archaeologist, additional trees were marked for removal in order to enhance site conditions or better preserve specific features.

12. Slash (cut branches) was occasionally placed over historic features and/or areas of soft soils in order to protect and stabilize them.

13. Clean fill dirt was brought in and spread over a concrete foundation that crossed one of the main roads. This was done to protect the foundation while allowing the road to be used for both skidding and hauling.

These mitigation methods worked well at Bannister, and I would recommend their use at other sites. I believe that these methods (or variations of these methods) could be used successfully on other selected historic and prehistoric sites. However, not all sites should be harvested. The need for timber harvest or other environmental treatments on a site should be carefully considered prior to such an undertaking, and actions should be based on the preservation needs of the site rather than on the concerns of other resources. However, the needs of archaeological and environmental resources can complement each other, and cooperation can lead to shared and lasting benefits for all.

ACKNOWLEDGMENTS

I would like thank all of those involved in this project. A lot of folks put in some long hours and took a few risks to bring this about. Your efforts are greatly appreciated.

To Temple Inland Inc., a special acknowledgment for their willingness to work with us on this project. Their cooperation made this project possible. Thanks also to Doyle Davis and his crew who did an excellent job on the project and showed great deal of concern for the site (and great patience with the archaeologists!). A special thanks to Bill Martin at the Texas Historical Commission for his help and advise on this project, and for helping to expedite the process. And last but not least, a special thanks to Glenn Donnahoe, District Ranger on the Angelina National Forest, for allowing us the opportunity to try something new, and for his continued support of historic resource preservation.

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RECOVERY OF HYDROPERIOD AFTER TIMBER HARVESTING IN A FORESTED WETLAND'

Yi-Jun Xu, W. Michael Aust, James A. Burger, Steven C. Patterson, and Masato Miwa[2]

Abstract-Despite many studies on changes in soil physical and hydraulic properties caused by timber harvesting, the actual relationships of overall site hydrology and hydrologic recovery following stand establishment to surface soil disturbances have not been identified. We conducted a study on surface water table dynamics from pre-harvesting through early stand establishment on a wet pine flat, to determine effects of harvesting-induced soil disturbances on overall surface waterlogging, and to evaluate recovery of site hydrology across a gradient of site preparation. Three replications of two harvesting and three site preparation treatments were applied to a 22-year old loblolly pine (*Pinus taeda* L.) plantation located on the Lower Coastal Plain in South Carolina, U.S.A. In each treatment plot (about 3.3. ha) PVC wells were installed on a 20 by 20 m grid. Water table depths were measured monthly throughout five periods: pre-harvesting, post-harvesting, post-site preparation, and first and second year after stand establishment. The results showed that overall surface water table depths during the post-harvest period were elevated by 14 cm in the dry-weather harvested plots and 21 cm in the wet weather harvested plots, and that recovery of site hydrology following stand establishment was fastest on dry-weather harvested sites. The elevation of water table depth caused by harvesting was large during the growing season and very small during the dormant season, indicating that any changes in transpiring vegetation may significantly affect water table levels, and that vegetation disturbances may have a greater effect on water table changes than soil physical disturbances.

INTRODUCTION

Several decades ago, wetlands on the Lower Coastal Plain in the southeastern United States were generally considered as wasteland. During the 1950's, 60's and 70's, large-scale pine plantations were established after site drainage, and intensive forest management has, by now, been introduced to most of the region. Pine plantations on wet sites have become a significant resource for fiber and wood production. They are known to be among the most productive forests in the United States (e.g., Allen and Campbell 1988). A unique feature of the region is the site hydrology characterized by high seasonal water tables, and soil surface waterlogging on many sites due to the flat topography and the poor soil drainage (Stout and Marion 1993). Therefore, improving site drainage and soil aeration are among the most relevant silvicultural practices in this region.

Contrary to management that improves site hydrology, harvesting with heavy machinery may deteriorate soil drainage and aeration conditions. Numerous studies conducted on various forest soils have demonstrated that surface soil properties can be adversely altered by harvesting and logging operations, such as bulk density (Gent 1983 and 1984, Hatchell 1970, Lockaby and Vidrine 1984, Steinbrenner and Gessel 1955), macroporosity (Aust and others 1995 and 1998b, Dickerson 1976), and hydraulic conductivity (Aust and Lea 1992, Aust and others 1998b, Gent 1983, Gradwell 1966, Huang and others 1996). There is some concern that such changes in soil physical and hydraulic properties of wetland soils may lead to elevated overall surface water tables which may decrease productivity and alter wetland function.

The magnitude of the harvesting effect on surface soil disturbances in forested wetlands can be very different depending on soil moisture conditions. Based on a visual survey conducted immediately after harvesting a wet pine site, Aust and others (1998b) reported that 87 percent of the harvested area was compacted, rutted, or churned under wet weather conditions, while nearly 95 percent of the harvested area remained undisturbed under dry weather conditions. Although the authors pointed out that different classification methods may result in different disturbance levels, there is a general trend that harvesting impacts on surface soils increases with increasing soil water content. However, it is not clear whether or not overall surface water table will be affected by harvesting disturbances.

Bedding is a common site preparation practice on wet pine flats to improve seedling survival and tree growth by elevating planted trees on beds further above the surface water table. The restoration of site productivity through bedding has been repeatedly reported from the southeastern US region (e.g., Aust et al 1998a, Burger and Pritchett 1988, Hatchell 1981, Mann and Derr 1970, McKee and Hatchell 1986, McKee and Shoulders 1970, Pritchett 1979). In fact, bedding may have only microsite effects on soil water and aeration conditions especially on sites with flat topography and impermeable subsoils. In addition, the microsite effect of bedding may diminish with changes in microsite topography under warm, humid climate conditions. This may be the main reason why some researchers from the region (e.g., Cain 1978, Haywood 1983, Tiarks 1983, Wilhite and Jones 1981) observed a diminution of tree growth rates during stand closure to mid rotation on bedded sites. In view of maintaining both site productivity and wetland function, it is crucial to understand if bedding has an effect on overall depths of the surface water table, and to what extent this effect will have on long-term surface hydrology.

Site hydrology in forested wetlands is the factor dominating the functional development in soil physical, chemical and biological processes. In contrast to our knowledge of changes in surface soil water dynamics affected by harvesting from uplands, less is known about these effects

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on forested wetlands. This study is only a part of a long-term, multi-disciplinary project that intends to answer the questions introduced above. In this paper, with results gained from the past six years, we will focus on: (1) harvesting effects on overall surface water table dynamics, and (2) recovery of site hydrology across a gradient of site preparation.

STUDY SITE AND METHODS

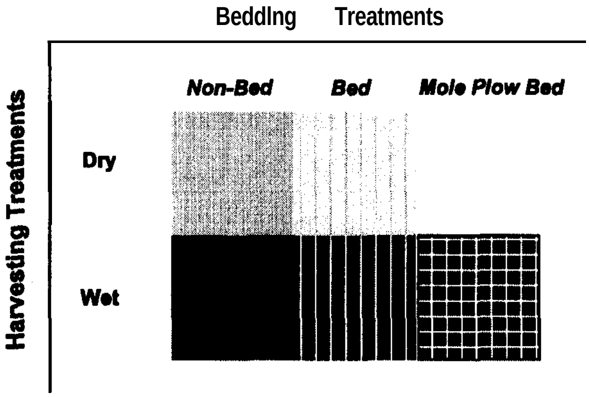
Site Description

The study site was located near Cottageville (32°56'N, 80°29'W) in Colleton County, South Carolina in the United States, approximately 50 km west of the Atlantic coastal line. The area is characterized by a lower coastal terrace landscape (< 10 m a.s.l.). Long-term climate data (1850-1990) of the area present a mild winter with a mean temperature of 10.1 °C in January and a humid warm summer with a mean temperature of 26.5 °C in July. Annual precipitation is approximately 1200 mm, of which 50 percent fall in the period from June to September. The average growing season is between mid March and beginning November, about 240 days during the year. The loblolly pine plantation in the study site was 22 years old in 1994, with an average height of about 23 m and a mean volume of 371 m^3 ha^{-1}. The understory is dominated by sweetgum, winged elm, oak spp., green ash, red maple, and iron wood.

Soils of the study site are derived from Oligocene and Pleistocene marine and fluvial deposits. They are a series of hydric soils within the order of Alfisols in the U.S. classification system. A typical profile presents sandy loam textured A and E horizons overlaying a massive Btg horizon with sandy clay loam material. The depths of the A and E horizons vary spatially from 1 to 51 cm and 0 - 81 cm, respectively. This depth variation is mainly a result of previous logging and site preparation operations. The sharp gradients of bulk density and saturated hydraulic conductivity from A (1 .18 g cm^3 & 4.85 cm hr^{-1}) via E (1.72 g cm^3 & 0.02 cm hr^{-1}) down to Btg (1.47 g cm^3 & < 0.000 cm hr^{-1}) horizons contribute to seasonal waterlogging and create a water table near the soil surface for long periods during the year. A deep water table fluctuates from the surface down to the bottom of Btg horizon, a span at 150 cm from wet to periods.

Treatments

Treatments were done within a randomized complete block design (fig. 1). In 1991 three study blocks were selected based on similarity of drainage patterns and soil type. Each block was subdivided into six 3.3-ha (8-acre) plots, and two operational harvesting treatments were randomly assigned to five plots per block: (a) two plots were dry harvested, and (b) three plots were wet harvested. The dry-harvest treatments were installed in the fall of 1993, and the wet harvest treatments were installed in the spring of 1994. Two levels of site preparation were randomly assigned to the dry harvested plots: (a) none, and (b) bedded, while three levels of site preparation: (a) none, (b) bedded, and © mole-plow and bedded, were randomly assigned to the wet harvested plots. The mole-plowing was conducted before bedding using a modified deep plow device consisting of a 1.5 m long shank and 70 cm plow. The operation was designed to create a channel in the massive Btg horizon to improve site drainage. The site preparation treatments were installed in November, 1995. All plots were hand-planted in early February, 1996, using genetically improved loblolly pine seedlings.



Fiaure 1—A studv desian with lwa harvestina treatments (wet-weather and dry-weather harvesting) and three site preparation levels (non-bedded, bedded, and mole-plowed plus bedded). Each treatment plot has an area of approximately 3.3 ha.

Measurements

A 20 by 20 m grid system was laid out in each plot. At each grid point a well hole was dug using a gasoline power auger. PVC pipes, with an inside diameter of 5 cm and a length of 100 cm, were inserted into the holes. In each plot 75 to 81 wells were installed, and, in total, 1409 wells were installed in the 18 treatment plots. All wells in the treatment plots were removed and re-installed during and after the harvesting and site preparation operations. Water table depths were monitored monthly since May 1992.

Data Analysis

To test the treatment effect on the elevation of the surface water table through time, five measurement periods were selected: (1) pre-harvesting (May 1992 - July 1993), (2) post-harvesting (July 1994 - July 1995), (3) post-site preparation (February - April 1996), (4) first-year after stand establishment (May 1996 - April 1997), and (5) second-year after stand establishment (May 1997 - April 1998). Water table depths measured from all wells were averaged for each treatment and observation period to present an overall surface waterlogging status of the sites. Elevation in the water table depth (Δ) caused by different treatments were quantified using the equation:

$$\Delta = WT\_Treat_{i,j} - WT\_Ref_{I,j} \pm \beta$$

where *WT_Treat* and *WT_Ref* are the mean water table depths in the treatment and reference plots, β is the adjustment in water table depths between the control and treatment plots during the pre-harvesting period, an d I and j represent each treatment block and reference datum, respectively. Harvesting and site preparation treatment effects on water table changes were tested at an alpha level of 0.1 using an unbalanced ANOVA.

RESULTS AND DISCUSSION

Long-Term Hydrologic Characteristics and Heterogeneous Nature

Fig. 2 summarizes the average surface water table for the 1992 to 1998 period in the three uncut control plots, illustrating (in both means and medians) a deep water table from April to May (>65 cm) and a high water table from

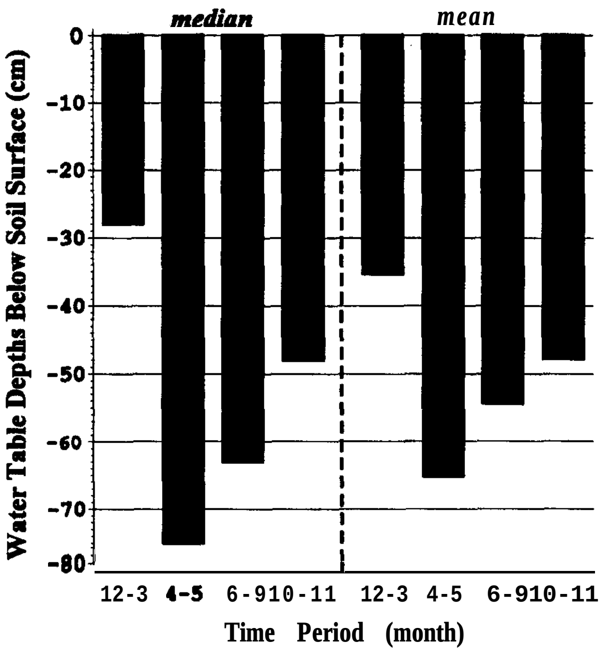


Figure P-Long-term characteristics (1992-1998) of surface water dynamics on a wet pine flat in South Carolina, the United States.

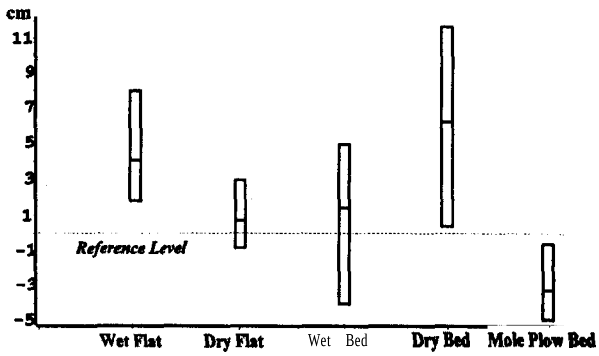


Figure 3-Differences induced by heterogenous nature in mean water table depths between treatment and control plots during pre-harvest period (three replicates in each treatment).

December to March (< 35 cm). During the growing season in summer and fall (June - November), the water table depths fluctuate between about 30 and 60 cm below the soil surface. This seasonal fluctuation in the water table depth is largely reflected by seasonal evapotranspiration at the study site (Xu and others 1999). Because of the strong effect evapotranspiration has on the water table level, this is an indicator that the removal of, or any changes in, transpiring vegetation may significantly impact water table levels on sites characterized by a flat landscape with poor drainage.

The monthly averages of water table depths between the replicate treatment plots show a more or less constant disparity during wet and dry seasons (data not presented). Mean water table depths during the pre-harvesting period (May 1992 - July 1993) demonstrates this site-specific effect among the treatment plots (fig. 3). It is crucial to separate this effect from that induced by the treatments on water table depth using relative changes in elevation as described in the data analysis section above.

Responses of Water Table Depth to Harvesting Treatments

The response of water table depth to the harvesting treatments was significantly different (figs. 4a-4d). Compared to the control references, the mean water table depths during the post-harvest period (July 1994 - July 1995) were elevated by 21 cm in the wet-weather harvested plots and 14 cm in the dry-weather harvested plots.

Interestingly, the seasonal water fluctuation during this one-year post-harvest period (fig. 5) shows that the elevation in surface water table caused by harvesting occurred mainly during the growing season, up to 42 cm at the wet-weather harvested sites. There was no difference in the elevation of the water table between wet-weather harvesting and dry-weather harvesting during the dormant season. The results indicate that the harvesting impact on water table depth of a flat plain with poor drainage is limited to the summer season, and that the magnitude of this harvesting effect should be dependent on the disturbance intensity on ground vegetation that affects site evapotranspiration.

Based upon their survey on the surface soil disturbance after harvesting at our study site, Aust and others (1998b) reported that 87 percent of the wet-weather harvested areas was disturbed by compression, rutting and churning, while only 5.2 percent of the dry-weather harvested areas was disturbed by compression. Many studies of harvesting disturbances concentrate on changes in soil physical and hydraulic properties on the disturbed areas which influence site drainage. However, our results indicate that the effect of ground vegetation disturbances on surface water level may far exceed the impact of soil physical property changes caused by harvesting. Soil compression can result in a reduction of macroporosity (Aust and others 1995 and 1998b, Dickerson 1976) and hydraulic conductivity (Aust and Lea 1992, Aust and others 1998b, Gent 1983, Gradwell 1966, Huang and others 1996), while deep rutting and churning in a large area caused by wet-weather harvesting can considerably diminish surface vegetation cover.

Responses of Water Table Depth to Site Preparation

Fig. 4b demonstrates that bedding significantly reduced overall surface water table depths during the short period of post-site preparation (February - April 1996). Compared to the non-bedded sites, the bedded sites showed a reduction in water table elevation up to 22 cm. The initial hydrologic response to bedding was very similar at all wet-weather harvested and dry-weather harvested sites, suggesting that microsite topography changes induced by bedding minimize harvesting impacts on overall surface water levels. Compared to bedding alone, mole-plowing did not significantly improve site drainage.

The post-site preparation period was a short dormant season. The difference in water table depth at both wet-weather and dry-weather harvested sites without bedding during the period was marginal: 45 cm in the wet-weather harvested plots and 43 cm in the dry-weather harvested plots. This is similar to the water table dynamics at the sites

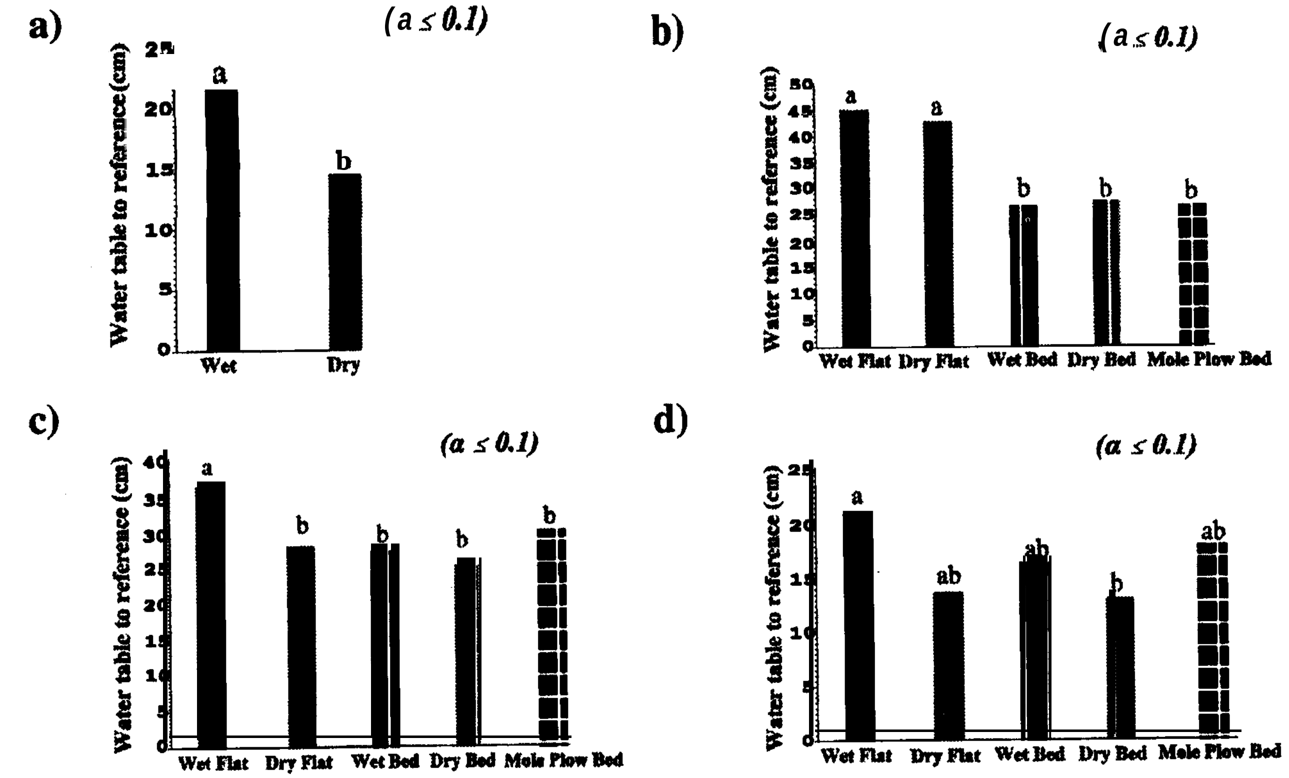


Figure 4—Harvesting and site preparation effects on elevation of overall surface water table during: a) post-harvest period (July 1994-July 1995), b) post-site preparation period (February 1996-April 1996), c) first year (May 1996-April 1997), and d) second year afler stand establishment (May 1997-April 1996).

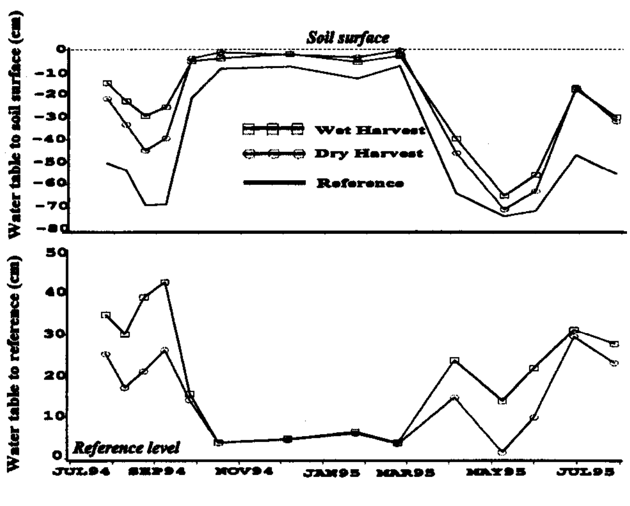


Figure E-Seasonal surface water dynamics following harvesting under wet-weather and dry-weather conditions on a wet pine flat.

during the one-year post-harvest period: a very small difference in water table changes during the wintertime. The results suggest that the most common hydrologic change in forested wetlands following harvesting (elevation of water table depth as stated by several researchers (Aust and Lea 1992, Lockaby and others 1997, Perison and others 1997)) is not clearly reflected during the wintertime or dormant season.

Hydrologic Recovery following Stand Establishment
During the first year after tree planting, compared to the water table depths of the control references, elevation in the water table depth remained highest at the wet-weather harvested, non-bedded sites, and lowest at the dry-weather harvested, bedded sites (fig. 4c). Surprisingly, no significant difference was evident in the water table depth between the bedded plots harvested under both wet- and dry-weather conditions and the non-bedded plots harvested under dry-weather conditions. Compared to the bedded sites without the mole-plow treatment, the mole-plowing still did not demonstrate a drainage improvement, as expected, during the two years following stand establishment (fig. 4c and 4d). In contrast, the elevation of water table levels at the mole-plowed and bedded sites were even higher than those of dry-weather harvested and non-bedded sites.

The amelioration effect of site preparation on the harvesting-caused elevation of water table tends to decrease rapidly two years after stand establishment (fig. 6). Compared to the control references, the elevation of water table depths at the dry-weather harvested sites was smallest. The dry-weather harvested sites without bedding presented the relatively

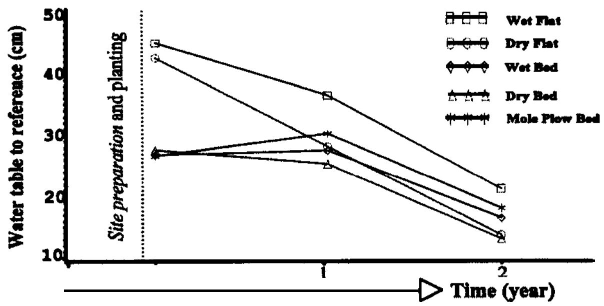


Figure 6—Recovery of overall surface hydrology after site preparation through stand establishment on a wet pine flat.

fastest recovery of site hydrology among all treatments, indicating that bedding itself is a disturbance on soil surface properties and ground vegetation that influence recovery of overall surface hydrology in poorly-drained wetlands. With our results gained from only two years after tree planting, however, we cannot predict the long-term effect of these treatments on the surface hydrology of wet pine flats widely spread in the southeastern US regions. Our on-going study will closely follow this important question to find implications for both forest practices and wetland and water resources.

CONCLUSIONS

Harvesting elevated the overall surface water table depth by about 20 cm during a one-year post-harvest period. The difference in water table depths between harvested and non-harvested sites was large during the growing season and very small during the dormant season, indicating that vegetative transpiration was the main factor regulating surface soil hydrology on this wet pine flat.

Harvesting effects on the surface water regime under wet-weather and dry-weather conditions were significantly different. Wet-weather harvesting had a greater impact on surface water table, increasing it above that of the dry-weather harvested plots due to the greater amount of surface soil exposed and vegetation disturbed. The recovery of site hydrology from the post-harvest period through early stand establishment was fastest on dry-weather harvested sites, implying that harvesting and logging operations under wet-weather conditions should be avoided, especially on sites that have a low likelihood of being bedded.

Bedding decreased the overall surface water table and accelerated initial recovery on both wet-weather and dry-weather harvested sites. However, the amelioration effect decreased rapidly two years after stand establishment, suggesting that physical processes of the surface soil in the wet pine flat are highly dynamic.

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ASSESSMENT OF SITE AND STAND 'DISTURBANCE FROM CUT-TO-LENGTH HARVESTING'

Clyde G. Vidrine, Cornelis deHoop, and Bobby L. Lanford[2]

Abstract-Assessment of stand and soil disturbance resulting from cut-to-length (CTL) winter season harvest demonstrations performed on a 12-year-old pine plantation first thinning, 23-year-old second thinning, and a mixed pine/hardwood natural stand clearcut harvest is reported. The harvests were performed on Martin Timber Company lands in central Louisiana, during February and March, 1997. Soil disturbance results show that 11 .O percent of the total harvest area was disturbed to some level, soil bulk density in disturbed areas was increased by 21.4 percent in the most severe cases, rut depth averaged 13.0 inches in the most severely disturbed areas along the corridor trail, and logging slash occupied up to 70 percent of the corridor trail distance. Mean soil bulk density in traveled areas covered with slash was 0 to 14 percent higher than the undisturbed areas. In first thinning harvest trials, 2.1 percent of the residual trees had bole injuries. In second thinning trials less than 1 percent of the residual trees had bole injuries.

INTRODUCTION

Forest managers in the southern central region of the United States are becoming increasingly interested in Scandinavian-designed timber harvesting/forwarding systems developed during the early 1970's for tinning and clearcutting southern pine plantations, principally for environmental reasons. The ability of the system to perform thinning harvests with minimum damage to the residual stand and to the soil is important to forest managers. Also, logging slash being distributed at the harvest site rather than being left in piles at the processing site is important to forest managers and loggers as reported by Gingras (1994). Logging slash distributed at the site and in direct contact with the soil is also important for minimizing nutrient losses. Gingras also reported that CTL harvest costs are comparable or lower than full-tree harvesting with processing at roadside, that CTL systems require reduced supervision and support requirements, and CTL systems minimize adverse impact in harvesting wet sites allowing more operable days per year-all of importance to loggers. Guimier (1997) reported that about 30 percent of the timber being harvested in Canada uses CTL logging systems, up from 10 percent in 1990. The CTL system is generally composed of two machines: a harvester and a forwarder. The harvester consists of a rubber-tired carrier with a felling/processing head and usually an on-board computer-linked measuring system which allows the operator to cut stems to lengths and diameters in accordance with mill specifications for logs. The forwarder consists of a carrier with a load-carrying rack and loader which allows it to self-load and self-unload onto logging trucks. Advantages claimed for this systems includes less damage to the residual stand than harvesting by conventional systems, the ability to merchandise products in the woods, increased recovery of higher valued products, minimum site damage, elimination of the need for a loader, large forwarder payload, and operator safety and comfort (Tufts and Brinker 1993, Richardson and Makkonen 1994, and O'Connor 1991). Disadvantages of CTL systems include high initial cost of individual machines, complexity requiring highly skilled mechanics and operators, productivity sensitive to tree size (due to single-stem processing), log size/weight limitation, forwarders less versatile than skidders, and log length limitation of the forwarder (Tufts and Brinker 1993, O'Connor 1991, and Conway 1982). Because the harvester felling head is boom-mounted, the machine does not have to drive to every tree harvested, as is the case with commonly used wheeled feller-bunchers. This may reduce the number and severity of residual tree injuries and extent of ground area compaction. In a site and stand impact study of a first thinning harvest of an 18-year-old pine plantation stand comparing a CTL operation to a feller-buncher-skidder operation, Lanford and Stokes (1995) reported the CTL system disturbed significantly less area than the skidder system. They also reported that the skidder system injured 25 trees per acre compared to 10 trees per acre for the CTL system. After severing the tree from the stump, the harvesters boom is retracted to allow the top to fall within the growing space the tree occupied rather than being forced through the canopy or carried through the residual stand. Processing the tree in front of the machine and then driving over the slash is reported to reduce soil compaction from the harvester and the forwarder. Seixas and others (1995) reported that for a single forwarder pass on wet soil, slash coverage at 20 kg/m^2 was effective at controlling soil compaction. However, on dry, loamy sand soils, Seixas reported the presence of slash did not decrease soil compaction for a single forwarder pass but did for multiple passes. The forwarder typically follows in the same path as the harvester and makes fewer trips than a skidder for the same production. Although the CTL system is not being used extensively in Louisiana, many forest managers are interested in its potential for their lands.

OBJECTIVES OF STUDY

The objectives of this study were to assess ground disturbance of a CTL harvesting system to the harvested area for first thinning, second thinning and clearcut operations, and damage to residual stands in the first and second thinning harvests.

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STUDY SITES

The CTL harvests were performed on Martin Timber Company lands in the north central Louisiana parishes of Bienville and Natchitoches during February and March, 1997. The first thinning operation was in Bienville parish, Section 28 of Township 15 North, Range 8 West. At that site, the soil is described by the Soil Survey of Bienville Parish as being of the Malbis fine sandy loam (MgB) series and Sawyer very fine sandy loam (SnC) series. The MgB and SnC soils have 1 to 5 percent slopes and are described as well drained soils. Moist bulk density of the MgB soil is 1.30 to 1.60 g/cc and for the SnC soil 1.45 to 1.60 g/cc-according to the Soil Survey. Soil texture classification performed on a sample taken from the first thinning study site indicated the soil to be composed of 6 percent clay, 36 percent silt, and 58 percent sand which is classified as a sandy loam soil.

The second thinning was located in Section 17 and the clearcut harvest site was in Section 23-both in Township 11 North, Range 8 West of Natchitoches Parish. According to the Soil Survey of Natchitoches Parish the soils are described as belonging to the Gore-Acadia-Wnghtsville series, which are level to gently sloping, moderately well drained, some poorly drained, and poorly drained soils that have a loamy surface layer and a clayey subsoil. Those soils are formed in old stream deposits. According to the soil survey, moist bulk density is from 1.30-l .50 for the Gore series, 1.35-1.70 for the Acadia series, and 1.35-1.65 for the Wrightsville series.

In the second thinning site a bulldozer cleared out the old rows of the first thinning to facilitate timber cruising. Unfortunately, this caused some problems with the logging equipments flotation, so the CTL operators cut new rows where the ground was particularly soft. The new rows were approximately perpendicular to the original thinning rows. No soil bulk density samples were taken in the bulldozer tracks.

The logging occurred during the time of year when the ground conditions are typically the least favorable for equipment flotation because ground conditions are at their wettest from winter rains and because evapotranspiration is at its seasonal lowest. The logging conditions during these trials were even wetter than normal. Originally, it was planned to perform conventional harvest operations adjacent to the CTL operations using feller-buncher/skidders, but ground conditions were too wet on both thinning sites to permit conventional skidder operations.

Timber cruise summaries for the first and second thinning trials are provided in Table 1. Cruise data on the clearcut harvest site, which was a mature upland pine-hardwood stand, was not taken.

THE CTL MACHINES

The CTL machines used in this study were a Ponsse HS 15 Ergo harvester and Ponsse S 15 Ergo forwarder (Lumpkin, 1996) Both 114-kw (153-hp) diesel engine powered machines were 6-wheeled all-wheel drive and were equipped with 700/55-34 tires on the single axle and 700/50-26.5 tires on the tandem/bogie axles. The bogie axles on both machines were equipped with 34-inch wide "over-the-tire" type metal tracks and tire chains were fitted to the 700/55-34 single axle tires for the tests. According to Ponsse technical data, total weight of the harvester is 13,050 kg (28,770 lb),and for the forwarder total weight is 10,970 kg (24,184 lb) + 12,000 kg(26,455 lb) load capacity. Specified ground clearance for the front axle was 560 mm (22-inches) and 640 mm (25-inches) for the rear axles-for both machines. Wheel tread measured 2.1 m (83-inches) and wheelbase measured about 4.8 m (190-inches) with the bogies spaced 1.4 m (57-inches). The knuckleboom/slideboom-mounted harvester head had a reach of 1 0-meters (32.8 feet) from the pivot center. Operators for the harvester and forwarder were provided by Ponsse USA, Incorporated.

Table l-Timber cruise summaries of the first-thinning and second-thinning tracts; confidence intervals are 95 percent

	First thinning trial		Second thinning trial	
Variable	Pre-harvest	Post-harvest	Pre-harvest	Post-harvest
Tract number	4-5-320		4-6-814	
Age, years	12		23	
Average d.b.h., in	6.1 ± 0.1	6.8 ± 0.2	9.9 ± 0.4	10.7 ±0.4
Quad. mean d.b.h., in	6.2 ± 0.2	7.0 ± 0.2	10.1 ± 0.6	10.8 ±0.6
Basal area, ft^2/ac	91.6 ± 7.09	42.6 ± 2.62	90.7 ± 9.98	65.4 k6.94
Merch. height, ft[a]	26 ± 0.3	28 ± 0.2	48 ± 1.0	49 ±1.0
Harvested area, ac	15.6		19.5	
Number of trees/ac	431 ±40	160 ±12	163 ±16	103 ±11
Volume (cords/ac)	21.67± 1.84	10.36± 0.84	32.39± 3.75	23.51± 2.40
(CCF/ac)	16.02± 1.25	7.57± 0.49	25.91± 3.00	18.81± 1.92

"Average merchantable height to a 2-inch top diameter.

METHODS

In the first thinning trials of the 12-year genetically-improved loblolly pine plantation planted on 8 by 8-feet spacing, every seventh row was removed for an expected corridor center spacing of 56 feet. Desired residual stand density was 165 trees per acre. The corridor row was clearcut and the adjacent three rows to right and left of travel were thinned by operator selection. Logging slash consisting of limbs and tops discarded by the harvester was placed in the path in front of the harvester travel way to act as a cushion for the wheeled machines to travel on and to provide ground cover to minimize the disturbances. Stems processed by the harvester were placed on either side of the corridor in sorted piles as pine pulpwood, hardwood pulpwood, or pine logs. Pulpwood was taken to a minimum top diameter of 3-inches and lengths of 8 to 20 feet. Pine logs for plywood manufacture were cut to lengths of either 9 or 17.5 feet, with the small end diameter greater than 5-inches. Traffic on each trail consisted of a minimum of three machine passes-one pass of the harvester as it traveled in operation from roadside into the harvest area (or returning as it operated from the far end of the area to roadside), one pass of the forwarder as it traveled empty from roadside to the far end of the harvest area, and one pass as it loaded itself while traveling to the roadside-all in an effort to minimize loaded travel distance. Two additional machine passes would result when the forwarder completed its load before reaching roadside.

In the second thinning study of the 23-year pine plantation with a targeted final stand density of 100 trees/acre, the harvester operator did not align machine travel with planted rows or the corridor cut out from the first thinning but cut new corridors generally perpendicular to the original corridors. Corridor spacings were in accordance within the 32.8-foot "reach" distance of the harvester's boom. The clearcut harvest was in a natural stand and operating width of the harvester was also in accordance with the "reach" of the harvester head.

Site disturbance for the CTL harvest system was assessed by determining the portion of the total harvest area disturbed and the severity of disturbance for the three harvest trials. Percentage of area disturbed was determined from measurements of corridor center-to-center distances and machine trail width along the cut corridor. Severity of disturbance was determined by measuring distance occupied by slash along the corridor trails, depth and width of rutting, and level of soil compaction resulting from the operations of the wheeled machines. Rutting depth and width means were determined from ten measurements each, taken at areas of severe disturbance along the corridor trail-away from slash accumulations or where roots limited rutting depth. Measurements were confined to the most severely disturbed areas and not taken at random along the corridor trail. Soil compaction was determined by comparing values of soil bulk density in undisturbed areas to that of disturbed areas from surface soil core samples taken 0 to 4-inches deep. Soil bulk density values were determined from ten samples each from each of the three harvest trials-first thinning, second thinning, and clearcut operations for undisturbed area values, under slash, and in the deepest of the rutted areas which resulted in a total of ninety samples analyzed. All soil samples for bulk density and moisture content reporting were oven-dried to a constant weight at 105 °C. Representative values of soil moisture content were determined for background information. Damage to the final stand was determined by visual inspection for tree injuries in one harvest area each for the first thinning and second thinning trials.

DISCUSSION OF RESULTS

Site disturbance assessment values are given in Table 2. For the first thinning trial of the plantation planted on 8 by 8-ft spacing with seventh row removal, corridor trail spacing was 56.0 feet-in exact agreement with the expected value. Mean corridor center spacing for the second thinning harvest was 52.0 feet. Trail spacing for the clearcut harvest was not measured because the harvest area was irregular in that mixed pine-hardwood natural stand. Overall width of the corridor opening was about 15 feet, which was controlled by spacing of the planted stand. Mean spacing between rutted centers along the trail was from 84.6 inches for the clearcut harvest to 86.4 inches for the first thinning. Those values are in agreement with the 83-inch wheel tread measurement and indicates that the forwarder traveled in the tracks made by the harvester. Mean rut depth and width were 13.0 and 37.1-inches for each rut in the most severely rutted areas along the corridor trail for the first thinning study. Mean rut depth in the second thin and clearcut harvests were somewhat lower. Considering the rutted width of 37.1-inches and trail center spacing of 56-feet for the 1st thinning, 11 .O percent of the area was disturbed by travel of the harvester and forwarder but at varying levels of severity. The 11 .O percent disturbance value did not include disturbance at the end of the harvest area as the harvester travels from the end of a completed corridor to the beginning of the next corridor. Considering the depth of the harvest area in this trial was typically 581 feet and the corridor spacing was 56 feet, which the harvester traversed at the far end of the harvest area every second pass, the area disturbed by wheel traffic was 11.6 percent. Ground area disturbance for the 2nd thin harvest was somewhat higher at 12.4 percent since the rutted width was higher and the trail center spacing was less than for the first thinning operation. Again, the 12.4 percent value did not include ground disturbance at the end of the harvest area as the harvester moved from a completed corridor to the next corridor. Ground area disturbed for the clearcut was not determined because trail centers could not meaningfully be measured. Hunt, 1995, in a CTL harvest soil disturbance study reported average trail spacing to be 17.7 m (58 feet) with trail width 3.1 m (10 feet) and resulting area disturbance of 17.9 percent but with space between ruts not accounted for.

Soil compaction occurred along the wheel traffic areas for the three harvest trials as was evident from the resulting permanently formed wheel ruts. Soil bulk density was as high as 1.53 g/cc in the deepest ruts of the sandy loam soils of moisture contents from 22.4 to 24.1 percent (dry weight basis) for the first and second thinning harvest trials where mean rutting depth was as high as 13.0-inches. The presence of logging slash deposited along the trail reduced compaction levels resulting from multipass wheel traffic from 1.53 g/cc in the unprotected rutted areas to 1.35 g/cc. Undisturbed soil bulk density determined from samples taken near the vicinity of the trails varied from 1.35 for the first thinning harvest, 1.24 for the second thinning, to 1.23

Table 2—Site disturbances from first thinning, second thinning, and clearcut CTL harvests

Factor evaluated	Mean values with 95 percent confidence interval'		
	First thin	Second thin	Clearcut
Trail traverse results			
Rut depth, inches	13.0 il.6	9.3 ± 1.3	10.4 ±1.3
Rut width, inches	37.1 ±2.7	38.7 ± 2.4	41.6 k3.9
Rut center spacing, inches	86.4 ±2.0	84.7 ± 1.7	84.6 ±2.9
Corridor trail center spacing, feet	56.0 ±2.3	52.0 ± 6.5	—
Percentage of total area disturbed	10.9	12.4	—
Soil mc in undisturbed site, percent[b]	25.8 ±2.8	27.0 ± 4.4	29.4 ±2.2
Soil mc under slash, percent	28.9 ±3.5	29.0 ± 5.0	26.7 ±1.9
Soil mc in trail rut, percent	24.1 ±2.4	22.4 ± 2.8	24.8 ±3.6
Soil mc in shallow ruts (2-6 inches), percent	—	—	23.1 ±2.5
Soil bulk density, undisturbed site, g/cc	1.35±0.05	1.24± 0.08	1.23±0.09
Soil bulk density, under slash, g/cc	1.35±0.06	1.34± 0.08	1.39±0.05
Soil bulk density, in rutted site, g/cc	1.53±0.03	1.53± 0.09	1.49±0.09
Spacing between slash deposits, feet	18.8 ±3.7	22.0 ±11.0	10.4 ±2.37
Distance along slash deposits, feet	a.7 ±1.7	10.0 ± 4.27	18.9 ±5.3
Space along trail occupied by slash, percent	46.5	34.6	69.9
Slash depth, inches	6.7 ±1.2	6.2 ± 1.3	a.5 ±2.0
Soil mc too wet to operate, percent	41.6 ±8.4	—	—
Stand damage, percent residual trees injured	2.1	.6	—

[a] Confidence interval reported only when applicable.
[b] Soil moisture content reported on dry weight basis.

g/cc for the clearcut harvest. In the first thinning, the bulk densities of the samples from the undisturbed soil were essentially identical to the samples from under the slash. Samples taken from the exposed ruts (1.53A0.03 g/cc) had bulk densities that were significantly higher than samples from the undisturbed (1.35A0.05 g/cc) and slash sites (1.35A0.06 g/cc)-according to those means with 95 percent confidence intervals.

In both the second thinning and the clearcut corridor trails however, bulk densities of samples from the rutted areas, under slash, and undisturbed areas were all significantly different indicating that compaction occurred in both the rutted areas and the under slash trafficked areas. In the rutted areas soil bulk density was 1.53A0.09 g/cc compared to 1.34A0.08 g/cc in the under slash trafficked areas. Undisturbed soil bulk density was 1.24A0.08 g/cc-all as reported in Table 2.

All bulk density values reported are on a dry weight basis and were determined from cores taken 0 to 4-inches deep. According to Proctor Density tests for sandy loam soils, the optimum moisture content for maximum compaction is about 12 percent (Oglesby and Hicks, 1962) which indicates that compaction may have been even more severe had soil moisture been about 12 percent.

An interesting side-note was an opportunity to measure soil moisture where operations were limited by high soil moisture. It was found that logging operations could not be performed on the sandy loam soil having a moisture content of 41.6 percent because of wheel rutting to the machine ground clearance limit of 22 inches. Operations were performed with some level of rutting where the soil moisture was about 22 to 29 percent as discussed earlier.

Slash accumulations were highly variable in depth and spacing. Spacing between slash deposits along the corridor travel paths, which resulted in soil unprotected from wheel compaction, varied from a mean of 10.4 feet for the clearcut harvest to 22.0 feet for the second thinning harvest. Distance occupied by slash varied from an average of 6.7 feet for the first thinning to 16.9 feet for the clearcut trials. In the second thinning, slash occupied 34.6 percent of the corridor trail distance while in the clearcut slash occupied 69.6 percent of the trail. Considering that the presence of slash significantly reduced soil bulk density in the traveled areas for the three harvest trials and that from 34.6 to 69.9 percent of the distance was covered with slash, it is important to note that considerably less than 12.4 percent of the total area is impacted as reported for the second thinning harvest. Mean slash depth varied from 6.2 inches for the second thinning to 6.5 inches for the clearcut harvest after having been compacted by at least three machine passes.

Damage to the residual stand was found to be 2.1 percent in the first thinning trial which was determined by inspecting all trees in a randomly selected harvest block which was of area 0.75 acres. Three trees out of 137 trees were found to be injured-one injury being 2 by 3 inches at 1.5 ft above ground, 3 by 4 inches 4-ft above ground, and one a continuous strip from 2.5 to 6-ft above ground. This was equivalent to 4 trees per acre being injured. Lanford and Stokes (1995), reported 10 trees per acre to be injured in a similar study. In the second thinning harvest trial damage to the 100 tree/acre final stand was found to be 0.6 percent in which only one tree was found to be injured out of 163 trees inspected in one of the harvest areas. That injury was 2 by 3 inches at 6-h above ground and that tree was next to the corridor. The machine operators were highly skilled, which resulted in a minimum of injuries to the final stand.

CONCLUSIONS

Assessments of ground and stand disturbances from CTL winter harvest demonstrations performed on a first pine plantation thinning, second thinning, and a mixed pine-hardwood clearcut harvest in northern central Louisiana show low adverse impact from operation of the system for extremely wet soil conditions. Ground disturbance results show about 11 percent of the total harvest area was disturbed to some level which is considerably less than reported by Lanford and Stokes (1995) in a study of a first thinning harvest using conventional harvesting equipment. (They reported only 30 percent of the site was undisturbed, or 70 percent disturbed, using a drive-to-tree type feller-buncher and wheeled skidders performing a thinning harvest using 5th-row corridor removal for access and the remaining trees selectively removed.) Soil compaction in disturbed areas was increased by 21.4 percent in the most severe cases. Rut depth averaged 13-inches in the most severe cases and was limited to the corridor trail and only in that portion of the trail not covered with slash. Logging slash from tops and limbs removed from felled trees covered up to 69.9 percent of the corridor trail distance in the clearcut trials and was shown to limit compaction significantly in that portion of the trail. In first thinning harvest trials with 160 trees per acre left, 2.1 percent of the residual trees had some bole injury and in the second thin trials injury to the stand was 0.6 percent. The ability of the harvester to operate with seventh row removal in an 8 by 8-ft spacing stand should allow leaving more quality crop trees in first thinning harvest operations compared to conventional feller-buncher/grapple-skidder operations doing 3rd or 5th row removal in first thinning harvests. The value of that capability needs to be further explored. Also, the value of slash distributed at the harvest site rather than left concentrated in piles at the processing site needs to be evaluated for soil nutrient benefits for southern conditions.

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HARVESTING AND SITE PREPARATION EFFECTS ON THE HYDROPERIODS OF WET FLAT PINE PLANTATIONS[1]

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Abstract-Intensive forestry operations on wet sites may alter soil and hydrological properties, and these alterations could decrease seedling survival, growth, and future site productivity. The objectives of this study were to characterize different harvesting and site preparation effects on site hydrology and to evaluate altered micro-site hydrology with respect to the wetland hydrology criterion. This study was located in an intensively managed loblolly pine (*Pinus taeda* L.) plantation in the lower coastal plain of South Carolina. The site was harvested under dry and wet conditions and site-prepared with bedding and mole-plowing. Perched water table has been measured monthly on a 20 x 20 m grid of 1 m wells since 1992 and continuously monitored by automated-wells since 1996. Study results indicated that micro-site water flow patterns might be altered by wet-weather harvesting and bedding, and micro-topography and precipitation pattern significantly affected perched water dynamics. These results revealed that the hydrologic components of wetland delineation were difficult in the wet pine flatwoods.

INTRODUCTION

Southeastern pine forests are some of the most productive forests in the United States because of the warm climate, long growing seasons, abundant water supplies, and relatively fertile soils in the region (Stout and Marion 1993). Specifically, Southeastern Lower Coastal Plain pine plantations are some of the most intensively managed, productive forests in the United States (Allen and Campbell 1988). Site index of these forests often exceed 25 m (80 ft) in 25 years, and relatively well stocked sites, such as SI25 of 21 m (70 ft) with stocking of 1925 trees per ha (780 trees per acre), could yield approximately 5.66 m^3 ha^{-1} yr^{-1} (0.9 cord per acre per year) (Walker 1994).

Wet pine flatwoods of the Southeastern Lower Coastal Plain have little topographic relief and often have poor drainage (Stout and Marion 1993). Typical soils in the area consist of relatively coarse but organic-matter-rich surface soil horizons (A or Ap) and an eluviated sandy albic horizon (E) over a fine textured argillic horizon (Bt) (Allen and Campbell 1988). These subsurface soil horizons usually have extremely slow hydraulic conductivity which impedes vertical flow of surface water. These flat-topography and impermeable subsurface soils slow down surface and subsurface lateral water flow, which causes high perched water tables during the wet season.

The Southeastern Lower Coastal Plain wet pine flat consists of some jurisdictional wetlands and large areas of marginal wetlands. Bengtson and others (1991) showed the effect of the gradual topography and impermeable subsurface soils on perched water levels at a typical wet pine flat in South Carolina and demonstrated the complexity of wetland delineation in the area. They found that 4 percent of the study area became jurisdictional wetland by the 1987 COE/EPA Wetland Manual Hydrology Criteria, which was "inundated or reached to the surface soil saturation for more than 12.5 percent of the growing season" (Gaddis and Cubbage 1998). However, 81 percent of the area was classified as jurisdictional wetlands by the 1989 Federal Wetland Manual Hydrology Criteria, which was "inundated or reached to the saturation within 15-46 cm of soil depth for seven consecutive days." These results showed that delineation of wetlands based on hydrological characteristics was complex and difficult. These results also showed that a large area of wet pine flats had relatively high perched water tables during the growing season, and hydrology had a critical role in wetland function.

Over one million hectares of wet pine flat in the Southeastern Lower Coastal Plain are intensively managed industrial forests (Aust and others 1998b). These areas are commonly managed for the production of loblolly pine (*Pinus taeda* L.). Intensive management may include road and ditch installations, secondary ditching, mechanized harvesting, bedding, planting of genetically selected pine seedlings, fertilization, and other silvicultural manipulations. These intensive silvicultural practices often cause severe soil disturbance and alteration of site hydrological characteristics (Allen and Campbell 1968, Aust and others 1998a, 1998b). Tiarks and Haywood (1996) indicated that alteration of soil physical properties and site hydrology altered subsequent soil chemical and biological processes that might play a critical role in long-term site productivity.

Characterization of hydrologic responses to forest operations in disturbed areas is necessary in order to determine the degree to which soil disturbances affect site hydrology and subsequent forest sustainability and long-term site productivity. However, not many studies have addressed these questions. Most previous studies of wetland hydrology have relied upon much less data intensive hydrologic measurements within a wetland at specific times and points. Subsequently these measurements were extrapolated to the entire site. Those studies sometimes failed to present spatial and temporal characteristics of wetland functional changes. This study consisted of an intensive grid of water table wells that allowed the use of spatial data analysis techniques, and the monthly measurement of the water tables throughout the

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pre-harvesting to post-site preparation periods allowed determination of temporal changes of the water table which were caused by harvesting and site preparation. The spatial data analysis techniques used in this study provided enhanced interpretation capabilities and allows visual characterization of site hydrology and micro-site hydrological changes. The objectives of this study were (1) spatial characterization of forest harvesting and site preparation effects on site hydrologic properties and (2) evaluation of predicted perched water table with respect to wetland hydrology criteria.

MATERIALS AND METHODS

This site hydrology characterization study was conducted as a part of a long-term soil productivity study that is located approximately 55 km west of Charleston, SC. The area is in a typical wet pine flatwoods. Typical soils within the study area are Argent (fine, mixed, thermic Typic Ochraqualfs) (Soil Conservation Service 1982). These soils typically have a heavy clay Bt (argillic) horizon at a depth of 50-60 cm and an incipient E horizon just above the Bt. Drainage classes of these soils are poorly drained, as indicated by 'aquic' suborder taxonomic classes, and Argent is listed as a hydric soil in Hydric Soils of the United States (Soil Conservation Service 1991). The average growing season is between March 14 and November 10, and the average total precipitation at Walterboro, SC, approximately 15 km northwest of the study site, is 1,120 mm annually, and 897 mm during the growing season (Soil Conservation Service 1982). Potential evapotranspiration estimated by the Thornthwaite equation (Thornthwaite and Mather 1955) is 849 mm annually, and 760 mm during the growing season.

This study consists of three 19.2-ha blocks that have six 3.2-ha treatment plots. The treatments are no-harvesting (Control), dry-weather harvesting/bedding (Dry/Bed), dry-weather harvesting/no bedding (Dry/None), wet-weather harvesting/bedding (Wet/Bed), wet-weather harvesting/mole channeling/bedding (Wet/Mole/Bed), and wet-weather harvesting/no bedding (Wet/None). The study site was established in 1991, and baseline information was collected. Dry- and wet-weather harvesting were completed summer, 1993 and winter, 1994, respectively, and site preparation was completed fall, 1995. Details of the study layout and project design were described in Miwa(1999).

Perched water monitoring wells were installed in a 20 by 20 m grid pattern throughout the study area, and all wells were measured monthly between March, 1992 and June, 1993 (pre-harvesting), July, 1994 and July, 1995 (post-harvesting), and February, 1996 and February 1998 (post-site preparation). Automated perched water monitoring wells were installed in each treatment plot, and perched water table was monitored in 4-hour intervals since March, 1996. Relative elevation from common datum and surface soil depth were measured at each well point before and after harvesting and after site preparation. Disturbance class, which was a weighted average of qualitative soil disturbance levels within a 10 m radius of a well (Aust and others 1998c), was determined at each well point immediately after harvesting.

Spatial and temporal surface water dynamics in the study area were characterized in four steps. First, relative hydraulic gradient was determined at each well point, and micro-topography index and hydraulic gradient vector were determined from the relative hydraulic head difference between the well points. Second, the relationships between monthly surface water table and the temporal, spatial, and physical properties were established by a multiple linear regression. Third, daily perched water tables at each well point during the 1996 and 1997 growing seasons were predicted based on the multiple linear regression equations. Finally, the predicted daily perched water tables were evaluated with respect to the wetland hydrology criteria (1991 Wetland Delineation Manual proposed revisions), to evaluate forest harvesting and site preparation effects on site hydrology.

The statistical design used to test harvesting, site preparation, or harvesting/site preparation combination effects on measured variables were randomized complete block design. A 2 by 2 factorial within the block design was used for evaluating harvesting, site preparation, and harvesting x site preparation interaction effects.

RESULTS AND DISCUSSIONS

Hydraulic Gradient Characterization (Step 1)

Characterization of wet pine flat surface water movement, which includes above ground and perched water movement, is very important for evaluating harvesting and site preparation effects on site hydrology. Water movement is driven by hydraulic gradient among points: water flows from a point of higher potential to a point of lower potential. Our hypotheses are that harvesting soil disturbance created heterogeneous micro-topography (i.e. surface water hydraulic gradients were altered), and site preparation ameliorated the micro-topography change.

Surface water movement can be expressed by a hydraulic gradient vector. Vector angle (q) and magnitude (L) represent a direction and volume of water flow, respectively. Vectors of each well point were determined from following equations:

$$q=\tan^{-1}(Y/X) \qquad (1)$$

$$L=(X^2+Y^2)^{0.5} \qquad (2)$$

where X and Y were hydraulic gradient of the X and Y coordinate directions. The hydraulic gradient between two well points was assumed to be equal to the elevation difference between two points since fluid pressure and velocity in a perched water system were negligible compare to elevation. Detailed calculation processes were described by Miwa (1999).

Hydraulic vector angle and magnitude changes among pre- and post-harvesting and post-site preparation periods were evaluated to test the significance of harvesting and site preparation effects on site hydrology (table 1). Vector angle change was the average of absolute differences between two periods at each point since the direction of the vector angle change was not of interest. Vector magnitude change was calculated by subtracting post-treatment values from pre-treatment values at each point because positive or negative changes indicated a decrease or increase of water flow, respectively. Vector angle change caused by dry-weather harvesting was significantly larger than the change in the control plots, and wet-weather harvesting change was

Table l-Vector angle and magnitude change by harvesting and site preparation treatments among pre- and post-harvesting and post-site preparation periods

	Vector angle change					Vector magnitude change				
	Degrees					Index				
Pre-harv. to Post-harv.	Wet 94.9[a]c[b]		Dry 72.6b		Control 14.0 a	Wet 0.039[c]a		Dry 0.032a		Control 0.006a
Post-hat-v. to Post-site prep.	Bed 96.4a		None 14.3b		Control n/a	Bed -0.016a		None -0.044a		Control nla
Pre-harv. to Post-site prep.	Wet bed 111.2c	Wet none 113.6c	Dry bed 115.3c	Dry none 63.0b	Control 17.1a	Wet bed 0.059a	Wet none 0.021a	Dry bed -0.026a	Dry none -0.002a	Control 0.005a

[a] Mean values of absolute differences at each point within a treatment between two periods.
[b] Same letter within a period and variable are not significantly different at the 0.05 level.
[c] Mean values calculated by subtracting post-treatment value from pre-treatment value at each point.

significantly larger than dry-weather harvesting change. Vector angle change caused by bedding (including mole/bed) site preparation was significantly larger than the change in non-bedded plots. Furthermore, the overall effect of harvesting and site preparation showed that both wet-weather harvesting and bedding site preparation changed the vector angles significantly. These results indicated that micro-site water flow patterns were significantly altered by wet-weather harvesting and bedding. However, vector magnitude (water flux) change was no different among the treatments and periods (table 1). These results indicated that overall site hydrological characteristics might not be altered by the harvesting and site preparation.

Perched Water Dynamics Characterization (Step 2) and Daily Water Table Prediction (Step 3)

To characterize perched water dynamics and the changes caused by treatments, monthly perched water table at each well point should be expressed by a multiple linear regression function of the temporal, spatial, and physical properties of study site. The temporal properties were represented by continuous well measurement (WT_{auto}), the spatial properties were represented by the X and Y coordinate of each well point and distance between a well point and an automated well (DIST), and the physical properties were represented by surface soil depth (DEPTH), disturbance class (DC), and micro-topography index (TOPO). Micro-topography index is a summation of relative elevation differences among a point and four adjacent points: therefore, a positive or negative value indicated convex or concave micro-topography, respectively, and the value close to zero indicated plain micro-topography. Monthly water table data (WT) at each well point during the post-site preparation period was used for a response variable of the multiple linear regression. Detailed information of each variable was explained by Miwa (1999). The general form of the regression equation is:

$$WT = b_0 + b_1(WT_{auto}) + b_2(DEPTH) + b_3(TOPO) + b_4(DC) + b_5(DIST) + b_6(X) + b_7(Y) \quad (3)$$

After multicollinearity diagnostics, highly influential observation detection, and regressor selection procedures, each regression equation showed significant overall p-values (p-value < 0.05), and the weighted block average of the adjusted R^2 was 0.67, 0.61, and 0.54 for Block 1, 2, and 3, respectively. These results indicated that the regression equations were sufficient to predict perched water tables; therefore, daily perched water tables at each well point for the 1996 and 1997 growing season (March 14 through November 10) were calculated from the equations using corresponding automated well data.

Wetland Hydrological Criteria Evaluation (Step 4)

Site hydrological alteration by treatment and site physical properties was evaluated with respect to a criterion in the 1991 Wetland Delineation Manual proposed revisions, which were "saturated to the surface 21 or more consecutive days" (Gaddis and Cubbage 1998). This paper is focused on the soil saturation criteria because surface soil saturation is more difficult to determine than soil inundation.

In order to evaluate the predicted daily perched water table with the wetland hydrology criterion, soil-saturation-equivalent water level was determined from surface soil moisture-perched water table relations (unpublished data from M.A. Burger 1994), and a minimum soil-saturation-equivalent water level was estimated as -18.4 cm. A detail calculation process was described by Miwa (1999).

The predicted daily perched water tables were evaluated with a wetland hydrological criterion: perched water table higher than -18.4 cm 21 or more days. Then, number of days which exceeded the criterion was summed as 'Cumulative Wet Day' for each plot and each growing season, and the potential wetland area which exceeded the criterion was calculated as 'Percent Wet Site' for each plot and each growing season. (Cumulative Wet Days' were adjusted since some plots had different numbers of well points.) The test result of 'Percent Wet Site' and adjusted 'Cumulative Wet Day' were no different among the treatments because of large variances (table 2) which was probably caused by inherent variation of micro-site hydrology.

caused prolonged ponded conditions in the Block 3, Control plot which had a relatively low and flat topography. These results suggested that micro-topography and precipitation pattern during the growing season have a significant influence on wet pine flat site hydrology.

CONCLUSIONS

Wet-weather harvesting and bedding significantly altered micro-site hydrology, but overall site hydrology (water flux) was probably not affected. Evaluation of predicted perched water table indicated that micro-topography and precipitation pattern during the growing season had a significant influence on micro-site hydrology. Local depressional areas became wetter after harvesting and bedding.

Table 2-'Percent wet site' and adjusted 'Cumulative wet day' based on predicted daily perched water table for 1996 and 1997 growing season

Growing season	Wet bed	Wet mole/bed	Wet none	Dry bed	Dry none	Control
			Percent wet site			
1998	18.8[a]	25.8	31.1	28.0	22.4	36.6
1997	16.3	20.4	24.2	15.4	10.8	.0
			Cumulative wet days[b]			
1996	396	480	804	793	228	482
1997	352	348	577	591	139	0

[a] Values are mean of three plots.
[b] 'Cumulative Wet Day' is a summation of 'Wet Days' of each point within a plot.

A distribution plot of 'Wet Site' with different 'Wet Day' showed trends caused by micro-topography and precipitation pattern (fig. 1). 'Wet Site' patterns were observed at Block 1, upper and lower section of Wet/Mole/Bed and Wet/None plots, and the middle section of the Dry/None plot were associated with localized depressions because both 1996 and 1997 growing season plots showed similar patterns (fig. IA and 1 B). Contrarily, different wet site patterns between the growing seasons were observed at Block 3, Control plot (fig. 1C and 1 D). Although annual precipitation of 1997 was more than that of 1996 (1019 mm and 829 mm, respectively), precipitation pattern of the 1996 growing season was more concentrated than that of the 1997 growing season. This concentrated precipitation pattern of the 1996 growing season probably

Wetland delineation using hydrologic criteria during the stand establishing period would be very difficult because of temporarily-increased water table level, micro-site variability, and yearly differences in hydroperiods.

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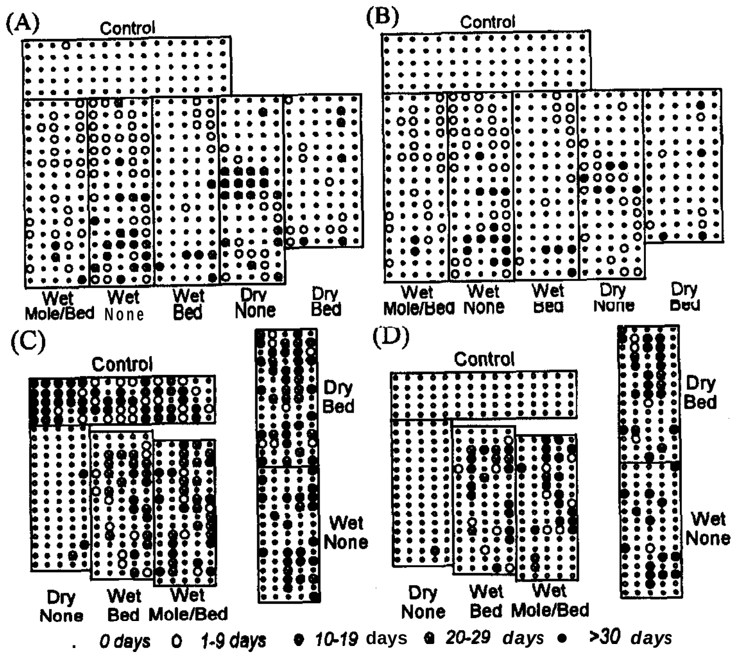

Figure l-Spatial distribution of predicted Wet Site' and 'Wet Day' for Block 1, (A) 1996 growing season and (B) 1997 growing season and Block 3, (C) 1996 growing season and (D) 1997 growing season.

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SLASH INCORPORATION FOR AMELIORATION OF SITE, SOIL AND HYDROLOGIC PROPERTIES ON POCOSINS AND WET FLATS IN NORTH CAROLINA[1]

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Abstract-k was hypothesized that mulching and incorporation of slash as part of site preparation treatments could affect soil water characteristics. Two forested wetland sites, an organic pocosin and a mineral wet flat, located in the lower coastal plain of North Carolina, were selected for treatments. Treatments consisted of slash mulching and incorporation in combinations with bedding and flat planting. These treatments were arranged in a randomized complete block design and an incomplete block design. Volumetric soil moisture percent, water table depths, and soil water chemical characteristics were monitored for one year following treatment installation. Preliminary results suggest that bedding in general affects soil water characteristics while differing methods of slash incorporation do not.

INTRODUCTION

Many of these sites are logged during moist or wet conditions that may lead to negative site quality impacts (Gent and Morris 1986). This research is designed to explore the possibility of incorporating post harvest slash residues into site preparation treatments as a means of reversing negative site impacts. It is possible that this incorporation of organic matter into site preparation treatments would have significant impacts on soil water characteristics through the alteration of soil physical properties, rooting environment elevation, and organic matter decomposition rates.

Near surface water table depth, soil volumetric moisture, and soil water chemistry are the major variables being considered. Water chemistry concerns include the presence and movement of nitrate, ammonium, and orthophosphate. These issues could have significant effects on short and/or long term tree growth.

SITE DESCRIPTIONS

Two sites in Beaufort County N.C. in the lower coastal plain south of the town of Washington N.C. were selected for treatment. Site elevations range from approximately 10 to 20 feet above mean sea level. The average daily maximum temperature in January is 55 degrees F and the average daily minimum temperature is 34 degrees F. The average daily maximum temperature in July is 87 degrees F and the average daily minimum temperature is 70 degrees F. Total annual precipitation is approximately 53 inches with 55 percent falling in April through September (USDA NRCS 1995).

The soil of the mineral wet flat is a Lenoir series, Clayey, mixed, thermic, Aeric Paleaquult, while the soil of the organic pocosin is a Pantego series, Fine, loamy, siliceous, thermic, Umbric Paleaquult (USDA NRCS 1995). The mineral wet flat has an ochric epipedon, while the organic pocosin has a histic epipedon (USDA SCS 1997). Drainage ditches are common along roads on the wet flat site. Drainage is more extensive on the pocosin site and tertiary ditches are connected to road ditches.

Both sites were intensively managed for loblolly pine (*Pinus taeda*) production. Other common species present were water oak *(Quercus nigra),* chenybark oak *(Quercus pagoda*), red maple (*Acer rubrum*), and sweet gum (*Liquidambar styraciflua*).

METHODS

Experimental Design

Treatment plots measuring 2 chains by 2 chains were arranged in blocks of five plots on the wet flat site and four plots on the pocosin site. There are four blocks on each site. A ½ chain buffer was left between each treatment plot and between each block. A 1/50 acre circular measurement plot was delineated in the center of each treatment plot. The design on the wet flat site is an incomplete block design while the design on the pocosin site is a randomized complete block design. In some cases the plots were split by soil horizon. All hypothesis test results are based on an alpha level of .10. In some cases an individual significance value will be reported for a parameter. Tukey's studentized range test was used to determine any significant differences between treatment means.

Treatments

Treatment one consisted of conventional site preparation methods for the North Carolina coastal plain. The conventional treatment utilized a tractor mounted V-shear blade to push slash and debris away from the bed-lines followed by traditional bedding with a tractor mounted plow. Treatment two consists of strip surface mulching of slash and stumps along the bedline followed by traditional bedding. A tractor mounted Rayco hydra stumper mulching head was used to perform the mulching tasks. This mulching head was used to mulch all slash and stumps in a 6.5 feet wide strip along the left and right side of the bed line. The resulting mulched strip was 13 feet wide centered on the bed lines. This mulched material was then incorporated into

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the beds by the tractor mounted plow. Treatment three consists of the exact manipulations described for treatment two except that the Rayco mulching head was set to till the soil to a depth of 4 inches which incorporated the mulch into the soil surface prior to bedding. Treatment four consists of broadcast surface mulching of all slash and stumps within the treatment plot followed by bedding along the bed lines. The mulching was again be performed by the Rayco mulching head and no soil tilling was involved. Treatment five is identical to treatment four except that the plot was not bedded after broadcast mulching. Treatment six is the control treatment and was left in post-harvest condition and flat planted. All of the above treatments were installed on the wet flat site while only treatments one, two, three, and six were installed on the pocosin site. In this case, treatment six above is renumbered as treatment four. All treatments were planted with genetically improved **loblolly** pine seedlings.

Approximately 40 Ibs elemental phosphorous and 35 Ibs elemental nitrogen were applied to each treatment plot as diammonium phosphate. Arsenal and Oust herbicides were banded to control herbaceous competition (Weyerhaeuser 1998).

Measurements

One bar tension lysimeters were installed into the soil profile to collect soil water samples from the soil profile (Wagner 1962). The water samples were analyzed using colorometric procedures to determine the concentrations of nitrate and ammonium (Technicon 1973). Soil volumetric moisture percentage was monitored using Time Domain **Reflectometry.** Iron rods were installed into the soil profile to a depth of 32 inches to monitor the depth of iron reduction within the profile. Near surface water table wells were installed to monitor water table depth below the soil surface in each treatment plot. Measurements were taken monthly beginning in May 1998 continuing through April 1999.

Table I-Soil water nitrogen concentration results for the wet flat site by treatment

Treatment	Nitrate	Ammonium
	Ppm	
1 shear bed	0.35	1.66 a
2 mulch bed	1.60	.66 ab
3 till bed	1.51	.28 b
4 broadcast	.71	.49 ab
5 broad bed	.47	.39 b
6 flat plant	1.26	.40 b

Table 2—Soil water nitrogen concentration results for the wet flat site by soil horizon where all treatments are combined

Horizon	Nitrate	Ammonium
	Ppm	
Ap surface	0.15 b	1.03 a
Bt subsurface	1.84 a	.24 b

RESULTS AND DISCUSSION

The results are based on preliminary data that was gathered between May 1998 and September 1998. The chemical data from water samples was collected in May 1998 and all current findings are based on that single data set. Findings based on the entire data set from May 1998 to April 1999 will be made available upon completion of the study.

Soil Water

Wet flat-There were no significant differences between treatment means for nitrate (ppm) in soil water (table 1). The effect of high variability between treatments is evident. However there are significant differences between soil horizon means (table 2). The nitrate concentrations in soil water from the Bt clay subsurface horizon was significantly higher than in the water from the Ap surface horizon. These results imply that the decomposition of surface and incorporated organic material, as well as the applied fertilizer, has caused nitrate to leach into the Bt horizon with downward water flow. The ammonium from the fertilizer and decomposing organic material is readily converted to nitrate in the presence of oxygen (Tisdale and others 1993). This seems reasonable because of the wetting and drying cycles common on this site.

Additionally there are significant differences between treatment means for ammonium (ppm) in soil water (table 1). These unexpected differences can not be explained at this time and the data do not correlate with changes in slash incorporation or bedding procedures. There are also significant differences between soil horizons means for ammonium in water (table 2). The ammonium concentrations in water from the Ap surface horizon are significantly higher than in the Bt subsurface horizon. This is probably due to the decomposition of surface and incorporated organic material and fertilizer application in the Ap horizon (Tisdale and others 1993). The lower ammonium values in the Bt subsurface horizon are reasonable given the tendency of ammonium cations to be retained on soil cation exchange sites, thus resisting leaching.

Pocosin-There are no significant differences between treatment means for nitrate (ppm) in soil water (table 3). There also are no significant differences between horizon means for nitrate in water (table 4). The pocosin site is very often saturated at or just below the soil surface. This creates a generally anaerobic soil environment that is not conducive to the conversion of ammonium derived from organic material and fertilizer to nitrate (Tisadle and others 1993).

Also, there are significant differences between treatment means for ammonium (ppm) in soil water (table 3). Treatments one, two, and three are bedded treatments while treatment four is non-bedded. Any difference between bedded and non-bedded treatments is probably due to the

Table 3-Soil water nitrogen concentration results for the pocosin site by treatment

Treatment	Nitrate	Ammonium
	---------- *Ppm* ----------	
1 shear bed	0.31	1.76 a
2 mulch bed	.10	1.77 a
3 till bed	.12	1.59 ab
4 flat plant	.06	.80 b

Table 4—Soil water nitrogen concentration results for the pocosin site by soil horizon where all treatments are combined

Horizon	Nitrate	Ammonium
	---------- *Ppm* ----------	
Ap surface	0.18	3.54 a
A subsurface	.08	.70 b
Btg subsurface	.10	.20 b

increased aeration and incorporated organic material in the bed. This combination would increase the decomposition of organic material in the bed thus releasing ammonium into the soil and water (Mitsch and Gosselink 1993). It is also likely that fertilizer applied to non-bedded plots was lost to surface water movement away from the plot. There are however significant differences between soil horizon means for ammonium in water (table 4). The Ap surface horizon ammonium concentration is significantly higher than the A and Btg subsurface horizons. This is due to the fertilizer and organic material that was incorporated into the beds.

Depth of Iron Reduction

Wet flat and pocosin-Iron reduction depth means for the bedded treatments are all significantly greater than the means for the non-bedded treatments (table 5 and 6). This is true for both sites. This is due to the increased aeration within the beds. Increased aeration is due to the increased soil surface elevation above the water table as well as increased porosity resulting from tillage and organic material incorporation (Allen and Campbell 1988).

Depth of Water Table

Wet flat and pocosin-The results indicate that there are no significant differences between treatment means on the wet flat site (table 5). The effects of high data variation between plots within treatments is evident. There are significant differences between treatments on the pocosin site (table 6). The results show that the bedded treatment means are significantly higher than the non-bedded treatments. This is due to the increased elevation of the soil surface on the bed.

Volumetric Soil Moisture

Wet flat and pocosin-The results indicate that there are no significant differences between treatment means for the wet flat site (table 5). There are significant differences between treatment means on the pocosin site (table 6). The results show that the bedded treatment means are significantly lower than the non-bedded treatment means. This is due to the increased porosity and subsequent drainage within the beds as well as the increased elevation of the soil surface above the water table on the beds. The increased porosity in the beds is due to tillage and incorporation of organic material (Allen and Campbell 1988).

Table 5—Soil moisture and water table results for the wet flat site

Treatment	Volumetric moisture	Water table depth	iron reduction depth
	Percent	---------- *Cm* ----------	
1 shear bed	30.8	54.2	27.5 a
2 mulch bed	31.1	72.5	26.5 a
3 till bed	29.2	78.8	33.0 a
4 broadcast	48.8	38.4	12.2 b
5 broad bed	25.1	68.6	30.0 a
6 flat plant	36.4	67.4	17.4 b

Table 6—Soil moisture and water table results for the pocosln site

Treatment	Volumetric moisture	Water table depth	Iron reduction depth
	Percent	---------- *Cm* ----------	
1 shear bed	45.2 a	44.1 a	14.5 a
2 mulch bed	47.9 a	41.3 a	15.7 a
3 till bed	42.6 a	40.0 a	15.2 a
4 flat plant	62.2 a	25.5 b	6.7 b

CONCLUSIONS

Wet Flat

The diammonium phosphate fertilizer applications have made it difficult to determine the effects of bedding and organic material incorporation on nitrate and ammonium in soil water. It is apparent that ammonium from the fertilizer and organic material is being converted to nitrate in the presence of oxygen and is moving downward into the Bt subsurface clay horizon with precipitation inputs.

The relatively dry nature of the wet flat site has negated any possible effects of bedding and organic material incorporation on water table depths below the soil surface as well as soil volumetric moisture. The iron reduction depths do indicate that bedding affects aeration within the early period of seedling rooting environment. In this case the differing methods of organic material incorporation did not affect water table depth, soil moisture, or soil aeration within the beds.

Pocosin

It is apparent that fertilizer and organic material has elevated the ammonium levels in soil water in the Ap surface horizon in the bed. The results suggest that the very wet nature of this site has restricted the conversion of ammonium in the beds to nitrate. As a result there is no apparent movement of nitrate downward into the soil profile.

The very wet nature of this site has made obvious the effects of bedding on rooting environment aeration, water table depth, and soil moisture. The iron reduction depths show the aeration increase within the beds that is critical to early seedling survival. The depth to water table is increased with bedding while volumetric soil moisture is decreased. These factors all contribute to enhanced seedling survival and growth on wet sites. It is evident that the differing methods of organic material incorporation did not affect these soil moisture and aeration properties.

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SOIL, GROUNDWATER, AND FLORISTICS IN A SOUTHEASTERN UNITED STATES BLACKWATER SWAMP EIGHT YEARS AFTER CLEARCUT WITH SKIDDER AND HELICOPTER LOGGING[1]

John M. Rapp, Theodore H. Shear, and Daniel J. Robison[2]

Abstract-This study was initiated in a cypress-tupelo forest adjacent to the South Fork Edisto River in South Carolina. Our objective was to compare the impacts of helicopter and rubber-tired skidder harvesting on the structure and function of a blackwater forested wetland eight growing seasons after harvest. We compared the structure and composition of the plant communities of the three treatments (helicopter, skidder, and unharvested control), as well as soil and water quality. Ordination of the overstory species shows no separation of vegetative communities by treatment, but rather, shows a pronounced separation of vegetation along an elevational and hydrologic gradient. Cellulose decomposition at 5 and 10 centimeters below soil surface and sedimentation rate are significantly greater in the harvest treatments than the control. Nitrate, ammonium, and orthophosphate concentrations in soil water were not significantly different between treatments.

INTRODUCTION

Forested wetlands in the southeastern United States have long supplied high quality hardwood timber. In addition to timber, their contributions to environmental quality (e.g., water quality, sediment trapping, plant community richness) are also valued by society. Recently, traditional extraction methods have been scrutinized for their potential role in influencing future timber supply and environmental quality. Timber extraction in forested wetlands is most commonly performed with rubber-tired skidders, and helicopter extraction has become a viable and used alternative. We investigated the impacts of timber harvesting in a southeastern United States blackwater swamp eight years after clearcut using skidder and helicopter extraction.

SITE

The 10 hectare site is in the Middle Coastal Plain in Orangeburg County, SC at the junction of the South Fork Edisto River and the Little River. In 1990, Perison (1993) conducted a direct gradient analysis of eight parameters to create an experimental design with the least variation between treatment blocks. The layout (fig. 1) is a complete block design, with a minimization on randomization, containing three treatments and five replications. The treatments are clearcut with helicopter removal, clearcut with skidder removal, and an unharvested control. The forest grades from Coastal Plain bottomland hardwood forest to cypress-gum swamp (as described by Schafale and Weakley 1990).

In January 1991, all trees greater than or equal to IO cm dbh were chainsaw felled in the harvest blocks. In April 1991, the merchantable timber was extracted by helicopter from both the helicopter and skidder treatments as the site was inundated with water, making skidder operation impossible. In November 1991, a rubber-tired skidder with a load of logs was driven throughout the intended skidder treatments to simulate skidder extraction.

METHODS

To determine if treatment differences were present eight years after clearcut and extraction, we measured soil, groundwater, and vegetation parameters (table 1) within the control and harvest treatments. These were also measured in 1992 and 1993, two and three growing seasons after harvest, respectively (Perison 1997, Pavel 1993). Soil and water parameters were analyzed using analysis of variance.

Vegetation was inventoried using the North Carolina Vegetation Survey protocol (Peet and others 1998). This system utilizes a nested plot design, with the number of nests chosen depending on the level of characterization sought. We used a IO x 10 meter plot with eight nested plots (four plots in opposite corners), the smallest being IO x IO cm. Decreasing the scale of observations (nested plots) aids in characterizing changes in species composition caused by environmental variables (e.g., microtopography).

Non-Metric Multidimensional Scaling (NMS) was used to analyze separation of vegetation type by treatment and block. For each species in a plot, we computed an importance value using the equation: (relative cover + relative frequency)/2. Using analysis of variance, we tested the eigenvalues (input variables for NMS) for significant treatment differences.

RESULTS AND DISCUSSION

Of the eight soil parameters tested, three showed significant differences between treatments: 5 year sedimentation depths, and decomposition at 5 and IO cm below soil surface. The harvest treatments had significantly higher mean annual sediment depths than the control, as well as higher mean rates of decomposition at 5 and 10 cm below soil surface.

Mean annual sedimentation rates for the control, helicopter, and skidder treatments were 7.82, 15.01, and 14.71 mm yr^{-1}, respectively (fig. 2). Eight years after clearcut, the ability to trap sediment is nearly doubled in the harvest treatments as compared to the uncut control. Ground cover in the control treatment was sparse in all blocks visited; ground cover was never greater than 20 percent and averaged only 8 percent. In contrast, the herbaceous and woody cover in the harvest treatments was dense, and ground cover was commonly

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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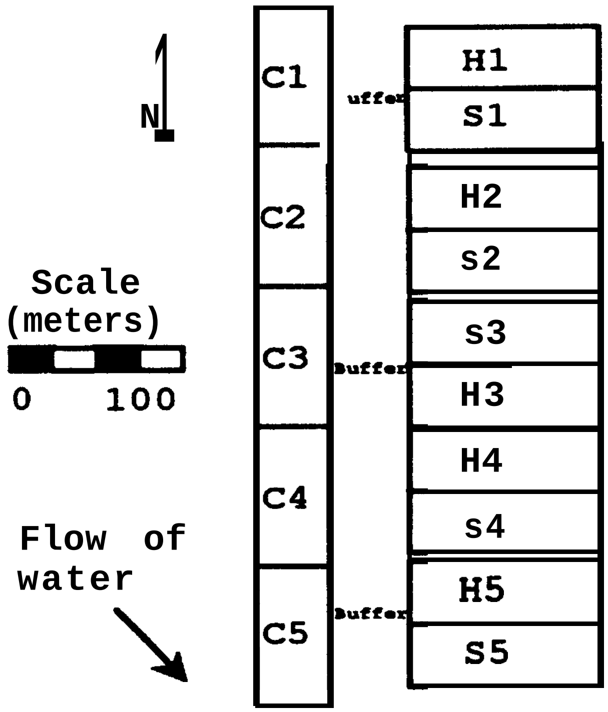

Figure 1-A complete block design comprised of three treatments and five replications was established in 1991. Treatments are: C-control, H-helicopter, S-skidder. Block identification number follows number (i.e., Sl =**skidder** treatment, block 1). South Fork Edisto River is 300 meters south of block 5.

greater than 100 percent. In addition, the accumulated sediment is mineral soil, while the soil below is **mucky-**mineral to mucky. Therefore, we are confident that the sediment measured was not transported from within the site. While other studies of sediment deposition in swamp forests also found increased sediment loads in harvested areas compared to the uncut treatments, none of the studies had found such elevated depths of sediment. Perison (1997) and Aust and others (1991) both attributed increased sediment deposition in harvest areas to surface coarseness caused by a dense understory.

Cellulose decomposition rates at 5 and 10 cm below soil surface are 50 percent to 90 percent greater, respectively, in the harvest treatments than the control treatment. Previous studies of this area and other areas reported strong correlation between soil temperature and increased levels of decomposition. However, we found no significant differences for soil temperature between treatments. So, temperature alone does not control decomposition rates on this site eight years after clearcut.

Nutrient concentrations (nitrate, ammonium, and orthophosphate) in soil water were not significantly different between treatments. In 1992 and 1993, ammonium levels within the skidder ruts were greater and significantly different in the two harvest treatments than the control treatment. We could not discern skidder ruts eight growing seasons after harvest, therefore, they were not sampled intentionally.

Table l-Methodology used to test soil, water, and vegetation parameters during the summer of 1998

Soil parameters	**Methodology**
Sediment rate	Sediment bars det to soil surface in 1993. Measurements of sedimentation rates taken in 1998. (n = IO/block)
Bulk density	Cores were extracted using a sliding hammer. Samples dried at 70EC for 72 hours and weighed. (n = **8/block)**
Percent organic matter	Loss-on-ignitio? method. (n = P/block)
Soil temperature	Measured 10 cm below soil surface with digital probe. (n = **16/block)**
Cellulose decomposition	Cotton strips incubated in soil for 14 days then extracted, cleaned, and cut into sections corresponding to the soil surface **5-** and 1 O-cm depths. Tested on **Sintech** tensiometer for loss of tensile strength. (n = **4/block/depth)**
Soil water parameters	**Methodology**
Well-water chemistry	Sampled **from** passive wells and tension lysimeters 122 cm and 20 cm deep, respectively. NO_3^-, NH_4^+, and P_2O_4 concentrations were determined. (n = **4/block)**
Vegetation survey	**Methodology**
Four strata inventoried: herbaceous, **understory,** midstory, and overstory	North Carolina Vegetation Survey protocol-l 0 x 1 O-m plots with eight nested subplots were used. Presence/absence, cover, height, and diameter were recorded. (n = **5/block)**

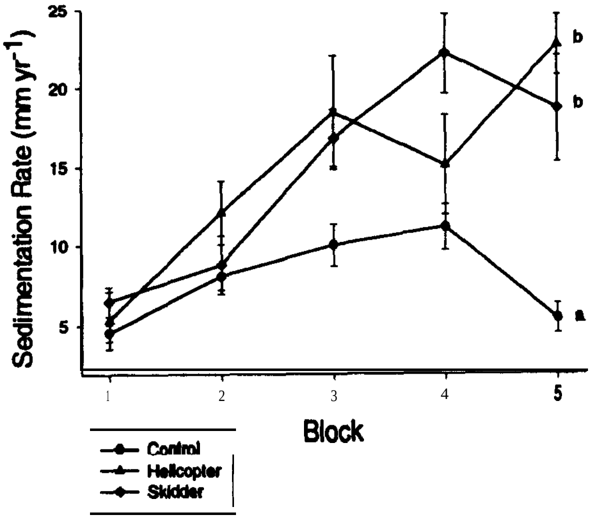

Figure Z-Mean annual sedimentation rate (1993-1998) by block. Significant differences between treatments are noted by different letters.

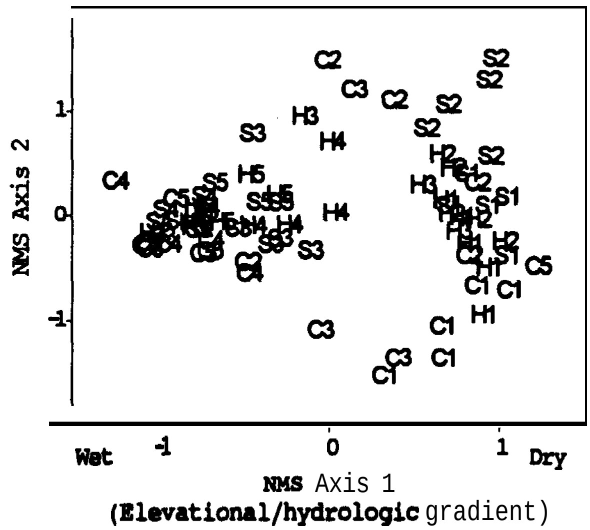

Figure 3-Vegetation plots (represented by **treatment/block)** are separated along an elevational and hydrologic gradient, not by treatment.

The NMS graph (fig. 3) shows no separation in species composition by treatment along axis 1 or 2 (i.e., overlapping and spread of C, H, and S), but does show grouping of blocks along axis 1. Axis 1 is an elevational and hydrologic gradient. A strong correlation exists between tupelo (*Nyssa aquatica* L. and Nyssa *biflora* Walt.) and axis 1. Tupelo is absent from block **1,** but abundant in block 5 (composing greater than 90 percent of the basal area). In addition, the mean block elevation decreases 0.33 meters from block 1 to 5. Due to a lower elevation, the duration of flooding is lengthened and different canopy species can tolerate inundation. This interpretation of axis 1 is corroborated by findings of greater sediment deposition in block 5 than in block 1 (fig. 2). At this time, we are only able to determine the environmental gradient influencing the vegetation plot distribution along axis 1; axis 2 is yet undefined.

Though we found no separation of treatments by vegetation type using NMS, we were able to determine the environmental gradient (elevation and hydrology) that influenced the pattern of plant community distribution. Analysis of the eigenvalue input variables by analysis of variance detect no significant differences between treatments, but highly significant differences between blocks.

SUMMARY

Eight years after **clearcut** and extraction, we found 1) that sedimentation rates were higher in the harvested areas as compared to the unharvested control area. We hypothesize that the increased sediment accumulation is due to greater surface coarseness from dense ground cover and logging slash, 2) that cellulose decomposition is greater at 5 and 10 cm below soil surface in the harvest treatments than the control treatment, and 3) that there is similarity of vegetation plots by block across axis 1. We determined axis 1 to be an elevational and hydrologic gradient.

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Site Preparation for Pine Establishment

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EARLY-SEASON FOREST SITE PREPARATION WITH IMAZAPYR AND COMBINATIONS OF IMAZAPYR AND GLYPHOSATE OR TRICLOPYR IN OIL EMULSION CARRIER: SECOND YEAR RESPONSE FOR PLANTED PINES AND ASSOCIATED WOODY AND HERBACEOUS VEGETATION[1]

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Abstract-Operational scale helicopter applications were made at four study locations in the southeastern United States to test three rates of imazapyr alone and combinations of imazapyr plus glyphosate or triclopyr in oil emulsion carrier in comparison to imazapyr in water based carder plus surfactant. Imazapyr alone at 0.75 lb ae/A in oil emulsion performed well in terms of control of tree forming hardwood, shrub control, and pine response. There was a large improvement in control of tree forming hardwood, shrub control, and pine response for an increase in imazapyr rate from 0.5 to 0.75 lb ae/A. Adding 0.75 lb ae/A glyphosate to 0.75 lb imazapyr improved control of tree forming hardwood, shrub control, and pine response over 0.75 lb imazapyr alone in oil emulsion. Adding 0.38 lb ae/A triclopyr to 0.75 lb imazapyr improved the level of shrub control over 0.75 lb imazapyr alone. Reducing the imazapyr rate to 0.50 lb and increasing the rate of glyphosate or triclopyr in the mix resulted in a decrease in competition control compared to 0.75 lb imazapyr alone. Treatment with 0.5 lb imazapyr plus 1.5 lb ae/A glyphosate resulted in over two-fold more shrub competition than 0.75 lb imazapyr alone and three-fold more shrub competition than for 0.75 lb imazapyr and 0.75 lb glyphosate. There is strong evidence of antagonism for combinations of imazapyr and high rates triclopyr. When applied in oil emulsion, 0.5 lb imazapyr plus 1 lb ae/A triclopyr resulted in over two-fold more tree forming hardwood than with 0.5 lb imazapyr alone and over five-fold more tree forming hardwood than with 0.75 lb imazapyr. Although 0.75 lb ae/A imazapyr in water carrier resulted in good shrub control, this treatment was not as good as 0.75 lb imazapyr applied in oil emulsion carrier in terms of weed free area after one year, control of tree forming hardwood after two years, and pine response.

INTRODUCTION

Chopper@ herbicide is an emulsifiable concentrate formulation of imazapyr. Chopper contains 2 pounds acid equivalent (ae) imazapyr per gallon plus emulsifier. Chopper is formulated to be applied in oil, oil and water emulsion, or water carrier. Chopper applied in oil emulsion carrier increases initial vegetation brownout, particularly for grasses, vines, seedling pines and hardwoods, which may be desired for improving fuel for site preparation burning (Minogue 1994, Minogue and others 1994, Nelson and others 1996). For low-volume applications (5 gallons per acre, gpa) using oil in water emulsions, the best performance for initial brownout is obtained with oil proportions between 25 and 50 percent of the total carrier volume, depending on oil type (Minogue 1994, Minogue and others 1994, Minogue and others 1995). A study examining emulsion proportions at 5, 10, 20, and 40 percent of 10 gpa total spray volume applied by mechanized ground sprayer indicated brownout of grasses, broadleaf weeds and vines was not related to oil proportion, whereas brownout of hardwoods increased from 27 to 48 percent as oil proportion increased (Quicke and others 1996). Operational experience indicates that for aerial applications at 10 gpa, at least 12 and preferably 25 percent oil:water should be used where brownout for burning is desired.

Use of oil emulsion carrier improves herbicide absorption by the target vegetation (Ramsey and Minogue 1996) and has been shown to enhance imazapyr performance for control of grasses, trees and shrubs (Minogue 1996, Nelson and others 1997). Emulsion carrier improves efficacy for the control of species with thick cuticles such as gallberry and waxmyrtle (Minogue and others 1996) as well as species which normally require a high imazapyr rate such as hickory and yellow-poplar (Minogue 1996). Emulsion carrier improves imazapyr absorption by reducing surface tension which increases contact area on the leaf, by increasing drying time on the leaf surface fostering greater initial diffusion into the cuticle, by reducing droplet bounce due to greater affinity of oil to the wax, cutin and suberin of the leaf cuticle, and by solvent action to these oil soluble constituents of the cuticle (Ramsey and Minogue 1995, 1996). Emulsions improve herbicide dose response, facilitating imazapyr performance in the early-season (full leaf to July) but also improving efficacy in late-season applications (August-September) when application timing is optimum (Nelson and others 1997).

Oil emulsions also provide application advantages. Oil emulsions provide greater spray deposition efficiency because they have lower rates of evaporation than water carriers. With water carrier, typical evaporation rates in the southeastern United States range from 20 to as much as 50 percent of the volume applied, whereas with emulsions evaporative losses are typically between 10 and 20 percent (Ramsey and Minogue 1995). Differences in evaporation potential also effects droplet size. As droplets move toward the target vegetation the mean droplet diameter (MDD) is reduced due to evaporation. Small droplets (<200 micron MDD) are prone to drift away from the target area. Emulsion carrier coupled with the use of controlled droplet application equipment provides greater control of droplet size, reducing the potential for drift.

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The objectives of this research were to examine rate response for Chopper and performance of Chopper tank mixtures with glyphosate and triclopyr in oil emulsion carrier during the early-season application period, relative to water based sprays with Arsenal AC. Initial vegetation brownout and first-year results were previously reported in the proceedings of the Southern Weed Science Society (Minogue and others 1996, Minogue and others 1997).

METHODS AND MATERIALS

Operational scale helicopter applications were made at four study locations in the southeastern United States (table 1). Treatments included three rates of imazapyr as Chopper® (0.5, 0.75 and 1 .O lb ae/A), two imazapyr/glyphosate tank mixes (0.5 lb imazapyr + 1.5 lb ae/A glyphosate, 0.75 lb imazapyr + 0.75 lb ae/A glyphosate), and two imazapyr/triclopyr tank mixes (0.5 lb imazapyr + 1 .O lb ae/A triclopyr, 0.75 lb imazapyr + 0.5 lb ae/A triclopyr). These treatments were applied in 25 percent oil emulsion carrier using Sun-It II® methylated seed oil. Each study site also included 0.75 lb ae/A imazapyr as Arsenal@ Applicators Concentrate applied in water carrier plus 1 percent (v:v) glycol surfactant.

All applications were made between May 13 and 23, 1995 using controlled droplet booms and nozzles to apply 5 gallons per acre of total spray emulsion. Treatment plots were between 5 and 10 acres, and at least 5 swaths wide. Five permanent 1/40-acre subplots were installed on line transects 2 chains apart in the middle of the center swath. Loblolly pine seedlings were operationally planted across the entire study area in the dormant season following application.

Evaluations included: cover by grasses, broadleaf weeds, vines, *Rubus* and weed free area after one year; a tally of all hardwood, shrub and non-crop pines over 1.5 ft tall by species and height at treatment and one and two years after treatment; pine ground-line diameter and height after planting and one and two growing seasons after planting.

Treatment means were compared using planned contrasts to test for: linear or quadratic responses to increasing rates of straight imazapyr; differences between imazapyr/glyphosate and imazapyr/triclopyr tank mixes: and an interaction between imazapyr rate and the tank mix partner. Pine response was analyzed using covariance analysis. Covariates for pine height and ground-line diameter two growing seasons after planting were pine height and ground-line diameter at planting, respectively.

RESULTS

Weed Cover After One Year

None of the sites received herbaceous weed control treatments following planting. This means that differences in vegetation cover one year after the applications can be ascribed to the site preparation treatments. The largest differences in herbaceous cover were observed in *Rubus*

Table l-Study locations, physlographic region, and dominant pre-treatment competitors in order of decreasing abundance

		Dominant pre-treatment competitors	
Location	Region	Arborescent hardwood	Non-arborescent hardwood
Calhoun, GA	Piedmont	Sassafras Black tupelo Persimmon Black cherry Hickory Red oaks	Sumac *Vaccinium*
Great Falls, SC	Piedmont	Sassafras Yellow-poplar Red maple Black tupelo	*Vaccinium* Sumac
Bar-tow, GA	Coastal Plain	Sweetgum Red oaks Black cherry Persimmon Sassafras	*Vaccinium* Sumac
Curtis, AR	Coastal Plain	White oaks Hickory Red oaks Sweetgum Winged elm	*Vaccinium* Sumac

Table 2—Control of vegetation components and pine size after two growing seasons

Treatment	Weed cover after 1 year		Arborescent hardwood level[a]		Non-arborescent hardwood level[a]		Pine response*	
	Rubus	Weed free area	Sum of heights /acre	Stems /acre	Sum of heights /acre	Number lacre	Height[c]	Groundline diameter[d]
	Percent		*Feet*		*Feet*		*Feet*	*Inches*
			Chopper@ in oil emulsion carrier					
0.5 lb ae/A Imazapyr	10	35	1,151	356	1,461	570	3.0	0.79
0.75 lb ae/A imazapyr	17	33	482	170	498	218	3.2	.86
1 .O lbae/A imazapyr	6	39	302	112	408	190	3.0	.81
0.5 lb Imazapyr + 1.5 lb ae/A Giyphosate	5	40	537	144	1,014	434	3.2	.86
0.75 lb imazapyr + 0.75 lb ae/A Giyphosate	3	48	374	134	350	156	3.4	.95
0.5 lb imazapyr + 1.0 lb ae/A Triciopyr	3	37	2,658	680	454	210	3.3	.86
0.75 lb imazapyr + 0.5 lb ae/A Triciopyr	7	40	508	172	64	26	3.2	.83
			Arsenal@ AC in water carrier					
0.75 lb imazapyr	21	28	690	260	113	48	3.0	.76

[a] Two years after treatment.
[b] Two growing seasons after planting.
'Adjusted by covariance analysis for height at planting.
*Adjusted by covariance analysis for groundline diameter at planting.

cover (table 2). Average *Rubus* cover on the treatments with straight imazapyr at 0.5 or 0.75 lb was 13 percent compared to 4 percent on the tank mix treatments. However, at a imazapyr rate of 1 .O lb ae/A, *Rubus* cover was reduced to 6 percent. There was no overall difference between imazapyrlgiyphosate and imazapyrltriciopyr tank mixes. *Rubus* cover on the tank mix treatment with 1 .O lb ae/A triciopyr was less than half that on the tank mix treatment with 0.5 lb triclopyr (3 percent vs. 7 percent). The average weed free area on the treatments with straight imazapyr at 0.5 or 0.75 lb ae/A was 34 percent compared to 41 percent on the tank mix treatments. The tank mix combination of 0.75 lb imazapyr plus 0.75 lb ae/A giyphosate had the most weed free area at 48 percent.

Arborescent Hardwood Control

The variable used to describe the level of tree forming hardwoods after two years is the sum of the live heights of arborescent hardwood stems over 1.5 ft tall. This variable accounts for hardwood mortality, terminal dieback, resprouting and stunting and has been shown to correlate well with longer term pine growth. Table 2 also provides the number of hardwood stems per acre.

There was a marked improvement in hardwood control as the imazapyr rate increased from 0.5 to 0.75 lb ae/A, with a smaller improvement in hardwood control for a further increase in the imazapyr rate to 1.0 lb (table 2). For the tank mixes there was an interaction between imazapyr rate and the tank mix partner **(p=0.049).** There was very strong evidence of antagonism between low imazapyr rates and high triciopyr rates. Adding 1 .O lb ae/A triciopyr to 0.5 lb imazapyr resulted in a marked decrease in hardwood control over 0.5 lb ae/A imazapyr alone. Treatment with 0.5 lb imazapyr + 1 .O lb ae/A triciopyr resulted in over two-fold more hardwood than straight imazapyr at 0.5 lb ae/A and over five-fold more hardwood than 0.75 lb imazapyr. Straight imazapyr at 0.75 lb ae/A oz resulted in the same level of hardwood control as 0.75 lb imazapyr + 0.5 lb triclopyr. Species resprouting on the treatment with 0.5 lb imazapyr + 1 .O lb triclopyr included black cherry, dogwood, sweetgum, hickory and red oak. Differences between the imazapyrlglyphosate tank mixes were not as dramatic as those between the **imazapyr/triclopyr** tank mixes. For the imazapyrlglyphosate tank mixes there was also an improvement in control as the imazapyr rate increased from 0.5 to 0.75 lb **ae/A.**

Non-Arborescent Hardwood Control

Trends for non-arborescent hardwood levels (shrubs) demonstrate a strong imazapyr rate response **(p=0.050).** There was a marked improvement in control as the imazapyr rate increased from 0.5 to 0.75 lb **ae/A,** with a smaller improvement in control with a further increase in the imazapyr rate to 1 .O lb (table 2).

There was no interaction between imazapyr rate and the tank mix partner **(p=0.704).** For both glyphosate and triclopyr tank mixes there was an improvement in shrub control as the imazapyr rate increased from 0.5 to 0.75 lb **(p=0.152).** Overall, the imazapyr/triclopyr tank mixes provided better shrub control than the imazapyr/glyphosate tank mixes. Noticeable is the excellent shrub control from 0.75 lb imazapyr plus 0.5 lb triclopyr and the poor control on 0.5 lb imazapyr + 1.5 lb **ae/A** glyphosate. The treatment of 0.5 lb imazapyr + 1.5 lb **ae/A** glyphosate resulted in two-fold more shrub competition than straight imazapyr at 0.75 lb and three-fold more shrub competition than 0.75 lb imazapyr plus 0.75 lb **ae/A** glyphosate.

Non-Crop Pine Control

The study was not specifically designed to look at non-crop pine control. The authors suggest that studies of non-crop pine control should consider sampling methods which account for the patchy distribution of natural pine regeneration. The Calhoun site had virtually no non-crop pines present at the initial assessment and two years later. Prior to treatment, the Great Falls site had much higher levels of non-crop pines on plots that ended up being treated with straight Chopper. On the **Bartow** site, the range in pre-treatment non-crop pine densities was 40 to 680 stems per acre. On the Curtis site the range in pre-treatment non-crop pine densities was 8 to 1080 stems per acre, with the highest densities occurring on plots that ended up being treated with imazapyr/triclopyr tank mixes. Because of the pre-treatment variability, these data could not be used to interpret treatment efficacy in terms of non-crop pine control.

The effect of the non-crop pine on crop pine response was investigated by adding the level of non-crop pine two years after treatment as a covariate in the pine response analysis. The covariate was not significant and resulted in no meaningful differences in the ranking of treatments. While the non-crop pine did not appear to impact crop pine growth after two years, they will certainly have some effect on diameter growth in future years.

Crop Pine Response: Age Two

Site preparation treatments control woody competitors and may also change herbaceous components in the years following treatment . The full impact on pine growth will not be evident for many years because herbaceous competition has a greater impact on pine growth in the early years, while woody competition becomes more important at later ages (Zutter and others 1995). The treatment effect on pine growth in terms of height and diameter was not significant **(p>0.24).** However, 0.75 lb imazapyr + 0.75 lb **ae/A** glyphosate stands out above the rest in terms of pine growth (table 2). This treatment had the largest weed free area at the start of the first growing season, explaining the early growth response. Because of the excellent shrub and arborescent hardwood control, this treatment is expected to remain a good long-term performer. There was also no treatment effect on pine survival. Survival ranged from 63 percent to 70 percent.

COMPARISON OF CHOPPER TO ARSENAL APPLICATORS CONCENTRATE

All study sites included a comparison of Chopper in 25 percent oil emulsion carrier to the standard 0.75 lb **ae/A** imazapyr as Arsenal@ herbicide Applicators Concentrate (Arsenal AC) applied in a water based spray with a glycol surfactant at the rate of 1 percent of the total spray solution volume. Total spray volume for the Arsenal AC treatment was 15 gallons per acre (Calhoun and Curtis) or 5 gallons, per acre (Great Falls and **Bartow).** Arsenal AC is an aqueous solution containing the isopropylamine salt of imazapyr with 4 lb acid equivalent per gallon. Arsenal AC contains no emulsifiers or surfactants and is formulated to be applied in water based sprays.

Herbaceous components after one year differed between the Arsenal and Chopper treatments. The Arsenal treatment had the most broadleaf, vine and ***Rubus*** cover of any treatment. Weed free area was 28 percent compared to a range of 33 percent to 48 percent for the Chopper treatments (table 2). The Arsenal AC treatment also had a higher level of arborescent hardwood competitors compared to straight Chopper at 48 oz or any of the Chopper tank mixes, with the exception of 32 oz Chopper + 1 .O lb **ae/A** triclopyr. Non-arborescent control on the Arsenal AC treatment was better than straight Chopper at 48 oz and better than any Chopper tank mix, with the exception of 48 oz Chopper + 0.5 lb **ae/A** triclopyr. This may be due to the higher application volumes, resulting in better penetration of the spray mix through the canopy to the shrub component. Another possibility is that there was better fuel availability with Chopper and Chopper combinations with glyphosate and triclopyr, as burning promotes shrub development (Harrington and others 1998).

Pine growth on the Arsenal AC treatment was less than that on any of the Chopper treatments. These initial growth differences can be explained by the higher levels of weed free area on the Chopper treatments at the beginning of the first growing season.

CONCLUSIONS

lmazapyr at 0.75 lb **ae/A** applied in 25 percent oil emulsion carrier performed well in terms of control of tree forming hardwood, shrub control and pine response. Adding 0.75 lb **ae/A** glyphosate to 0.75 lb imazapyr improved control of tree forming hardwood, shrub control and pine response over 0.75 lb **ae/A** imazapyr alone. Adding 0.5 lb **ae/A** triclopyr to 0.75 lb imazapyr improved the level of shrub control over straight imazapyr at 0.75 lb **ae/A.**

Reducing the imazapyr rate to 0.5 lb and increasing the rate of glyphosate or triclopyr in the mix, resulted in a decrease in competition control over tank mixes with 0.75 lb imazapyr.

In particular, 0.5 lb imazapyr + 1.5 lb **ae/A** glyphosate resulted in poor shrub control and 0.5 lb imazapyr + 1 .O lb **ae/A** triclopyr resulted in poor control of tree forming hardwood. There was strong evidence of antagonism between high triclopyr rates and imazapyr. The hardwood recovery on the 0.5 lb imazapyr + 1 .O lb **ae/A** triclopyr treatment was not readily apparent one year after treatment. It is, therefore, very important to consider longer term performance when evaluating different treatments.

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COMPARISON OF DICAMBA TANK MIXTURES FOR SITE PREPARATION APPLICATIONS-SECOND-YEAR RESULTS'

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Abstract-Dicamba has been available for use in forestry for many years but has had reduced utilization in the recent past with the advent of other herbicides such as hexazinone, imazapyr, and tank mixtures involving imazapyr, glyphosate, triclopyr, and metsulfuron methyl. The purpose of this study was to evaluate the efficacy of dicamba applied along and in tank mixtures for site preparation prior to pine plantation establishment. A total of 11 treatments were applied in a randomized complete block design at each of three geographic locations (South Carolina, Mississippi, and Arkansas). All plots were evaluated at 6 weeks after treatment for percent brownout of different vegetation classes to gain insight into the potential for burning. Hardwood stems were recorded by species and height class prior to application and at the end of the second growing season following application to evaluate treatment efficacy. Brownout evaluations revealed that best results were obtained from tank mixes which contained higher rates of glyphosate or imazapyr. Total species response in second year evaluations varied by location, but overall results were consistent among treatments. Hardwood control was greatest in the treatment blocks which received high rates of imazapyr or glyphosate. Any tank mix which contained higher rates of glyphosate or imazapyr have good results. Overall results indicate that dicamba tank mixtures could be effective in forestry site preparation, but rate of application should be greater than 64 oz. per acre.

INTRODUCTION

Controlling competing vegetation during regeneration activities remains one of the principal challenges for forest managers in the South. Herbicides have been used in forestry for over 50 years to varying degrees and research seeks to find more efficacious uses for products which are or could be labeled for such applications.

Dicamba has been labeled for use in forestry for many years. The advent of newer herbicides resulted in a reduced usage for dicamba either applied alone or in tank mixtures. Therefore, the purpose of this study was to evaluate the efficacy of dicamba applications for pine plantation site preparation either applied alone or through tank mixtures.

MATERIALS AND METHODS

Treatments

A total of 11 treatments were utilized in the study (table 1). Dicamba was applied as Vanquish@ and the other materials in the study were imazapyr (Arsenal AC@), glyphosate (Accord@), and triclopyr (Garlon 4®). In addition to the 10 active treatments, an untreated check was included. All treatments were applied in a randomized complete block design.

Study Sites

The treatments in this study were applied and evaluated at three separate geographic locations. In Arkansas and Mississippi, sites were representative of Upper Coastal Plain conditions and had been harvested approximately 8-I 2 months prior to the time of study installation. In South Carolina, site conditions were representative of Piedmont conditions and had been harvested 18-20 months prior to study installation. All sites had substantial coverage of herbaceous and woody vegetation.

Plot Establishment

Treatment plots were rectangular areas 25 ft. wide and 100 ft. long. The center of each plot was marked by nylon string stretched between metal stakes and the measurement plots were areas IO ft. wide and 80 ft. long centered in the treatment plot.

All treatments were applied with a CO,-powered backpack sprayer equipped with a pole extension and KLC-9 nozzle. Application was such as to simulate an aerial application and total spray volume was IO gallons per acre.

Evaluation

Within the measurement plot, all woody stems greater than 1.5 ft tall were recorded by species and height class prior to treatment application. At six weeks after treatment, an ocular estimate of the brownout on herbaceous vegetation was completed. At the end of two growing seasons after treatment, all woody stems in the measurement area were again recorded by species and height class. Data were subjected to analysis of variance and Duncan's New Multiple Range Test.

RESULTS

Brownout

Results of the brownout evaluations are presented in Table 2. Overall, the response was consistent among all study sites and the evaluations have been consolidated into a single table. In general, the mixtures of Vanquish and Accord or the high rate of Accord applied alone gave best brownout. This response was not unexpected as glyphosate is often added to site prep mixtures to aid in brownout, and it should be noted that reduced brownout does not automatically indicate reduced control.

Woody Stem Control

Treatment efficacy varied by site depending on the primary species found at each location (tables 3, 4, and 5). In Arkansas, loblolly pine was a major component of the woody stems. Thus, any of the imazapyr treatments may have exhibited very good control of sweetgum or the oaks on the

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Table l-List of treatments in dicamba field trials

Treatment number	Herbicide	Application rate per acre
		Oz. product
1	Untreated	
2	Vanquish	64
3	Vanquish Garlon 4	64 32
4	Vanquish Arsenal	64 4
5	Vanquish Arsenal	64 8
6	Vanquish Arsenal	64 12
7	Vanquish Accord	64 96
8	Vanquish Accord	64 128
9	Accord	192
10	Arsenal	24
11	Garlon 4	128

Table 2-Average percent brownout of herbaceous vegetation in dicamba field trials (average of all reps on all sites)

	Vegetation class	
Treatment	Grass	Broadleaves
	Percent	
Untreated	6	3
Vanquish - 2 qt/A	8	10
Vanquish - 2 qt/A Garlon 4 - 1 qt/A	8	10
Vanquish - 2 qt/A Arsenal - 4 oz/A	13	17
Vanquish - 2 qt/A Arsenal - 8 oz/A	23	26
Vanquish - 2 qt/A Arsenal - 12 oz/A	28	32
Vanquish - 2 qt/A Accord - 3 qt/A	60	55
Vanquish - 2 qt/A Accord - 4 qt/A	82	79
Accord - 6 qt/A	88	90
Arsenal - 24 oz/A	33	30
Garlon 4 - 2 qt/A	2	21

site, but overall, stem reduction would be much lower due to a lack of pine control.

In Mississippi, oaks and red maple were the primary woody species evaluated. Both imazapyr and glyphosate are effective on the oaks. However, glyphosate is not extremely effective on red maple. Thus, overall treatment rating for glyphosate treatments are lower on this site.

In South Carolina, the presence of privet was influential in overall treatment efficacy ratings. Treatments with triclopyr, glyphosate, or imazapyr were effective on black cherry and water oak, but overall control of privet was poor.

Overall, the treatments utilizing glyphosate or higher rates of imazapyr were most effective on all sites. From all the sites, only black cherry was adequately controlled by dicamba alone at 2 qts/A.

Table 3-Mean percent stem reduction for primary species in Arkansas

Treatment	Sweetgum	Pine	Oaks	Total
	Percent			
Untreated	0 r"	+11 cd[b]	0 e	+6 e
Vanquish - 2 qt/A	0 f	6 bcd	16 cde	6 cde
Vanquish - 2 qt/A + Garlon 4 - 1 qt/A	32 cdef	29 b	48 abc	37 ab
Vanquish - 2 qt/A + Arsenal - 4 oz/A	0 f	9 bcd	15 cde	9 cde
Vanquish - 2 qt/A + Arsenal - 8 oz/A	8 ef	+2 cd	6 de	2 de
Vanquish - 2 qt/A + Arsenal - 12 oz/A	58 abc	8 bcd	46 abc	25 bc
Vanquish - 2 qt/A + Accord - 3 qt/A	26 cdef	13 bcd	24 bcde	17 bcd
Vanquish - 2 qt./A + Accord - 4 qt/A	39 bcde	20 bc	17 cde	24 bc
Accord - 6 qt/A	43 abcd	60 a	26 bcde	46 a
Arsenal - 24 oz/A	73 a	+3 cd	75 a	13 cde
Garlon 4	22 def	15 bcd	36 bcd	23 bcd

[a] Values in a column followed by the same letter do not differ at p = 0.05.
[b] Plus signs indicate an increase in the number of stems.

Table 4-Mean percent stem reduction for primary species In Mississippi

Treatmerit	Cherrybark oak	Water oak	Red maple	Total
	Percent			
Untreated	+380 h[a]	+125 g[b]	31 d	58 h
Vanquish - 2 qt/A	+80 g	8 e	0 e	9 ef
Vanquish - 2 qt/A + Garlon 4 - 1 qt/A	6 e	+11 f	100 a	20 d
Vanquish - 2 qt/A + Arsenal - 4 oz/A	12 e	33 d	50 c	17 de
Vanquish - 2 qt/A + Arsenal - 8 oz/A	81 b	55 cd	75 b	67 b
Vanquish - 2 qt/A + Arsenal - 12 oz/A	38 d	73 b	100 a	76 ab
Vanquish - 2 qt/A + Accord - 3 qt/A	17 e	+20 f	33 d	3 fg
Vanquish - 2 qt/A + Accord - 4 qt/A	48 cd	26 de	50 c	41 c
Accord - 6 qt/A	60 c	63 bc	0 e	37 c
Arsenal - 24 oz/A	100 a	--[c]	100 a	85 a
Garlon 4	+33 fg	33 d	66 bc	3 fg

[a] Values in a column followed by the same letter do not vary at p = 0.05.
[b] Plus signs indicate an increase in stems.
[c] Did not occur in all replications.

Table 5—Mean percent stem reduction for primary species in South Carolina

Treatment	Black cherry	Water oak	Privet	Total
	Percent			
Untreated	+37 b[a]	+5 a[b]	+165 b	+78 b
Vanquish - 2 qt/A	78 a	33 a	+72 ab	47 a
Vanquish - 2 qt/A + Garlon 4 - 1 qt/A	100 a	+11 a	+116 ab	+26 ab
Vanquish - 2 qt/A + Arsenal - 4 oz/A	78 a	38 a	38 ab	43 a
Vanquish - 2 qt/A + Arsenal - 8 oz/A	56 a	65 a	+136 ab	20 a
Vanquish - 2 qt/A + Arsenal - 12 oz/A	100 a	78 a	31 ab	58 a
Vanquish - 2 qt/A + Accord - 3 qt/A	90 a	55 a	+28 ab	60 a
Vanquish - 2 qt/A + Accord - 4 qt/A	83 a	61 a	69 ab	60 a
Accord - 6 qt/A	25 ab	64 a	38 ab	50 a
Arsenal - 24 oz/A	89 a	85 a	0 ab	68 a
Garlon - 4	16ab	49 a	+78 ab	7 ab

[a] Values in a column followed by the same letter do not vary at p = 0.05.
[b] Plus signs indicate an increase in stems.

SUMMARY

In summary, the following points were notable in this study:

- Higher rates of imazapyr or glyphosate provided better brownout results.
- If dicamba is to be used alone, application rate should exceed 64 oz/A.
- Results varied for stem reduction on test species and no single treatment proved best.
- Arsenal (24 oz/A) provided excellent control of oaks, red maple, and sweetgum.
- Accord (6 qts/A) proved best for pine and privet control.
- Dicamba mixed well in all combinations, but acceptable control was achieved only by mixes with higher rates of imazapyr and glyphosate.

EFFECT OF SIX SITE-PREPARATION TREATMENTS ON PIEDMONT LOBLOLLY PINE WOOD PROPERTIES AT AGE 15'

Alexander Clark III and M. Boyd Edwards[2]

Abstract-The impact of weed control and fertilization on increased tree growth is positive and significant but the effects on wood properties are not well known. Increment cores were collected from loblolly pine (*Pinus faeda* L.) trees growing on an existing site-preparation experiment in the lower Piedmont of Georgia at age 15. The levels of site preparation were: 1-clearcut only; 2-chainsaw, 3-shear and chop; 4-shear, chop, and herbicide; 5-shear, rootrake, burn, and disk; 6-shear, rootrake, burn, disk, fertilize, and herbicide. Two, 0.472 in. increment cores were collected at d.b.h. from 35 trees representative of each site-preparation treatment. Wood basal-area growth increased significantly with increased site-preparation treatment. The site-preparation treatments did not affect length of juvenility which averaged 10 years for all treatments. Average increment core specific gravity was not significantly reduced with increased site preparation compared to the control trees. The diameter of the juvenile wood core, however, increased with increased site-preparation treatment.

INTRODUCTION

The pressure to produce wood fiber is leading to intensively managed plantations, which generally accelerate the early growth of the trees and reduce rotation length to maximize return on investments. The wood industry is now using intensive cultural treatments such as intensive site preparation, competition control, and fertilization to increase fiber production of southern pine. The impact of these intensive silvicultural treatments on increased growth is positive and significant, but their effect on wood properties is not well known.

A site-preparation study established in 1982 to evaluate and understand the benefits of various site-preparation treatments on pine survival and growth provided the opportunity to examine the effects of various site-preparation treatments on wood properties. Increment cores, 0.472 in. in diameter, were collected from 15-year loblolly pine (*Pinus taeta* L.) established using six levels of site preparation. The increment cores were analyzed to determine the effect of site preparation treatment on annual earlywood and latewood production, date of transition from juvenile to mature wood, and wood specific gravity.

LITERATURE REVIEW

In the Southeast a typical loblolly pine plantation can produce 50 to 110 ft^3 of wood per acre per year. However, research (Borders and Bailey 1997) has shown that with intensive management practices, such as complete competition control, multiple fertilizations, and genetically improved stock, these growth rates can be increased to 250 to 350 ft^3 per acre per year. These growth rates compare well with the fastest growing loblolly pine anywhere in the world.

A radial cross-section of a pine stem contains three zones of wood: l-core or crown-formed wood, which is produced by immature cambium in the vigorous crown and has anatomical, chemical, and physical properties that differ from that of mature wood: 2-transition wood, a zone where wood properties are changing rapidly before wood reaches maturity; and 3-mature wood (Clark and Saucier 1989). Juvenile wood is characterized as having lower specific gravity, shorter tracheids, thinner tracheid walls, larger lumens, lower percent latewood, and lower alpha cellulose content than that of mature wood. In the longitudinal direction there is a core of crown-formed wood surrounding the pith from butt to tip of stem surrounded by a band of transition wood from butt to base of live active crown surrounded by a wide outer band of mature wood (Bendtsen and Senft 1986). Both crown-formed and transition wood is commonly referred to as juvenile wood.

The definition of southern pine wood quality depends on the product for which the wood is used. High specific gravity is almost always considered a desirable wood quality trait. High specific gravity is positively correlated with wood strength and stiffness. Wood from young fast-growing pine plantations often has physical and mechanical properties that make it less desirable than older, slower grown wood for structural lumber because of large volumes of low specific gravity, juvenile wood (Bendtsen 1986, Bendtsen and Senft 1986, Bendtsen and others 1988, Biblis 1990, McAlister and Clark 1991, Pearson and Gilmore 1971). Wood and fiber properties that affect paper making include specific gravity, cellulose percent and other chemical constituents, fiber length, and microfibril angle (Erickson and Arima 1974, Megrow 1985, Schmidtling and Amburgey 1977, Zobel and Blair 1976). Paper from juvenile wood will have good tensile, burst, fold and sheet smoothness but lower tear and opacity than paper made from mature wood pulp (Zobel and Blair 1976). Higher specific gravity mature wood pulp will result in higher pulp yield and is generally associated with longer fibers with increased tear for linerboard and kraft sack papers.

The number of years a tree produces juvenile wood at a fixed height level (juvenile period) does not differ between slash and loblolly pine when the species are planted at the same location but does vary with geographic location (Clark and Saucier 1989). The length of the juvenile period of slash and loblolly pine in the Southeast decreases geographically from north to south. In loblolly and slash pine, the period of juvenile wood formation decreases from 10 to 14 years in the Piedmont to 6 to 8 years in the Gulf and Atlantic Coastal Plain. In a study by Cregg and others (1988), it was observed that the transition from earlywood to latewood occurred 1 month earlier in a year of low rainfall and high

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spring evaporate demand than in a year of low evaporate demand and high rainfall. Whether an early transition to latewood leads to an annual ring with a high percent of latewood, and thus high specific gravity, depends on the growing conditions that occur after the transition to latewood production. Based on Moehring and Ralston's (1967) work it appears the moisture supply and pan evaporation in the months of July, August, September, and October control the amount of latewood that is produced. The use of herbicides to reduce competing vegetation in a pine plantation will increase soil moisture and nutrients available for pine growth. Thus, competition controls could significantly influence the proportion of earlywood and latewood tracheids produced. Fertilization at stand establishment with no competition control will stimulate competition growth and thus could reduce soil moisture available for latewood growth.

The objective of this study was to determine the effect of increasing intensity of site preparation from no treatment, shear and chop with and without herbicide to shear, rootrake, burn, and disk with and without herbicide and fertilization on annual growth of earlywood, latewood, and wood specific gravity of loblolly pine in the lower Piedmont of Georgia.

PROCEDURES

The loblolly pine plantation sampled was hand planted with improved loblolly pine seedlings in early 1982 at a spacing of 6- by IO-ft (Edwards 1994). The original stand of loblolly pine and mixed hardwoods on the study tract was harvested in 1981. The 84-acre study tract is located in the lower Piedmont of Georgia, at the Hitchiti Experimental Forest and has an average site index of 80 at base age 50 years. Six site-preparation treatments were evaluated in the study and are listed in order of increasing intensity:

1) Clearcut only, control (CONT) - no site preparation and residual, non- merchantable trees retained.

2) Manual felling (FELL) - all residual trees greater than 1-in. d.b.h. were removed by chainsaw after harvest in August 1981.

3) Shear and chop (SC) - residual trees were sheared with a KG-blade mounted on a D7 tractor in September 1981 and downed residual was chopped with one pass of a single drum chopper in September and November 1981.

4) Shear, chop, and herbicide (SCH) - shear and chop as described in treatment 3 plus application of hexazinone herbicide (Velpar Gridball pellets of 0.5 cm^3) applied in 1.9- x 1.9-ft grid at a rate of 25 lb per acre in March 1992.

5) Shear, rootrake, burn, and disk (SRBD) - residual trees were sheared; rootstocks were raked into windrows and burned; remaining debris was scattered with a dozer blade; and plots were disked with an offset harrow to a depth of 6 to 8 in. in October 1981.

6) Shear, rootrake, burn, disk, herbicide, fertilize (SRBDHF) - site preparation was the same as described in treatment 5 plus the application of ammonium nitrate (34-O-O) fertilizer broadcast by hand at the rate of 300 lb per acre in March 1983 and the application of sulfometuron herbicide (Oust) at a rate of 8 oz per acre in April 1983, with backpack sprayers. Herbaceous weeds were essentially absent during most of the 1983 growing season.

The design of the site-preparation study was a randomized complete block with five blocks and six site-prep treatments randomly assigned to each block. Each treatment plot was 2 acres with a 0.2-acre internal measurement plot. The five blocks were located by topographic position to avoid site quality differences and to ensure reasonable uniformity within blocks. The impact of these site-preparation treatments on soils (Miller and Edwards 1985); size, abundance, and species diversity of competition (Harrington and Edwards 1996); and tree survival and growth (Edwards 1990, 1994) have been reported.

Two 0.472-in. increment cores were extracted at 4 ft above ground from seven trees for each treatment in each of five blocks for a total of 35 sample trees per treatment. Increment cores were taken from trees in the first buffer row next to the measurement plots. Mean d.b.h. of all trees on each measurement plot at age 15 was determined. Trees with d.b.h. within ± 1 in. of the average d.b.h. for the plot were selected for boring to make trees bored representative of the average tree on a plot. Table 1 shows the average d.b.h. and total height of the trees selected for boring by site-preparation treatment.

Increment core number 1 from each tree was dried at 50 °C, glued to a core holder, sanded and the radial growth of earlywood and latewood of each annual ring determined using image analysis. Increment core number 2 was used to determine whole core wood specific gravity based on green volume and oven dry weight.

An analysis of variance was conducted to test for significance by treatment differences in d.b.h., specific gravity, and percent latewood. Tukey's test was used to determine whether differences among means were significant at the 0.05 level. Data analysis was performed using Statistical Analysis Systems (SAS 1985).

RESULTS

The average cumulative wood basal-area growth plotted over year of formation for the trees sampled increased with increasing site-preparation treatment except for the SC compared to the SCH treatment (fig. 1). Thirty-five percent of the pine seedlings in the SCH treatment were killed in the first year because of rapid spread and up-take of the hexazinone herbicide as a result of heavy rain immediately following application. Mortality was replaced in the second year. Thus, about 33 percent of the pines in the SCH treatment are 1 year younger than those in the SC treatment. After the 1996 growing season the SC treatment had 127 percent, the SCH had 88 percent, the SRBD had 158 percent and the SRBDHF had 203 percent more basal area of wood per tree than the controls.

Average annual basal-area growth of earlywood plotted over year of formation increased with increasing site-preparation treatment except for the SC and SCH treatments (fig. 2). Average annual growth of earlywood increased from 1983 to 1989, peaked in 1989, and then decreased for all site-prep treatments.

Average annual latewood basal-area growth plotted over year of formation also increased with increasing site-prep treatment except of the SC and SCH treatments (fig. 3).

Table I-Average size characteristics for sample trees by site-preparation treatment

Treatment	Sample trees	D.b.h. Avg.	D.b.h. Range		Total height Avg.	Total height Range
	No.	Inch			Feet	
CONT	35	3.9	3.1–4.8		35	22–42
SC L	35	4.5	3.3-5.8		41	28-57
SCH	35	5.85.3	5.0–6.1	3.4-7.0	4238	30–48
SRBD	35	8.1	5.6-6.8		41	3249
SRBDHF	35	6.3	5.7-7.2		43	35-52

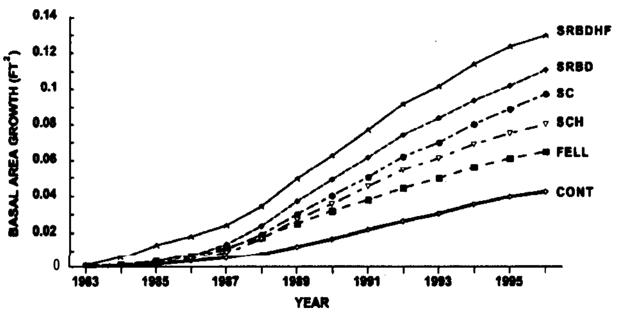

Figure l-Average cumulative wood basal-area growth over year of formation for 15-year Piedmont loblolly pine by site-preparation treatment.

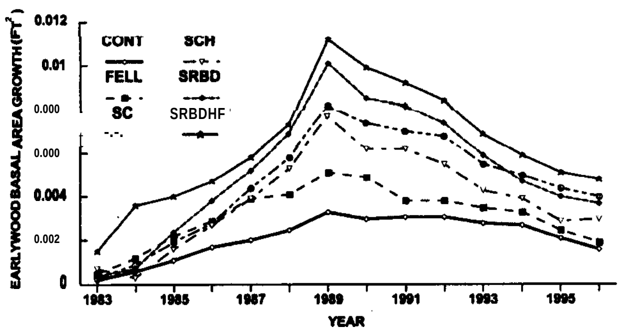

Figure 2-Effect of site-preparation treatment on **average** annual **earlywood** basal-area growth for Piedmont loblolly pine at age 15.

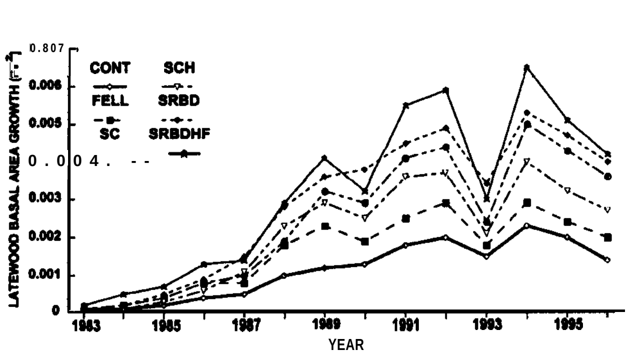

Figure 3-Effect of site-preparation treatment on average annual **latewood** basal-area growth for Piedmont loblolly pine at age 15.

The decrease in annual basal-area growth in 1990 and 1993 are the result of a mild summer drought in 1990 and **a** severe summer drought in 1993. The SRBDHF treatment showed the largest decrease in annual **latewood** growth in response to the summer drought. The decrease in annual **latewood** basal-area growth from 1994 to 1996 for all treatments is probably in response to overstocking.

Figure 4 shows the average proportion of annual ring in **latewood** plotted over rings from the pith for each **site-**preparation treatment. The plots show that for all treatments the trees were producing crown formed wood in rings 1-4, transition wood in rings 5-10, and mature wood by 11 rings from the pith. Thus, the length of juvenility was not significantly effected by site-preparation treatment and was 10 years for all treatments. The trees in SRBDHF treatment contained a slightly lower proportion of their annual ring in **latewood** for rings 5-9.

Although the length of juvenility was 10 years for all **site-**preparation treatments, the average diameter of the juvenile wood core increased significantly with increasing **site-**preparation treatment. The diameter of the juvenile wood averaged 2.2 in. in the CONT, 2.9 in. in the FELL, 3.4 in. in the SC, 3.2 in. in the SCH, 3.7 in. in the SRBD, and 4.1 in. in the SRBDHF trees. This increase in juvenile wood is caused by the increase in earlywood type growth that occurred with the increase in site-preparation treatment.

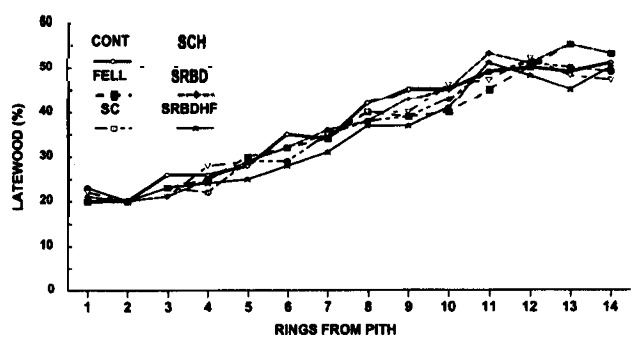

Figure 4-Average proportion of annual ring in **latewood** over rings from pith for M-year Piedmont loblolly pine by site **preparation-**treatment.

The site-preparation treatments examined resulted in increased averaged tree d.b.h. with increasing site-preparation treatment (table 2). The average d.b.h. of the trees on the CONT and FELL sites were significantly smaller that those on the SC, SCH, SRBD, and SRBDHF sites. The trees on the SRBDHF sites had the largest average diameter.

Core specific gravity increase from 0.43 to 0.44 for the FELL and CONT trees to 0.46 for the SCH and SRBD trees and then decreased to 0.44 for the SRBDHF trees (table 2). The decrease in specific gravity of the SRBDHF trees is probably related to the decrease in proportion of latewood for these trees in rings 5-9 (fig. 4). Average increment core specific gravity by treatment was significantly different at the P = 0.08 level. However, Tukey's test showed no significant difference at the P = 0.05 level.

Average proportion of latewood in an increment core did not vary significantly with treatment and averaged 35 to 36 percent (table 2).

Table 2—Average d.b.h., increment core specific gravity, and percent latewood for 15 year Piedmont loblolly pine by site-preparation treatment[a]

Treatment	D.b.h.	Specific gravity	Latewood
	Inches		*Percent*
CONT	3.9 a	0.44 a	35 a
FELL	4.5 ab	.43 a	35 a
SC	5.6 bc	.45 a	36 a
SCH	5.3 abc	.46 a	35 a
SRBD	6.1 c	.46 a	36 a
SRBDHF	6.3 c	.44 a	35 a

[a] Value with same letter not different at 0.05 level.

CONCLUSIONS

Site-preparation treatments consisting of shear and chop without and with herbicide; shear, rootrake, burn and disk without and with herbicide and fertilization 1 year after planting significantly increased wood basal-area growth compared to no site-preparation treatment of loblolly pine in the lower Georgia Piedmont. The average loblolly pine on the shear, rootrake, burn, disk, herbicide, and fertilize plots had 203 percent more wood basal area at age 15 than the tree on the no site-preparation plots. The six site-preparation treatments sampled did not affect length of juvenility, which averaged 10 years for all treatments. Average increment core specific gravity of the fast growing loblolly pine on the shear, rootrake, burn, disk, herbicide, and fertilize plots was not significantly reduced compared t120 that of the controls. However, the diameter of the juvenile wood increased with increased site-preparation treatment.

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SITE PREPARATION AND RELEASE AFFECT PLANTATION PRODUCTIVITY[1]

Charles A. Gresham[2]

Abstract-In two coastal South Carolina re-established loblolly pine (*Pinus taeda* L.) plantations, site preparation treatments that included rebedding produced stands with more bole volume per hectare than did site preparation treatments that did not rebed the site. Seedling release was effective following rebedding, and was much less effective following burning, disking, or herbicide site preparation. In one re-established plantation, the bole volume per hectare at age 10 years of plots receiving rebedding site preparation and seedling release was 94 percent of the bole volume of the previous stand at age 17 years. In the other stand, the bole volume per hectare at age 10 years of plots receiving rebedding site preparation and seedling release was 80 percent of the bole volume of the previous stand at age 20 years. This was considered evidence that there was not a decline in site productivity due to intensive forest management.

INTRODUCTION

Loblolly pine plantation management has become more intense in response to several forestry trends. Stewart (1995) clearly illustrates the dramatic decline in National Forest System annual timber sales from a maximum of almost 47 million cubic meters in 1969 to less than 12 million in 1994. Harvests since 1994 probably have not increased. The conversion of forestland to residential developments is commonplace and decreases the land base from which forest products can be cultivated. Finally, both the Endangered Species Act and the increasing adoption of ecosystem management principles have transferred forestland from solely timber production management to multiple use or endangered species management. The net result is a decrease in the landbase managed for timber production.

These trends have resulted in an increase in the management intensity that is manifest most clearly in plantation re-establishment operations. Intensive site preparation is used to create the best planting microsite and herbicide seedling release is used to minimize competition for site resources. Commonly recognized advantages of mechanical intensive site preparation include competition reduction, soil organic matter amendment, increased soil aeration, and microsite drainage. Benefits of chemical seedling release derive from the elimination of both woody and herbaceous competition, thus increasing available light, water, and nutrients. Also, any allelopathic retardation of seedling growth will be minimized.

Despite much site preparation (Lowery and Gjerstad 1991) and seedling release (Minogue and others 1991) research, few studies have compared combinations of site preparation methods and release methods in the same study. Also most of the site preparation results are for the first few years after treatment; few studies report long-term results that are of primary interest.

The purpose of this study was to determine the effects of five site preparation techniques and two levels of seedling release on loblolly pine plantation productivity at age 10. This was achieved by inventorying two coastal South Carolina installations of a randomized complete block experimental design.

SITES

Two site-prepared loblolly pine plantations located on forest industry land were selected for study. The Snow Mill stand is located in northern Georgetown County, South Carolina, in the lower Coastal Plain region. The soil is a poorly drained Bladen Loam; a clayey, mixed, thermic Typic Albaquult (Stuckey 1982). This stand was established by shear, rake, windrow and bed site preparation, and was phosphorus fertilized before planting with improved coastal loblolly pine. At age 17 years, the 25-year site index was 24 m. The Greeleyville stand is in southwestern Williamsburg County, South Carolina in the middle Coastal Plain region. The soil is a somewhat poorly drained Lynchburg fine sandy loam: a siliceous, thermic, Aeric, Paleaquult (Ward 1989). The previous plantation was intensively established and phosphorus fertilized prior to planting improved coastal loblolly pine. The 25-year site index at age 20 years was 20 m.

Treatment plots, 61 m square with 15 m buffers, were established in each stand and average height of codominants measured. Plots were then grouped into three blocks by similar average height. The stands were then clearcut harvested and burned. Three plots in the Snow Mill stand received each of the following site preparation techniques: burn only, herbicide residuals, rebed only, and shear, rake and bed. Likewise, three plots in the Greeleyville stand each received the following site preparation techniques: two-pass flat disk, herbicide residuals, rebed only, and shear, rake and bed. Each plot in both stands was split after planting improved coastal loblolly pine and one half received herbicide seedling release during the first growing season to keep 75 percent bare ground. The Snow Mill stand was clearcut and burned in June, 1986, site prepared in July 1987, and planted in December 1987. The Greeleyville stand was clearcut and burned in July 1987, site prepared in August 1987, and planted in December 1987.

PROCEDURES

Measurement plots (five adjacent beds by six planting locations) were established in each treatment plot half. The outer most trees of the measurement plot were considered buffer trees which left 12 non-buffer measurement trees. Ten growing seasons after planting, seven randomly selected trees in each plot half were selected for

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measurement. Ground line diameter, diameter at breast height, diameter at the base of the live crown, height to the base of the live crown, and total height were measured. The base of live crown was accessed with an extension ladder and total height was measured with sectional poles. Survival was determined from a tally of all 30 planting locations in the measurement plot. Bole volume was calculated as the sum of two truncated cones (ground line to DBH and DBH to base of live crown) and a cone (base of live crown to top). Analysis of variance was used to determine the significance of treatment and interaction effects.

RESULTS AND DISCUSSION

Stand Productivity

The Snow Mill stand with the higher preharvest site index remained the most productive over all site preparation and release treatments (table 1). The non-released shear, rake, and bed treatment is the sole exception. The most productive treatment produced 267 cubic meters per hectare at age 10 in the Snow Mill stand where as the same treatment in the Greelyville stand produced only 188 cubic meters per hectare.

Table I-Average bole volume per hectare (and one standard error) for each loblolly pine plantation by site preparation and release treatment at age 10 years, n = 3

Site preparation	Release treatment	Snow Mill	Greeleyville
		- - - - - m^3 *per hectare* - - - - - -	
Bum or disk	Control	101 (42)	64 (3)
	Released	144 (49)	57 (17)
Herbicide	Control	141 (8)	42 (3)
	Released	140 (29)	60 (14)
Rebed only	Control	154 (12)	128 (11)
	Released	267 (35)	188 (5)
Shear, rake, bed	Control	126 (12)	164 (6)
	Released	229 (50)	169 (34)

Statistical Significance of Main Effects and Interactions

The two stands responded differently to the site preparation and release treatments. In the Snow Mill stand, the site preparation main effect was significant only for survival at alpha=0.10 (table 2). The release main effect was significant only at alpha=0.10 except for survival. In contrast, the site preparation main effect was significant and the release effect was not (table 2) for the Greeleyville stand. The interaction effect was not significant in either stand for area-based variables.

Practical Results

Despite the general lack of statistical significance at alpha=0.05, site preparation and release treatments obviously affected stand productivity. In the Snow Mill stand, the site preparation treatments involving bedding resulted in greater productivity. Likewise, the seedling release treatment was far more effective following rebedding than following burn only or herbicide site preparation. The same trend was seen in the Greeleyville data.

In both stands, rebedding only site preparation followed by seedling release was the most productive treatment. Apparently both stands were wet enough to respond to bedding and, with this hindrance to growth removed, the seedlings were able to respond to release. The more intensive shear, rake, and bed site preparation treatment did not increase productivity more than rebedding only.

Site Productivity Decline

Will repeated rotations of intensively site prepared, clearcut harvested loblolly pine lead to a decrease in site productivity? This question is obviously of concern to land managers who might suffer productivity loss. It is also of interest to forest scientists who will have to devise a means separate all of the factors that contribute to stand productivity, so that only site quality can be measured.

Unpublished productivity data compared to the results of this study indicate that at 10 years into the second rotation, site productivity has actually increased. In the Snow Mill stand, the bole volume per hectare at age 10 years for plots receiving rebedding only site preparation with seedling release was 94 percent of the bole volume of the previous

Table P-Probability of a greater F for site preparation and release main effects and site preparation X release interaction effects for both loblolly pine plantations. Volume Is bole volume per hectare

	Snow Mill			Greeleyville		
Value	Site prep.	Release	Interaction	Site prep.	Release	Interaction
	- - - - - - - - - -	- - - - - - - - - -	- - *Probability*	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -
D.b.h.	0.534	0.053	0.050	0.019	0.368	0.242
Height	0.318	0.057	0.061	0.000	0.136	0.082
Survival	0.058	0.245	0.892	0.011	0.429	0.214
Volume	0.393	0.090	0.115	0.000	0.239	0.259

stand at age 17 years. That is, the same volume was produced seven years earlier in the second rotation. In the Greeleyville stand at age 10, rebedding only site preparation followed by seedling release produced 80 percent of the bole volume of the previous stand measured at age 20. These results do not support any concern about site productivity decline.

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THE EFFECTS OF HERBICIDES AND INDUCED COMPETITION ON KUDZU-DOMINATED PLANT COMMUNITIES AT THE SAVANNAH RIVER SITE, SOUTH CAROLINA'

Laura T. Rader and Timothy B. Harrington[2]

Abstract-Kudzu (*Pueraria lobata* Ohwi) is an exotic vine known to compete with and exclude neighboring vegetation, including mature trees. This experiment was designed to combine mechanisms of plant pest control to create a novel approach for controlling kudzu infestations. We used several herbicide treatments and fire to provide two full growing seasons of kudzu control and to allow other vegetation, including newly planted high-density stands of loblolly pine (*Pinus taeda* L.), the opportunity to capture the site. Crown cover, biomass, leaf area index, soil water, and photosynthetically active radiation (PAR) ware measured. Results from the first two years of the study appear promising for control of the species. Herbicide affects greatly reduced kudzu abundance, and reductions in resource availability, principally light, were detected in high-density pine stands. More time is needed to determine if induced competition from planted pines will limit the spread and recovery of kudzu.

INTRODUCTION

Kudzu is a unique pest problem. The difficulty in controlling kudzu infestations results from its characteristics as an exotic vine, which include an invasive growth strategy and tuberous root reserves. These characteristics have stimulated the expansion of kudzu infestations throughout the Southeast. It has displaced native flora as well as taken over forest **cutovers,** roadsides, hillslopes, and stream courses. Present complications in forestry involving kudzu are the killing of edge trees and the overtaking of artificially or naturally regenerated pine stands.

As an exotic species, kudzu's abilities as a weed are amplified. It is a perennial and has extensive belowground carbohydrate reserves that will enable it to leaf out early and rapidly in the spring. These belowground reserves are in the form of long twisted roots with tubers (Miller and Edwards 1983, Mooney and Gartner 1991). Kudzu roots can grow up to 2.5 m in length, 30 cm in diameter, and 182 kg in weight (Miller and Edwards). Stems can grow up to 0.3 meters a day in optimum conditions (Shurtleff & Aoyagi 1977) and about 30 meters in a season (Johnson 1997).

Wechsler (1977) described kudzu as being relatively intolerant of shade. Later, Tsugawa and others, (1985) as well as Fujita and others **(1993),** compiled more evidence for its lack of shade tolerance. Low shade photosynthesis values of 0.5 µmol CO, m^{-2} s^{-1} were found in kudzu plants growing under a forest canopy (50 percent shade) as compared to full sun, 7.8 µmol CO, m^{-2} s^{-1} (Carter and Teramura 1988). Considering its shade intolerance, kudzu would tend to be a less vigorous competitor in densely forested stands than at the forest edge. Where there are no structures present to grow on, kudzu has a crawling growth habit. When structures are present, crawling kudzu will develop a climbing habit (Tsugawa and others 1992). Edge trees act as vertical structures for kudzu to climb upon and escape from the vigorous interspecific competition present in openings or gaps. Once in the upper canopy of a tree, light availability is no longer limiting to its growth, and presumably it is able to increase its root reserves of carbohydrates.

Recent control measures for kudzu management include biological, chemical, and cultural methods. Several herbicides on the market today are labeled for kudzu control. Some are known to provide adequate first-year control (Edwards and Gonzales 1988, Michael 1988). Elimination of kudzu for one season may not eradicate it because root reserves may produce vines for an indefinite number of years. Another problem is that a few surviving kudzu plants can recolonize a site (Miller 1997).

Herbicidal control of kudzu can be costly in part because repeated applications are generally required to eradicate the species. Other factors to consider for herbicidal control are the dangers associated with ground application. The kudzu mat created in abandoned areas may shroud hazards such as old wells and farm equipment. Applicators with backpack sprayers are prone to injury from these dangers as well as from getting tangled in the mat of vine. Cultural control, such as mowing and grazing, have shown limited success. No method has provided 100 percent control of kudzu.

Integrating weed management strategies may increase effectiveness and decrease costs of kudzu control. Using these methods to create new conditions unfavorable to the target plant should be more effective. Combining methods may have a synergistic rather than simply an additive effect.

One aim of this experiment is to compare the effectiveness of several herbicides labeled for kudzu control. The second objective is to look at the effect of our treatments on non-target plants. Not only will the chemicals have an affect on the communities but also removing the kudzu canopy and thereby reducing competition is likely to foster more diversity and abundance of other plant species. Finally, the experiment was designed to determine the feasibility of combining two control agents to control kudzu: herbicides and ultra-high density plantings of loblolly pine.

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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METHODS AND MATERIALS

Study Area

Four research sites were located in the Upper Coastal Plain at the Savannah River Site near New Ellenton, South Carolina. Each had relatively uniform coverage of kudzu and was 0.4 to 0.8 ha in area. Soil series on the study sites include Troup (site B); Alley, Dothan, and Varina (site C); Fuquay (site F); and an unidentified fill soil (site P).

Treatments

The initial herbicide treatments were applied in July 1997. In December 1997, all study areas were broadcast burned in preparation for planting of pine seedlings. Genetically improved loblolly seedlings were planted in January 1998. A second spot application of the same herbicides was conducted in June 1998.

Herbicides-Clopyralid, triclopyr, metsulfuron methyl, a picloram + 2,4-D mixture, and tebuthiuron were the herbicides used in the experiment (table 1). Rates were 1.5 l ha", 7.2 l ha-‘, 0.3 l ha“, 14.0 l ha-‘, and 22.4 kg ha-’ of product, respectively. Of these chemicals, tebuthiuron was the only granular herbicide, and therefore it was soil applied with a fertilizer spreader. All other herbicides were applied with backpack sprayers using a total spray volume of 935 l ha^{-1}. Herbicide treatment was considered the main treatment plot in the split plot experimental design of the study. Each site (block) was evenly split into six plots to accommodate each herbicide treatment and an untreated check plot.

percent solution in water with 0.125 percent concentration of surfactant) were used to maintain a one-meter vegetation-free border around each main plot.

Vegetation Measurements

Cover-Measurements of percent cover by species were taken in three 1-m^2 quadrats per split plot. The measurements were taken in July 1997 (pretreatment), August 1997 (8 weeks after the first herbicide treatment), June 1998 (before the second herbicide application), and August 1998 (8 weeks after the second herbicide application). Cover measurements were taken in percentages and therefore an angular transformation was applied to normalize the data prior to statistical analysis.

Biomass-Biomass measurements were taken within 1-m^2 quadrats during July 1997 and August 1998. The 1997 samples included only kudzu samples and were taken from each plot since no herbicide treatments had yet been applied. Four species groups were sampled in 1998: kudzu, blackberry, herbaceous vegetation, and pine. The samples were taken from all main plots (herbicide and untreated check plots). In each main plot the 0 m^{-2} and 4 m^{-2} pine seedling density split plots were sampled. The pine biomass samples were taken from a border row in each of the 4 m^{-2} split plots in the border row. All samples were clipped in the field, bagged in plastic bags, transferred to paper bags in the lab, dried in an oven at 70°C, and weighed (nearest 0.1 g). Biomass and cover were found to be closely correlated.

Table l-Herbicides and application rates used in the study to control kudzu development; all liquid herbicides were mixed with 0.25 percent sutfactant in 935 l ha^{-1} (100 gal acre-‘)

Common name	Trade name	Rate (metric)	Rate (US)
Clopyralid	Translinee	1.5 l ha^{-1}	21 oz $acre^{-1}$
Triclopyr	Garlon 4®	7.2 l ha"	3.1 qt $acre^{-1}$
Metsulfuron methyl	Escort®	.29 l ha“	4 oz $acre^{-1}$
Picloram +2,4 D	Tordon 101-M®	14.0 l ha-’	6 qt acre-’
Tebuthiuron	Spike@	22.4 kg ha"	20 lbs acre-’

For the June 1998 herbicide treatments, clopyralid herbicide was the only one that was broadcast applied because of its high degree of safety when applied over newly planted pines and the large amount of kudzu recovery.

Loblolly pine stands-High-density loblolly pine stands were planted to induce competition and potentially exclude recovering kudzu. Within each main plot, three split plots were established. The split plots included pine seedling densities of 0 m^{-2} (no pine), 1 m^{-2}, and 4 m^{-2}. Each stand contained 100 trees. Measurement trees were designated as the inner 36 trees within each stand; the outer two rows were designated as buffer trees.

Maintenance of main plot buffers was needed to keep kudzu vines of adjoining plots from growing into each other. A brush cutter and monthly applications of paraquat (2.5

Biomass values for August 1997 and June 1998 were predicted from the cover measurements using regression equations developed for each species groups.

Leaf area-Leaf area samples of kudzu were taken with the biomass samples in July 1997. Twenty random leaves were sampled from each 1-m^2 area. In August 1998, leaf area samples were taken only from the untreated check because very little kudzu remained for sampling in the herbicide treatments. Six total leaf area samples were taken, two from each of the 0, 1, 4 m^{-2} pine seedling density split plots. After leaf area was determined for each sample with an AgVision video image analysis system (Decagon Devices, Inc, Pullman, WA), the samples were dried in an oven and weighed (nearest 0.01 g). Leaf area index (LAI), a measure of the amount of leaf area per unit of ground cover, was found to be closely correlated to cover and biomass.

Predictions of kudzu LAI were obtained from regressions with cover and biomass.

Soil water measurement- Soil water content (volumetric percentage at O-45 cm in depth) was measured monthly from April to October 1998 by TRASE Time Domain Reflectometry (TDR) (SoilMoisture Equipment Corporation, Goleta, CA).

Light-Photosynthetically active radiation (PAR) and sunfleck gaps were measured by a Sunfleck Ceptometer (Decagon Devices, Pullman, WA). Measurements were taken in August 1998 on two consecutive, clear days between 1100 and 1400 hours. Readings were taken above the canopy and on the ground to quantify how much light was reaching the soil surface.

Pine performance-Ground line diameter (mm) and height measurements (cm) of loblolly pine seedlings were taken in January 1998, immediately after planting. Each of the 36 inner trees in each 100 tree split plot was measured. The seedlings were measured again, one year later, in January 1999.

Statistical Analysis
The experimental design is a randomized complete block design with a split-plot arrangement of treatments. Each site was considered a block. Herbicide treatments were main plots and the pine stands were split plots. The soil water measurements were analyzed with a repeated measures design. All statistics were analyzed by SAS (1989).

RESULTS AND DISCUSSION

Cover, Biomass, and LAI

Kudzu abundance was uniform in June 1997 with an average cover of 70-80 percent. Eight weeks after initial treatment all herbicides showed some effect on kudzu and associated vegetation. Kudzu cover, biomass, and LAI dropped in the clopyralid, triclopyr, metsulfuron methyl, and picloram plots to levels approaching total control. Tebuthiuron plots showed marginal reduction and some chlorosis but little difference from the untreated check. The LAI in tebuthiuron plots did decrease in August 1997 but not as much as the other herbicide treatments. LAI increased in the untreated check plots from June to August 1997.

Different herbicide selectivity could favor different plant communities, which may affect resource uptake and therefore the competitive ability of the community. These different communities were predicted to flourish after being released from the kudzu overstory. However, in August 1997, the mat of dead kudzu stems and old leaves covered the surface of the soil and did not allow for light to germinate any residual seed bank. Once the kudzu canopy was killed most of what remained for the duration of the growing season in 1997 was dead kudzu.

The only response of other vegetation observed in August 1997 to the chemical treatments was an increase in blackberry abundance in the clopyralid treatment. On at least two of the sites, heavy blackberry was present in the understory. Blackberry was one of the few species that could coexist with the kudzu as a suppressed species. Picloram, metsulfuron methyl, and triclopyr controlled the blackberry understory. Clopyralid was not effective on blackberry and therefore the species' abundance jumped 36 percent. Taking off the dominating kudzu overstory released the blackberry in these plots.

Kudzu control was of limited extent in the tebuthiuron treatment. Because this herbicide was soil applied, it was absorbed by target vegetation at a much slower rate than the foliar-applied herbicides.

In June 1998, the untreated check essentially recovered in kudzu abundance from the fire. However, LAI did not. LAI in the untreated check was significantly less than the year before and LAI in herbicide treated plots were much less. The clopyralid plot had a recovery of blackberry and more kudzu recovery than did the triclopyr, metsulfuron methyl, and picloram plots. Tebuthiuron plots were almost completely denuded and as the growing season continued, the vegetation of these plots did not recover.

In August 1998, heavy herbaceous cover from species such as ragweed (*Ambrosia artemisiifolia* L.) and pigweed (*Amaranthus palmeri* Watson) occupied the site. However, all herbicide treatments were successful in holding kudzu sprouting to minimal levels.

Kudzu LAI in the untreated check did not recover to levels observed at study initiation. The fire burned most of the site debris, including live, overwintering kudzu stems. As the kudzu sprouted from rooted crowns, reserve energy was expended on stem as well as leaf growth. Kudzu has a high growth rate but in starting from the ground up, had to leaf out along the way. However, kudzu cover was at levels equivalent before the fire. The kudzu used the heavy forb structure the same way it had used blackberry the year before. It twined around and grew up to the higher light level.

Soil Water and Light

There was no difference in available soil water in any of the herbicide treatments as well as the pine densities. However, there was a difference in PAR reaching the ground. The pine seedling density treatments were significantly different from each other. The more dense pine stands had significantly more shade than the less dense and even more so in the areas absent of pine. Even though there was no effect of pine seedling density on kudzu or associated plants, there was an effect on the light availability at ground surface.

There were main plot effects on PAR as well. PAR was lowest in the untreated check, while picloram plots were not significantly different from the untreated check. The clopyralid, triclopyr, and metsulfuron methyl plots had significantly greater PAR than the untreated check but they did not differ from the picloram treatment, with values from 35 to 70 percent of full sunlight reaching ground level. Tebuthiuron had the highest value of PAR because there was very little vegetation present to block the sun. In addition, the exposure of the bare soil resulted in erosion in some of the tebuthiuron treatment plots.

Pine Performance
The high level of shade from kudzu in the untreated check apparently caused a low degree of survival (40 percent) of loblolly seedlings. The lowest survival rate was in the tebuthiuron plots (20 percent). This chemical is known to be toxic to pine seedlings and to have a prolonged half-life. It is expected that little vegetation will regenerate in this treatment during the next two years. All other chemical treatments had survival levels from 80 to 90 percent.

CONCLUSIONS

The herbicide treatments strongly affected the abundance of kudzu and associated vegetation. These treatments also affected PAR reaching the soil surface and pine survival. However, herbicide treatments did not affect soil water content. The pine stands limited light availability at the soil surface but they had no detectable effect on kudzu abundance.

Of the chemicals used, it appears that metsulfuron methyl would be the best herbicide to use for control of kudzu and establishment of pine seedlings. It is safe when applied over pines and therefore, repeated applications of herbicide could be used to foster the development of a densely stocked pine plantation that, perhaps, will minimize the horizontal and vertical development of kudzu.

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Artificial Regeneration of Pines

Moderator:

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PREVENTION OF COLD DAMAGE TO CONTAINER-GROWN LONGLEAF PINE ROOTS[1]

Richard W. Tinus, Mary A. Sword, and James P. Barnett[2]

Abstract-When longleaf pine (Pinus palustris Mill.) seedlings are container-grown in open fields, their roots may be exposed to damagingly cold temperatures. Major losses in some nurseries have occurred. We determined the cold hardiness of container-grown longleaf pine roots by measuring electrolyte leakage (a) of greenhouse-grown and growth-chamber hardened seedlings representing minimum and maximum cold hardiness, respectively, and (b) of seedlings that were outdoor grown between November 1996 and February 1997. Minimum tolerable root temperature was 25 °F, which varied little with season; a few degrees lower was lethal. Weather records at the W.W. Ashe Nursery near Brooklyn, MS, showed that damaging temperatures occurred on 7 nights per year, on average. Covering the seedlings with black plastic overnight held rootball temperatures 10 to 12 °F above ambient air temperature and saved the crop twice in December 1996. However, the best management strategy is to outplant seedlings before the onset of damagingly cold temperatures. We demonstrated that once outplanted the seedlings are safe.

INTRODUCTION

Within the last century, longleaf pine (Pinus palustris Mill.) forests of the southern United States have been reduced from 92 million to less than 5 million acres (Landers and others 1995). During this period, efforts to reestablish the species were unsuccessful (Landers and others 1995, Outcalt 1997) and, typically, the forest was converted to loblolly pine (Pinus taeda L.) or slash pine (Pinus elliottii Englm. var. elliottii) (Barnett and Dennington 1992, Landers and others 1995).

Recent research has defined desirable longleaf pine seedling characteristics and helped nursery managers develop good cultural growing schedules (Barnett and McGilvray 1997, Barnett and others 1990). This has led to consistent establishment of container-grown longleaf pine throughout the South (Landers and others 1995, McRae and Starkey 1996). As a result, production and planting of container-grown longleaf pine has increased 12-fold in the last decade (McRae and Starkey 1996). Although cultural improvements have made large-scale production and planting of container-grown longleaf a reality, there are still problems. Unlike poor survival rates in bare-root plantings, failure of container-grown longleaf pine plantings is generally not a result of poor seedling quality. Longleaf pine is commonly container-grown in the open, with the container trays elevated for air pruning. This practice exposes root systems to ambient air temperatures, which in winter can be cold enough to damage them, a situation that seedlings growing in the ground do not encounter. Exposure to one or more nights of very cold weather during over-wintering has been associated with failed establishment of container seedlings that appeared healthy when planted.

We need to know the minimum temperature tolerated by longleaf pine roots and how to protect them from damaging cold. In northern climates, the whole-plant freeze test and the freeze-induced electrolyte leakage test (FIEL) were developed to determine patterns of cold acclimation and deacclimation of nursery seedlings (Rietveld and Tinus 1967, Burr and others 1990). Such tests allow accurate prediction of optimum lifting and planting windows (Tinus 1996). In this study, we adopted the FIEL test because it gives precise results within 3 days, whereas the whole-plant freeze test takes 7 to 14 days (Burr and others 1990). Our objectives were to: (1) determine the seasonal pattern of cold hardiness of longleaf pine roots, (2) determine the minimum tolerable temperature of longleaf pine roots during their period of greatest risk (December through February), and (3) develop recommendations to reduce the risk of low-temperature damage.

MATERIALS AND METHODS

We sampled longleaf pine seedlings from the 1996 crop of container-grown seedlings produced at the USDA Forest Service W.W. Ashe Nursery in Brooklyn, MS. In late March 1996, seed from a 1992 bulk collection from a MS orchard was sown in Multipot 4/96 containers in a 1 :1 peat-vermiculite medium and grown using standard operational practices (Barnett and McGilvray 1997). The field crop was grown and hardened under full sunlight and remained outside in containers until the seedlings were pulled and packed for immediate transport to outplanting locations.

Before packing, 20 trays of seedlings were randomly identified and permanently marked. Every 2 weeks on seven dates from December 1996 through February 1997, we randomly removed 30 seedlings from the marked trays, and packaged and shipped them by overnight mail to the USDA Forest Service, Southern Research Station laboratory in Pineville, LA. Cold hardiness of the seedling root systems was evaluated by FIEL, modified from Burr and others (1990), to accommodate root segments.

On the morning after receipt, we washed the growing medium from the roots, removed the primary lateral roots from the taproot, and excised the upper one third of the taproot. Root segments were immersed in distilled water until all seedlings were processed. A 12-mm section excised

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from the upper portion of each taproot was placed in a capped test tube containing 2 g washed sand and 1 ml distilled water. Five test tubes were refrigerated at 1 °C as unfrozen controls, and five subsets of five test tubes were grouped into glass beakers. Copper-constantan thermocouples were submersed in two tubes per set and wired to a data-acquisition unit. The beakers of tubes were placed in a Styrofoam chest in the bottom of an upright freezer. Solution temperatures were recorded at IO-minute intervals. We regulated the speed of freezing by adjusting the lid of the chest and freezer door, so that solution temperatures did not decrease faster than 0.8 °C per 10 minutes. When the water had cooled to -2 to -3 °C, the tubes were shaken to induce freezing. Cooling continued, and a subset (a beaker of tubes) was removed at benchmark temperatures of approximately -3.0, -4.5, -8.0, -7.5, and -9.0 °C. The beakers were placed in a refrigerator and allowed to thaw. Five ml of dionized water was added to each tube, and the tubes were agitated on a horizontal shaker for 24 hours. The two thermocouple readings per subset at the time of removal from the freezer were averaged and considered to represent all five tubes in the subset.

After 24 hours, electrical conductivity (EC) of each sample solution was measured. The tubes were placed in boiling water for 20 minutes, placed back on the shaker, and the EC measurements were taken again 24 hours later. Using the two measurements before and after boiling, we calculated an index of injury attributable to freezing (Flint and others 1987). Indices of injury as a function of minimum temperature were fit to both linear and Weibull sigmoid models. From the modeled data, temperatures and their 95 percent confidence interval were calculated, representing the 10, 30, and 50 percent indices of injury (110, 130, 150). Choice of the model to describe the results depended on the degree of sigmoid shape to the data, and which model gave the smallest confidence interval. Our experience with other species has been that leakage less than II 0 represents temperatures from which the crop will recover without significant damage or mortality. At I30 level the seedlings are too badly damaged to use, and at the 150 level are completely dead. Differences among I10, 130, and I50 values at the seven sampling dates were considered significant if the 95 percent confidence intervals did not overlap (Jones 1984).

Meanwhile, a sample of the same longleaf pine seed lot was grown in 400-cc containers in a greenhouse at Flagstaff, AZ, from mid-April to mid-October 1998. Cultural treatments were standard (Tinus and McDonald 1979) with day temperatures between 20 and 27 °C, the night temperatures were about 15 °C, and seedlings were exposed to a 24-hour photoperiod. On October 15, 1996, some of the seedlings were moved into a growth chamber with an 8-hour photoperiod with day temperature of 5 °C and night temperature of +1 °C. The rest of the seedlings remained in the greenhouse at the same warm temperatures and on the same 24-hour day.

On January 21, 1997, we tested samples of both groups of seedlings for cold hardiness by FIEL. Our experience with other species has shown that 3 months under these growth chamber conditions is more than adequate for seedlings to reach their maximum cold hardiness. We therefore expected that the greenhouse seedlings were at minimum cold hardiness, while those in the growth chamber were at maximum cold hardiness.

RESULTS

Between December 1, 1996, and February 26, 1997, I10 values of the field-grown seedlings averaged -3.0 °C and were not significantly different (fig. 1). Between December 1, 1996, and January 15, 1997, I30 values averaged -5.6 °C and were not significantly different. However, the I30 on February 26 was significantly higher than on December 1, and January 15 and 29. Similarly, I50 values in December and on January 15 averaged -8.1 °C and were not significantly different. As winter progressed, however, I50 values on January 29, and February 12 and 26, were significantly higher than on December 1.

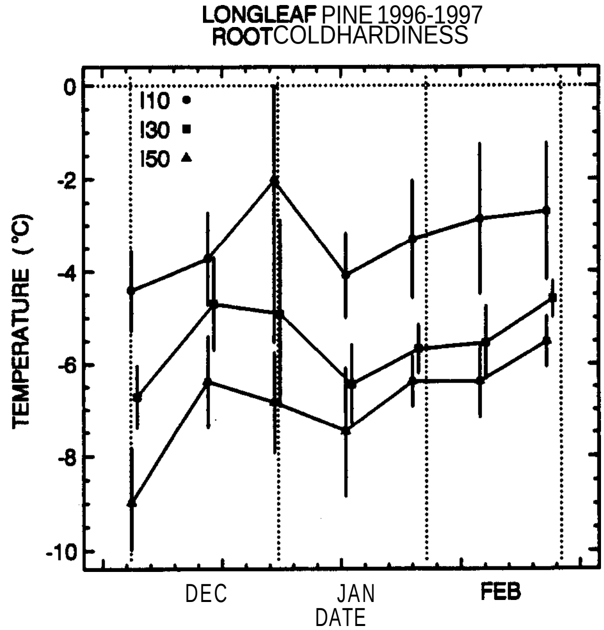

Figure I-Root cold hardiness, as measured by index of injury, of container-grown longleaf pine seedlings from the W.W. Ashe Nursery, Brooklyn, MS, December 1996-February 1997. Error bars are the 95 percent confidence interval.

Compared to the roots of longleaf pine seedlings growing in the greenhouse, the roots of those in the growth chamber had hardened very little (table 1). Only the I50 values were significantly different. There were no significant differences between succulent and fully hardy roots at the II 0 or I30 levels.

DISCUSSION

Temperatures that cause a IO-percent index of injury by the FIEL test represent the lowest temperatures that seedlings can experience without significant damage. Our results show that container-grown longleaf pine roots cannot withstand temperatures below -3.0 °C (26 °F), and there is negligible difference between the most hardy and least hardy as the seasons change. Further, there is little difference between temperatures longleaf pine roots can tolerate and what would damage them enough that they would perform poorly in the field. Potentially damaging low temperatures occurred on 11 days at the Ashe Nursery in the winter of 1996-97 (fig. 2). The clear management implication is that when damagingly low temperatures are forecast, exposed seedlings must be protected.

Table I-Cold hardiness of iongieaf pine roots from a warm greenhouse and after hardening in a growth chamber. Values with the same letter are not significantly different at p = 0.05. Lower case is for columns, upper case for rows

index of injury	Corresponding temperatures: Succulent	Corresponding temperatures: Fully hardy	Expected damage
Percent			
10	*-3.3* °C aA	-3.9 °C aA	Not significant Will recover
30	*-3.9* °C aA	*-5.6* °C aA	Heavy damage Not shippable
50	-4.4 °C aA	*-7.6* °C bB	Dead

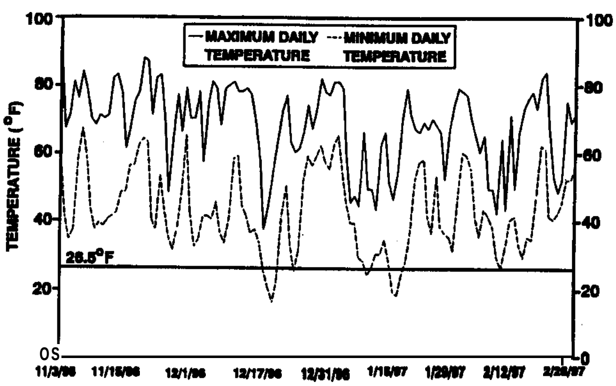

Figure 2-Daily maximum and minimum temperatures at the W.W. Ashe Nursery, Brooklyn, MS, November 1996-February 1997. Horizontal line at 26.5 °F is the threshold for root damage, and shows that seedlings would have needed protection on two occasions that winter.

At the Ashe Nursery in March 1996, we covered exposed seedlings with black polyethylene, which resulted in rootball temperatures 6 to 7 °C warmer than the ambient outside air temperature on a below-freezing night. This technique saved the crop twice in December 1996 and has done so several times since, most recently on January 3 through 5, 1999. This time, with minimum overnight air temperature of about -11 °C, the rootbails of covered container seedlings did not freeze.

Although covering exposed seedlings is a workable solution, it is not the best. It has worked in situations where temperatures have been potentially damaging, but not so low or of long enough duration to cool rootballs low enough to damage roots. There may indeed be occasions when simply covering seedlings is not enough. Furthermore, covering several hectares of container seedlings on short notice and then having to remove the cover is an expensive and difficult chore.

A far better solution is for the customers to receive and outplant the seedlings earlier, before there is a risk of damagingly cold temperatures. As a major cold front approached in December, 1996, Ashe Nursery personnel retrieved from the local ranger district a sample of container-grown longleaf pine that had recently been outplanted. They retrieved a second sample after the front had passed. Temperatures had indeed been cold enough to damage roots of exposed container seedlings. We ran the FIEL test using the first set of seedlings as the unfrozen control. There was no significant difference between the two groups, which meant that once outplanted, seedling roots were protected from damaging temperatures by the soil in which they were planted.

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EFFECT OF LIFTING METHOD ON FIRST-YEAR GROWTH OF LOBLOLLY PINE SEEDLINGS[1]

Thomas A. Greene and S. Tannis Danley[2]

Abstract-Replicated trials of loblolly pine (*Pinus taeda* L.) seedlings either hand- or machine-lifted from two Georgia nurseries were planted on six sites in Georgia and Alabama during winter 1997/98. Survival, height and ground-line diameter increments were measured. Hand-lifted seedlings from both nurseries outgrew machine-lifted seedlings on all sites, and survival of hand-lifted seedlings was significantly better for one nursery. Variability in first flush height growth was greater in all of the machine lifted lots compared to hand lifted lots of the same seedlings. A second, smaller experiment was conducted to compare growl .th of hand-lifted seedlings, machine-lifted seedlings, and hand-lifted seedlings with either root or stem damage artificially inflicted to simulate machine lifting. After one growing season, height increments of the machine-lifted trees and of the two sets of artificially damaged trees were not significantly different from each other, but all were significantly lower than that of undamaged hand-lifted seedlings.

INTRODUCTION

Seedling quality is receiving an increased amount of attention from industrial researchers as silvicultural regimes are intensified and as high-quality genetic material becomes available. Seedlings which survive but make only a small height growth increment the first year are no longer acceptable in a pulpwood system where the first year may represent up to 8 percent of a rotation. Industrial forest managers are demanding seedlings which respond to weed control, fertilization, and tillage by reaching heights of up to 1 m during the first season after planting.

Seedling variables such as size, root system configuration, root/shoot ratio, and handling and storage methods are known to affect survival and growth. For example, South and others (1995) estimated that increasing loblolly pine seedling root collar diameter (RCD) by 1 mm would yield an additional 4 to 6 percent in volume after 12 years. Switzer and Nelson (1963) found a positive relationship between field performance of loblolly pine seedlings and both size and foliar nitrogen content of seedlings. Lifting method, particularly the amount of damage sustained by the root system during the process, has been related to seedling performance. South and Stumpff (1990) found that manual root stripping reduced root growth potential of hand-lifted loblolly pine seedlings by 50 percent or more. Barnard and others (1980) reported that slash pine (P. *elliottii*) seedlings lifted by hand survived better than machine-lifted seedlings and attributed the difference to root damage associated with the mechanical lifting process.

We have observed variations in performance of hand-lifted and machine-lifted loblolly pine seedlings under operational conditions, and wanted to identify seedling quality variables under our control which would explain the differences in growth and survival after planting. We designed two experiments to address the following objectives:

1) Compare survival and first-year growth of seedlings lifted either by hand or with a belt lifter;
2) Compare survival and first-year growth of seedlings lifted from the outer two drills of the nursery bed and from the inside 6 drills;
3) Identify specific types of lifting-related injury which may be contributing to any observed performance differences.

METHODS AND MATERIALS

Experiment 1

Loblolly pine seedlings from two Georgia nurseries, one in Marion County and one in Randolph County, were selected for the study. Seedlings for five of the plantings were grown from 1 .5-generation, orchard-mix seed of Atlantic Coastal Plain provenance. Seedlings at the remaining site were of a single, half-sib family of Atlantic Coastal Plain provenance. Seedlings were lifted by machine or by hand on five dates during the 1997-98 planting season and planted by contractors on six sites in Georgia and Alabama. The Marion County nursery used a Mathis P-row belt lifter, and the Randolph County nursery used a Love 8-row belt lifter. Seedlings were stored in a seedling cooler less than 48 h after lifting in all but one case in which the seedlings were stored for 4 days. At the Marion County nursery, we separated seedlings grown in the outer two drills (one and eight) from those grown in the inner six drills. This was not possible at the Randolph County nursery because of the lifter configuration. Treatments were:

1) Marion County Hand-lift Inside drill
2) Marion County Hand-lift Outside drill
3) Marion County Machine-lift Inside drill
4) Marion County Machine-lift Outside drill
5) Randolph County Hand-lift
6) Randolph County Machine-lift.

Planting was done the same day as the rest of the tract on which the plots were located, and planters were instructed to plant the experimental trees the same way they were planting the adjacent operational trees. Because of operational constraints, seedlings from the Randolph County nursery were not included in the last site planted, and seedlings from the Marion County nursery were not represented at the first site planted. Therefore, each nursery was represented on five sites, and both were planted together on four of the sites. All sites received an application of Velpar + Oust herbicide for herbaceous weed control in late spring. Site information is presented in Table 1.

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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Table 1—Site and planting conditions at six experimental plantings of hand- and machine-lifted loblolly pine seedlings planted in 1997-98

County/state	Region	Soil A/B	Site prep.	Treatments	Plant date	Seed source
Talbot GA	Piedmont	SL(4cm)/ CL	Pied. plow	All	12111/97	Mix
Meriwether GA	Piedmont	SL(10cm)/ CL	Pied. plow	All	1/7/98	Mix
Lee AL	Piedmont	SL(10cm)/ CL	Pied. plow	All	1/7/98	Mix
Stewart GA	Coastal Plain	SL(75cm)/ CL	Pied. plow	All	Ill4198	Mix
Barbour AL	Coastal Plain	SL(4cm)/ C	Upland bed	Randolph only	12/3/97	Half-sib. family
Stewart GA	Coastal Plain	SL(10cm)/ C	Upland bed	Marion only	2/25/98	Mix

Planted height of each seedling was measured shortly after planting, and total height and survival were measured in mid-May, early July, and mid-August. Height, survival, and ground-line diameter (GLD) were measured in November. We calculated a volume index from the end-of-season height and GLD measurements. Growth flushes were measured separately; the third and subsequent flushes were combined for analysis. Some mortality was associated with operational weed control on the planting sites. Therefore, only the May survival data, before herbicide damage appeared, will be presented. All herbicide-damaged seedlings were excluded from analyses.

The study was designed as a series of randomized complete blocks, with three blocks at each planting site. Each treatment was represented in each block by 50 seedlings, except on one site, where plots had 30 seedlings. Data were subjected to analysis of variance; seedlings from each nursery were analyzed separately. A sample ANOVA model is presented in Table 2. The Site*Treatment term was used as the experimental error term. Least-squares means were calculated and compared within nursery by Duncan's Multiple Range test. Nursery means were not directly comparable because not all sites had seedlings from both nurseries.

Table 2-Analysis of variance model used to test height and volume increments of seedlings lifted mechanically or by hand from each of two Georgia nurseries and planted on five sites in Georgia and Alabama

Source of variation	DF (Randolph)	DF (Marion)
Site	4	4
Rep (site)	10	10
Treatment	1	3
Site*treatment	4	12
Treatment*block (site)	10	30
Error	1177	2234

Experiment 2

Mechanically lifted seedlings exhibit two general types of damage related to the lifting process. First, the area of the stem where the lifter belts grip the seedling can be bruised, crushed, or skinned. Needle stripping is also common in this area. Second, machine-lifted seedlings have many fewer fine roots than do hand-lifted seedlings, because they are pulled from the ground individually and with greater force. Hand-lifted seedlings are pulled in bunches of 25-50 seedlings, and a large clump of soil usually clings to the roots until it is shaken off. This process results in many more intact fine roots. We conducted a second experiment to test the hypothesis that two types of artificially inflicted damage would have similar effects on growth to those observed in machine-lifted seedlings.

We applied the following four treatments to seedlings from the same bed at the Marion County nursery:

1) lift seedlings by machine (Mathis two-row belt lifter,)
2) operationally lift seedlings by hand,
3) operationally lift by hand + lay seedlings on the floor of the packing shed and step on the lower part of the stem, and
4) individually pluck from the bed by hand (to simulate the root loss, but not the stem damage associated with belt lifting).

We took care not to let the seedlings dry out while we abused them.

Seedlings were sprayed with starch gel and wrapped in kraft paper bundles. All seedlings were stored in plastic buckets with lids, but unsealed, for 23 days at 4 °C. (These seedlings were part of a larger experiment in which ethylene was monitored during the storage.)

At the end of the storage period, 30 seedlings from each treatment were planted in a randomized complete block design with three blocks. We collected the same data from these seedlings as in Experiment 1. Weeds were controlled with herbicides throughout the growing season. Data were analyzed as a randomized complete block, with Treatment*Block used as the experimental error term. Means were separated by Duncan's Multiple Range test.

RESULTS

Experiment 1

Significance levels for the Treatment term are presented in Table 3. Significant height growth differences occurred among treatments in seedlings from both nurseries, while volume and survival differences were significant at the 5 percent level only at the Marion County nursery. Height increment means are presented in Figure 1. Hand-lifted seedlings from both nurseries and from both bed positions outgrew machine-lifted seedlings by 4-5 cm. Seedlings from outside drills outgrew those from inside drills, within a lifting method. Volume means generally followed the same pattern, but the difference between hand- and machine-lifted seedlings from the Randolph County nursery was significant only at $p=0.12$ (fig. 2, table 2). Mid-May survival means ranged between 93 and 99 percent; survival of machine-lifted seedlings from the Marion County nursery was significantly lower than that of hand-lifted seedlings (fig. 3). No survival differences were detected in the Randolph County seedlings.

Table 3—Significance levels for the treatment term in ANOVA models for height increment, volume increment, and survival of seedlings lifted mechanically or by hand from each of two Georgia nurseries and planted on five sites in Georgia and Alabama

Nursery	Variable	Pr > F
Randolph Co., GA	Height increment	0.037
Randolph Co., GA	Volume increment	.117
Randolph Co., GA	Survival	.514
Marion Co., GA	Height increment	.014
Marion Co., GA	Volume increment	.001
Marion Co., GA	Survival	.004

During measurements of the first flush growth in mid-May, we noticed that some of the machine-lifted seedlings had failed to initiate height growth, and that the growth increments seemed generally more variable than those of hand-lifted seedlings. An examination of coefficients of variation across sites for the six nursery and treatment combinations confirmed that hand-lifted seedlings had less variable flush lengths (fig. 4). We hypothesize that varying levels of lifter-induced damage caused the observed differences.

Experiment 2

Height increment means from experiment 2 are presented in Figure 5. Gently treated, hand-lifted seedlings grew approximately 40 cm, while height increments of machine-lifted seedlings and experimentally damaged, hand-lifted seedlings were between 26 and 29 cm. Gently treated seedlings significantly outgrew those in the other three treatments, but mechanically lifted seedlings and experimentally damaged seedlings did not differ in height growth.

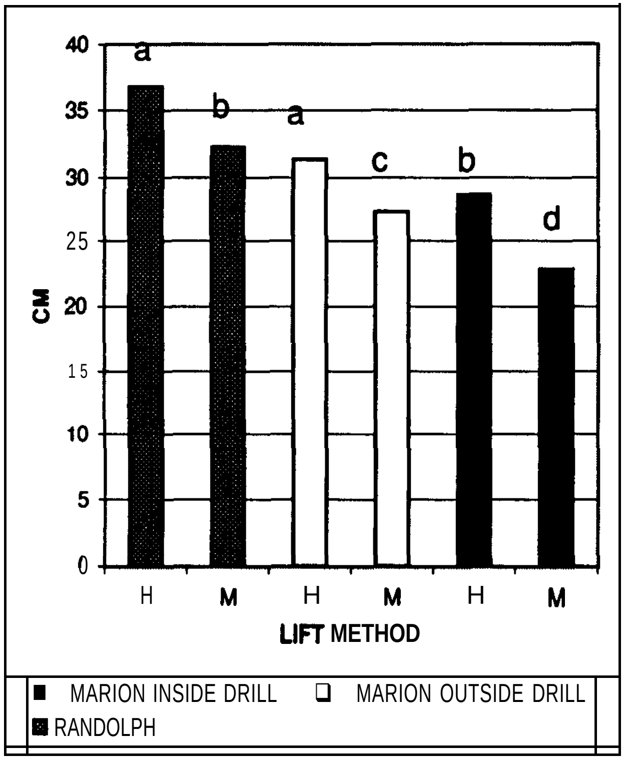

Figure I-Mean first-year height increment of seedlings lifted mechanically or by hand from each of two Georgia nurseries and planted on five sites in Georgia and Alabama. Means labeled with the same letter and representing seedlings from the same nursery were not significantly different according to Duncan's Multiple Range test, $p=0.05$.

DISCUSSION

Mechanical lifting of seedlings is a common practice in southern pine seedling nurseries. It allows nursery managers more flexibility and speed during the lifting season and reduces labor costs. However, it is apparent from these data that mechanical lifting with belt lifters reduces seedling quality. Seedlings lifted by hand consistently outgrew those lifted by machine in our study, and results from the second experiment suggest that specific types of lifter damage are the cause of observed growth losses.

The differences detected between inside and outside-drill seedlings from the Marion County nursery indicate that larger seedlings outperform smaller seedlings when other variables are constant. We did not measure pre-planting root collar diameters in this study, but operational outside-drill seedlings from the same nursery and year averaged about 1.5 mm larger in RCD than inside drill seedlings. This result is consistent with those reported by numerous other researchers (e.g. South and others 1995). In an operational context, additional growth and survival from larger seedlings must be balanced against costs associated with their production.

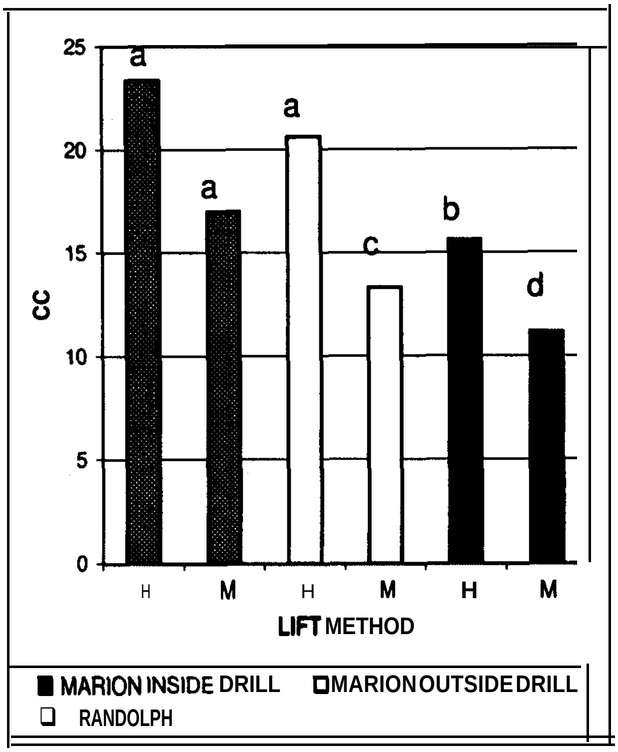

Figure 2-Mean first-year volume index of seedlings lifted mechanically or by hand from each of two Georgia nurseries and planted on five'sites in Georgia and Alabama. Means labeled with the same letter and representing seedlings from the same nursery were not significantly different according to Duncan's Multiple Range test, p=0.05.

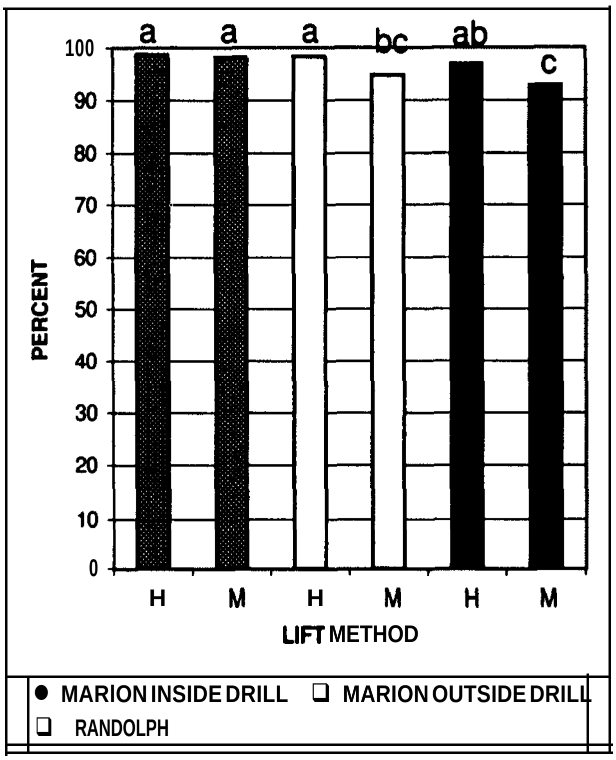

Figure S-Mean first-year survival of seedlings lifted mechanically or by hand from each of two Georgia nurseries and planted on five sites in Georgia and Alabama. Means labeled with the same letter and representing seedlings from the same nursery were not significantly different according to Duncan's Multiple Range test, p=0.05.

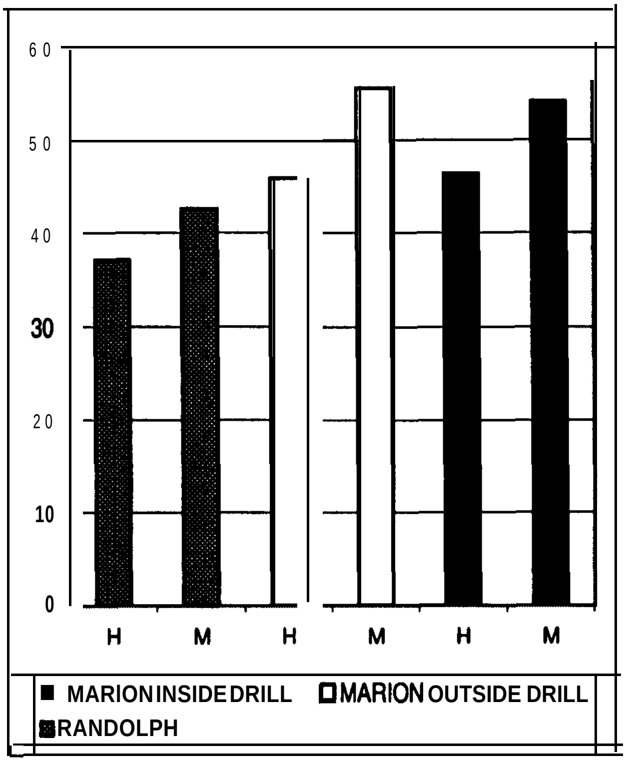

Figure 4—Coefficients of variation calculated from first-flush increments of seedlings lifted mechanically or by hand from each of two Georgia nurseries and planted on five sites in Georgia and Alabama.

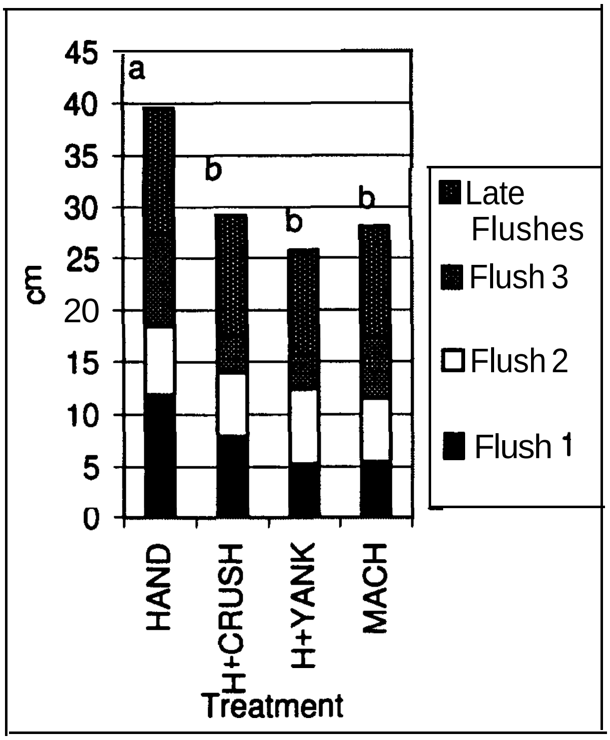

Figure 5—Mean first-year height increment of seedlings treated by either lifting mechanically (MACH), lifting operationally by hand (HAND), lifting by plucking from the soil individually (H+YANK), or lifting by hand and then stepping on the stem just above the root collar (H+CRUSH). Growth flushes are indicated by shading. Means labeled with the same letter were not significantly different according to Duncan's Multiple Range test, p=0.05.

Significant differences among treatments in survival of seedlings from the Marion County nursery suggest that the lifting process may be more severe at this nursery than at the Randolph County nursery, where survival differences did not occur. Two variables at these nurseries may explain these differences. Surface soil texture at the Randolph County nursery is a sand, while the soil texture on the Marion County nursery varies from loamy sand to sandy loam. It is likely that lifting seedlings from the heavier soil results in more severe root stripping because of higher soil strength associated with heavier-textured soils. We suspect that differences in lifter technology may be interacting with soils to accentuate differences between the nurseries. The two-row belt lifter employed by the Marion County nursery plucks seedlings individually from the soil, while the eight-row lifter used at the Randolph County nursery, because it lifts all eight drills at once, tends to keep the seedlings together until they are shaken free of soil. The eight-row lifter also has an undercutter blade which precedes the belts. This implement lifts up the soil and loosens the roots, making the process gentler. Undercutting for the Mathis two-row lifter is done in a separate pass before lifting.

We plan to continue to collect data from this study to determine if differences persist beyond the first year.

CONCLUSIONS

1) Hand-lifted seedlings outperformed seedlings lifted with two types of belt lifters during the first year after planting.
2) Seedlings from drills one and eight significantly outgrew those from drills two through seven.
3) Mechanical lifting increased variability in first-year growth of seedlings.
4) Lifting-related damage to stems or roots was sufficient to account for observed growth reductions.

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IMPROVING LONGLEAF PINE SEEDLING ESTABLISHMENT IN THE NURSERY BY REDUCING SEEDCOAT MICROORGANISMS'

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Abstract-Longleaf pine (*Pinus palustris* Mill.) seeds are sensitive to damage during collection, processing, and storage. High-quality seeds are essential for successful production of nursery crops that meet management goals and perform well in the field. We conducted a series of tests under laboratory and nursery conditions to evaluate what effect a number of presowing treatments, e.g., soaking, stratification, and coat sterilization, had on the performance of longleaf pine seeds of varying qualities. Test results indicate that removal of fungal contamination from the seedcoats will markedly improve seed germination and seedling establishment in the nursery. Both a l-hour soak in 30-percent hydrogen peroxide and a IO-minute drench in a 2.5 percent a.i. per liter benomyl solution improved longleaf pine seedlot performance, particularly in seedlots of low to medium quality. Based on seedling establishment 3 months after sowing, other treatments, which included water soaking and stratification, were less effective than sterilants. Because the benomyl drench was as effective as the hydrogen peroxide soak, it is the preferred treatment for controlling seedcoat contamination; it is both more economical and safer for the nursery manager to use. An effort is underway to extend the registration for this seed treatment to Southern States other than North Carolina, where it is currently labeled.

NTRODUCTION

Interest in restoring longleaf pine (*Pinus palustris* Mill.) to many sites in the South has increased dramatically over the last 10 years. One of the limitations of producing the quantities of seedlings needed for this reforestation effort is the lack of high-quality seeds. Following a marked increase in the quantity of seed collected and seedlings produced, the quality of longleaf pine seeds has been a problem across the South. Part of this problem relates to seed maturity at the time of collection and to difficulties in cone storage and processing (Barnett and Pesacreta 1993). Handling of large amounts of cones and seeds results in diminished seed quality, because many of the recommended criteria for maintaining high quality cannot be met. Nursery managers have looked for seed treatments that would improve seed viability and seedling performance. Treatments range from stratification to soaks in hydrogen peroxide or a fungicide: and specific use recommendations vary. A cooperative study among personnel of the Claridge Nursery at Goldsboro, NC, the National Tree Seed Laboratory (NTSL) at Dry Branch, GA, and the Seed Testing Facility (STF) of the Southern Research Station at Pineville, LA, was initiated to evaluate some of the current treatments. The study's objective was to develop recommendations for presowing treatments that will improve longleaf pine seed performance in the nursery.

METHODS

Treatments were applied to the seeds in late April of both 1997 and 1998. Germination tests were conducted at the NTSL, the STF, and at the Claridge Nursery.

1997 Tests

The presowing treatments were: (1) control, (2) a l-hour, 30-percent hydrogen peroxide (HP) soak, (3) l-hour HP soak and a 16-hour water soak (WS), (4) l-hour HP soak, a 16-hour WS, and a 14-day stratification (ST), (5) 16-hour WS and a 14-day ST, and (6) 16-hour water mist, and a 14-day ST. The l-hour soak in 30-percent HP was based on earlier research (Barnett 1976) and is labeled as a seed ST. This procedure is used operationally at the Claridge Nursery (Barnett and McGilvray 1997). The NTS recommends the 14-day ST treatment (Barbour 1996, Karrfalt 1988). Responses to ST are based on seed imbibition on the germination medium. Other tests of ST at the STF indicated that the 16-hour water soak, as it was conducted for operational ST may reduce germination by 10 percentage points (Barnett and Pescreata 1993). We, therefore, included a mist imbibition treatment (misting 1 of every 10 minutes) to compare with the water imbibition soak commonly used at nurseries to prepare seeds for ST. We felt that the rapidity of water absorption by longleaf pine seeds might be adversely affecting performance (Barnett 1981, Taylor and others 1992) and that an intermittent mist might slow imbibition and improve germination.

Three seedlots were selected for the study. One high-viability lot was provided by the STF, and Claridge Nursery personnel selected the two other lots as medium and low quality. Five dishes of 50 seeds each were used for laboratory testing; 10 trays of 96 cavities each were tested in the nursery. The NTSL applied presowing treatments to those seeds tested at NTSL and the Claridge Nursery. Seed Testing Facility at Pineville personnel applied treatments to the same seedlots that were tested at STF. Laboratory germination tests followed the Association of Official Seed Analysts (AOSA) guidelines. In order to determine peak day or the speed of germination, germination counts were made at 2- to 3-day intervals at STF. Counts at NTSL and Claridge Nursery were made at 7-day intervals. In all cases, germination was complete within 28 days.

A determination of seedling establishment or percent stocking was made at the Claridge Nursery 3 months after sowing. This evaluation was made to determine if some treatments were more effective than others in protecting seeds from damping-off diseases during germination and early seedling development.

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1 Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-16, 1999.

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1998 Tests

The study made in 1997 was repeated in 1998. However, treatment was dropped because the germination of these seeds in the laboratory did not differ significantly from those in the more conventional WS-ST. Added in its place was a IO-minute benomyl drench (0.05 percent solution of benomyl 50WP [2.5 percent a.i.], or 227 grams per 12 gallons water). This treatment was based on Weyerhaeuser Company research (Littke and others 1997) that demonstrated the efficacy of the benomyl seed-dip treatment for controlling seedborne *Fusarium* and was the basis for registration in North Carolina.

Three seedlots were again used in this study (high, medium, and low viability). A replication in time was a component of this test. All treatments were applied at the STF. Some of the seeds were then shipped to the NTSL and Claridge Nursery for testing that began in late April and was repeated 2 weeks later. Germination counts were made at 7-day intervals at the three testing locations. Seedling stocking was determined approximately 90 days after sowing. The other aspects of this test were the same as in the 1997 test.

Table l-Germination of longleaf pine seed and seedling stocking following treatments in 1997 under laboratory and nursery conditions[a]

Treatments	Peak day	Germination STF	Germination NTSL	Germination Nurs.1	Germination Nurs.2	Stocking Nurs.1	Stocking Nurs.2
	No.	Percent					
Control	7.0ab	76b	71c	75bc	72c	66bc	64b
Hydrogen peroxide (HP)	7.2a	84a	84a	70d	81ab	70b	78a
HP + 16-hr water soak (WS)	6.0bc	71b	74c	84a	85a	81a	80a
HP + WS + 14-day stratification	4.4d	76b	78b	79abc	85a	77a	82a
WS + 14-day stratification	4.0d	85a	84a	79bc	77bc	54d	5oc
Mist + 14-day stratification	5.0c	86a	82ab	80ab	76bc	62c	65b

[a] Germination 28 days after sowing in the Claridge Nursery (two separate tests of the same treatment applications sown 2 weeks apart) and Pineville (STF) and Dry Branch (NTSL) Laboratories. "Peak day" represents the time when maximum daily germination occurs and is a measurement of speed of germination. Seedling stocking is expressed as the percentage of seeds that became viable seedlings 90 days after sowing. Averages within columns followed by the same letter are not significantly different at the 0.05 level.

RESULTS AND DISCUSSION

Although essentially the same treatments were evaluated in 2 years of testing, sufficient differences in procedures necessitate discussing the results separately.

1997 Tests

Seedlots were selected to determine how different seed qualities were affected by the treatments; lots 1, 2, and 3 represented low-, medium-, and high-quality seeds. All tests showed consistent differences among seedlots. Most analyses showed statistically significant (0.05 percent level) interactions among seedlots and treatments. These interactions demonstrated that lower quality seedlots usually responded more positively to presowing treatments than the high-quality seedlot.

Table 1 shows seed responses to five treatments and a control. Some major differences in the results obtained occurred among testing locations, e.g., in Claridge Nursery Test 1, the hydrogen peroxide (HP) treatment performed consistently lower than in Test 2 at the Nursery or at either the STF or NTSL laboratories. However, HP treatment results in Nursery Test 1 were equal to the best response to treatments in the other tests. The HP plus 16-hour soak treatment performed best in Claridge Nursery Test 1, but performed worst in the laboratory tests. One possible reason such performance differences were noted in the nursery tests is that the treatment labels were switched when Test 1 seeds were sown. Nonetheless, it is fortunate that two evaluations were conducted at the nursery.

A flaw may have occurred in the Claridge Test 1 study related to the HP treatment. In Nursery Test 2, the HP treatments were superior to the control and equal to the stratification ones. Laboratory tests at NTSL and STF showed that the HP soak and the 14-day ST treatments (both soak and mist) performed best. Thus, there seem to be some differences between the nursery and the labs.

A determination of percent stocking in the nursery containers was done about 3 months after sowing on July 15, 1997. In both nursery tests, treatments with HP produced better stocking than the control or ST treatments. Stocking resulting from the WS-ST treatment was significantly poorer than that resulting from the mist-stratification treatment. Therefore, even though water imbibition occurred at comparable rates in the water soaking and misting treatments, it may be helpful to evaluate misting approaches that would result in slower rates of absorption.

1998 Tests

Differences in germination among seedlots, presowing treatments, and their interactions were statistically significant (at 0.05) in the individual tests (table 2). To make more straightforward evaluations of our responses resulting from measurement variables, we presented germination by presowing and **seedlot** treatments, and by presowing treatments and testing locations.

The effects of presowing treatments showed limited response in the highest-quality **seedlot** (table 3); germination at 28 days ranged from 84 percent in the control to 92 percent in the benomyl drench. In the medium- and low-quality lots, however, there were major differences in response to the various presowing treatments. The HP and benomyl treatments increased germination over that of the control; performance of the lower quality lot increased by 12 percentage points with the HP and 13 percentage points with the benomyl drench treatments. Treatments that included a IS-hour water soak reduced overall germination about 22 percentage points.

Table P-Germination of longleaf pine under laboratory and nursery conditions following seed presowing treatments tested in 1998’

Treatments	Seed quality	Test 1			Test 2		
		NTSL	Nurs.	STF	NTSL	Nurs.	STF
		Percent					
Control	High	91	84	83	82	85	80
	Medium	85	73	52	66	70	60
	Low	56	52	49	58	49	58
	Avg.	71	70	61	69	68	66
Hydrogen peroxide (HP)	High	92	92	76	90	92	86
	Medium	80	71	61	72	70	70
	Low	76	75	60	81	72	63
	Avg.	83	79	66	81	78	73
HP + water soak (ws)	High	84	86	88	74	85	88
	Medium	21	36	46	45	32	29
	Low	46	21	44	42	30	21
	Avg.	50	48	59	54	49	46
HP + ws + stratification	High	89	84	91	90	95	92
	Medium	25	40	33	49	27	52
	Low	24	15	23	46	45	44
	Avg.	46	46	49	62	56	63
WS + stratification	High	92	93	89	94	94	87
	Medium	56	50	34	61	57	60
	Low	41	43	39	53	39	40
	Avg.	63	62	54	69	63	62
Benomyl drench	High	92	93	91	92	95	92
	Medium	79	80	69	72	80	74
	Low	70	65	71	64	70	64
	Avg.	80	79	77	76	82	77

[a] Data are averages of 5 replications of 50 seeds each. Highest germination in the nursery may have been at 7, 14, or 21 days: counts were lower on 13 of the 18 seedlot-treatment combinations due to damping-off losses before the final count at 28 days. Differences due to treatments, seedlots, and their interactions were statistically significant at the 0.05 percent level for each separate test.

Table 3-Germination of longleaf pine seeds by presowing treatment and seed quality conditions in 1998

Treatments	Seed quality condition			
	High	Medium	Low	Avg.
	- - - - - - - - *Percent*- - - - - - - -			
Control	a4	64	54	67
Hydrogen peroxide (HP)	66	71	71	77
HP + water soak (ws)	64	35	34	51
HP + ws + stratification	90	38	33	55
WS + stratification	92	53	42	62
Benomyl drench	92	76	67	78

The responses to treatments followed similar trends at each testing facility and between the two replications in time (table 4). As expected, germination in the nursery was somewhat lower than in the laboratories. However, the HP soak and benomyl drench consistently improved germination over that of the control at all locations.

The tests in both 1997 and 1996 indicate that a significant problem in longleaf pine seed performance results from pathogens carried on the seedcoats. Fraedrich and Dwinell (1996) recently reported that the pitch-canker fungus (*Fusarium subglutinans* [Wollenw. & Reinking] Nelson, Toussoun & Marasas f. sp. *pini*) is a cause of significant mortality in longleaf pine germinants. Other species of *Fusarium* are often isolated from conifer seeds and may result in poor germination or pre-emergence and post-emergence disease (Littke 1996). Our results show that treatments to reduce microorganisms on the seedcoats improve germination of moderate- and low-quality seedlots. The HP soak improved seedling establishment at 90 days in the nursery in the 1997 tests by a significant amount (14 percentage points). In the 1996 tests, both the HP and benomyl treatments improved performance of lower quality seedlots. Stocking, overtime, at the two test sites was 15 and 23 percent more for those seeds treated with the HP and benomyl, respectively. The high-quality lot was largely unaffected by presowing treatments.

CONCLUSIONS

The results of both tests indicate that treatments to reduce seedcoat contamination will provide maximum improvement in longleaf pine seed performance. Both the l-hour soak in do-percent HP and the IO-minute benomyl drench were effective in increasing germination of medium- to low-quality seedlots. High-quality lots were little affected by any presowing treatment. Although operational ST increases the speed of germination of many seedlots by about 3 days, total germination of less than high-quality seedlots is usually reduced by ST treatment. The data confirm results of earlier tests showing that overnight soaking of longleaf seeds (as done in operational ST) may reduce total germination (Barnett and Pesacreta 1993). Data from both the 1997 and 1996 tests that determined the effect of presowing treatments on nursery stocking show that use of treatments that reduce seedcoat contaminants can markedly improve establishment of germinants in the nursery. Therefore, nursery practices that include treatments for controlling seedcoat pathogens common to longleaf pine seeds would be beneficial. The IO-minute benomyl drench was as effective as the 30-percent HP soak; and it offers a less expensive and safer treatment. We should seek additional labelling of this benomyl treatment because it provides an excellent opportunity to improve performance of typical longleaf pine seedlots.

Table 4—Germination of longleaf pine seeds and seedllng stocking following presowing treatments; tested two times in 1998 under laboratory and nursery conditions[a]

Treatments	Test 1				Test 2			
	STF	NTSL	Nurs.	Stock.	STF	NTSL	Nurs.	Stock.
				Percent -				
Control	71	70	61	49	69	68	66	55
Hydrogen peroxide (HP)	a3	79	66	64	81	78	73	70
HP + water soak (ws)	50	48	59	49	54	49	46	38
HP + ws + stratification	46	46	49	46	62	56	63	57
WS + stratification	63	62	54	47	69	63	62	36
Benomyl drench	80	79	77	76	76	a2	77	74

[a] Germination was tested at the Pineville STF, NTSL, and Claridge Nursery. Stocking was determined at the Claridge Nursery,

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EFFECT OF PLANTING DATE ON FIRST-YEAR SURVIVAL OF TWO PINES[1]

Awatif E. Hassan and Carlos Silva[2]

Abstract-A study of the effect of extending the planting season from 90 days to 126 days on survival of bare root seedlings planted two weeks apart was conducted using two pines and replicated for two years. The loblolly pine (*Pinus taeda*) and the longleaf pine (*Pinus palustris*) study was conducted on a bedded site in the Coastal Plain and on a flat site in the Piedmont region. The results of the first-year survival of seedlings in the Coastal Plain indicated that the planting date had no effect despite the high variability in the longleaf data. Survival of the longleaf pine was lower than the loblolly pine for the same planting days. The loblolly pine survival was higher in the Piedmont than the Coastal Plain region. Statistical analysis for the effect of planting date on survival by year, pine type, and region indicated no effect on survival, hence the planting season can be extended.

INTRODUCTION

About one million hectares (-2.5 million acres) were planted or seeded in the U.S. in 1996. Although there had been an increase of 7 percent in the number of private non-industrial land owners over their 1995 plantings, the planted acres were about 15,000 acres less than 1995 and much less than the 1988 planting of almost 3.4 million acres. In 1996, the South produced over 1.2 billion trees of the 1.53 billion trees of the U.S. total (Moulton & Snellgrave 1997). Most of these nursery trees were conifers and in the South, loblolly pine represented the favored species for forest regeneration.

During the time of the early settlers, the longleaf pine range extended from the Carolinas to Florida and covered over 25 million hectares (60 million acres). With urban development and conversion to loblolly pine, this range has been reduced to slightly over one million hectares in 1995 (Outcalt and Sheffield 1996). There has been a renewed interest in the longleaf pine ecosystem and future regeneration among foresters in general and wildlife biologists in particular.

The literature reveals very limited information on the effects of lifting date in the nursery and/or field planting date of the southern pines on their survival and growth. Zaerr and Lavender (1976) in a study of four planting dates reported a slightly higher survival of 2-O Douglas-fir seedlings planted in March than those planted in November on a bare site. They also reported that for all planting dates, seedling survival on the bare site was higher than on the grassy site due to the high moisture stress facing the Douglas-fir seedlings. They concluded that survival might depend on seedling physiology and planting site rather than date of planting (Zaerr and Lavender 1976). A study of the effects of planting month, planting depth, and seedling size was conducted over six years on the Cumberland Plateau in Tennessee (Boyd 1978). The results of a seven-month planting season from mid December to mid June over three years indicated that the loblolly seedling root collar diameter planting (shallow) had significantly lower survival in early winter and late spring plantings and that severe winter months adversely affected survival of even the deep planting. In another study on the effects of herbicides and planting dates on containerized and bare root loblolly pine seedlings, South and Barnett (1986) reported that survival rate was greater for seedlings planted in March than those planted in May. In a study of the effects of time and depth of planting on first year survival of loblolly pine seedlings planted in Texas, Bilan (1986) reported that the lowest mortality of IO percent was achieved by the seedlings planted at the root collar diameter and continued to be less than the deep planting over the second growing season. He also reported the mortality due to planting date (from November to April) to vary from 7-24 percent with the highest values for late planting in April. Ursic and others (1966) addressed the question of how long could loblolly pine seedlings be stored to extend the planting date to mid June in Mississippi. Based on the results of 10 years of field testing, they concluded that late-planted seedlings that were properly packaged and stored survived better than seedlings planted in December. They also recommended late planting of loblolly pine seedlings in its range between latitudes 33 and 37 °N.

The only study relating the effect of planting dates on longleaf pine was conducted by Goodwin (1976) who reported that summer planting of longleaf tublings resulted in higher first-year survival than winter planted 1-O bare root seedlings. However, first-year survival of loblolly pine tublings planted in the summer was not different than the 1-O seedlings planted in the winter.

Most forest planting in the South begins around December 1 and ends around February 28, making the planting season last for 90 days, hence the literature could benefit from a study that would widen the window for the planting season for both loblolly and longleaf pines.

The first author has been working with loblolly pine culture from seeding, planting, to harvesting for over 25 years. In the past 10 years, she concentrated her effort on nursery studies of physical parameters of loblolly pines during the lifting season which varied even after the seedlings became "dormant". The author desired to extend the study to field planting of loblolly seedlings at different dates and the company providing the in kind support asked to include the longleaf field planting in the study.

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Objective

The objective of the authors of this paper is to report the results of the first-year survival of loblolly pine seedlings planted in the Coastal Plain and Piedmont regions for a period of two years each and of **longleaf** pine seedlings planted in the Coastal Plain region for two years and to discuss the feasibility of extending the planting season for the two pines.

EXPERIMENTAL PROCEDURES

Nursery and Seedling Source

The study was conducted with an in kind support of an industrial nursery located in the Coastal Plain region of North Carolina. Each season the nursery manager provided an entire bed for the duration of the study. The loblolly pine seedlings were of improved seed from a second generation seed orchard for the Coastal Plain and Piedmont regions. The **longleaf** pine seedlings were bare root produced for limited applications. The seedlings were carefully **lifted** by hand on the day of planting, sorted according to root collar diameter, diseased trees removed, and then transported in containers with roots submerged in water for manual field planting on the same day. Loblolly pine seedlings were planted deep with 2-5 cm below root collar diameter in the ground, while extra care was given to plant the **longleaf** pine seedlings at conventional root collar diameter depth with terminal buds exposed and no soil particles above them.

Coastal Plain Site

The 1993-94 and 1994-95 plantings of loblolly and **longleaf** seedlings study took place at the **Pineland** Tree Farm located in Columbus County of North Carolina. The soil was a combination of two series; the Torhunta Series (fine sandy loam) consisted of very poorly drained soils that formed in loamy and sandy marine or **fluvial** sediments with severe seedling mortality and the Rains Series consisted of poorly drained soils that formed in loamy and clayey marine sediments with moderate seedling mortality. These soils are suited for loblolly pine with a site index of 88 to 94.

Piedmont Site

The **1995-96** and 1996-97 loblolly pine seedling study plantings took place at the North Carolina State University (NCSU) Hill Forest in Durham County. The soil was Georgeville silt loam with 2-6 percent slopes. This soil is well drained with moderate infiltration and medium runoff. The soil is suited for agricultural crops, hardwoods and pines. The site index for loblolly pine is 80.

Experimental Design and Planting Dates

The study was designed to extend the planting season from 90 to 126 days and to plant the seedlings two weeks apart. The design resulted in 10 planting dates extending from December to April in the Coastal Plain and from November to March in the Piedmont (table 1). Early planting, rather than April planting was employed in the Piedmont region to avoid moisture deficits associated with the Spring months. It is obvious from table 1 that the two-week (14 days) interval was interrupted on several occasions due to weather, field conditions, labor availability, etc. However, the periods were adjusted and set to 14 days in order to conduct the statistical analysis and to make appropriate graphical presentation of the test results.

The experimental design was a randomized complete block selected with consultation of the NCSU Statistics Department specialists. In the Coastal Plain, the site was bedded, hence the design included five blocks made of 10 beds and consisted of 10 different planting dates per block resulting in a planting at 6 x 10 ft spacing with few beds between the two pines which were commercially planted with loblolly pine. To avoid the problems associated with uniformity of site preparation and bed integrity, the per date planting was conducted across the ten beds in each block. The site at the Hill Forest was a cleared level farm field used for short term research studies, hence the same randomized blocks were easily flagged with 6 x 6 ft planting spacing. In either site, each block contained 100 seedlings with 10 seedlings planted at each planting date (a layout of the study plots is shown in the Appendix). The study was duplicated for two years in each region, and first year survival for each year was assessed after one growing season. Measurements of the five-year growth; tree height, diameter, and survival have begun for the 1993-94 planting season and will be reported at a future conference.

Table l-Planting dates for the two regions by season and their corresponding day of planting

	Planting date			
	Coastal Plain region		Piedmont region	
Time days	1993-94	1994-95	1995-96	1996-97
0	Dec. 7	Dec. 7	Nov. 16	Nov. 7
14	Dec. 22	Dec. 21	Nov. 30	Nov. 21
28	Jan. 5	Jan. 4	Dec. 14	Dec. 5
42	Jan. 19	Jan. 20	Dec. 29	Dec. 19
56	Feb. 2	Feb. 1[a]	Jan. 11	Jan. 2
70	Feb. 16	Feb. 17	Jan. 25	Jan. 16
84				
98	Mar. Mar. 2 16	Mar. Mar. 3 17	Feb. Feb. 8 22	Jan. Feb. 29 13
112	Mar. 30	Mar. 31	Mar. 7	Feb. 27
126	Apr. 13	Apr. 12	Mar. 21	Mar. 13

[a] Frozen ground on Feb. 1; planted on Mar. 31.

RESULTS AND DISCUSSION

Most foresters and practitioners admit that the first year survival of planted pine seedlings has a great element of luck due to weather and soil conditions. Because the seedlings in this study were planted immediately after lifting from the nursery bed, they might have not experienced a physiological stress when out planted. They might have also resumed photosynthesis and growth shortly after planting, hence these stresses should not have effects on seedling survival. Also the seedlings were treated with considerable care to eliminate other variables due to seedling handling and human factors. The same individuals (one for loblolly and one for longleaf) planted all seedlings at the 10 planting dates.

Survival in the Piedmont Region

The average loblolly pine survival in the Piedmont region was very high (fig. l), especially for the 1996-97 planting

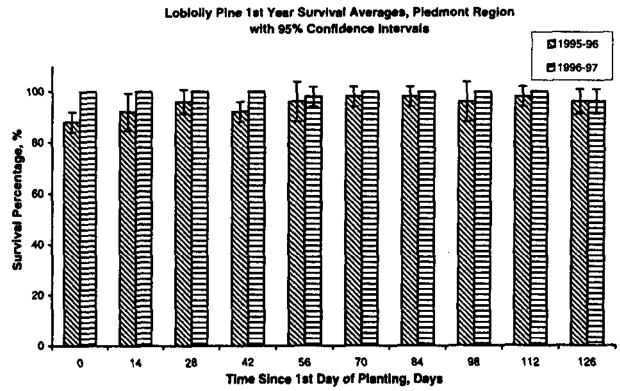

Figure l-First-year survival of loblolly pine seedlings planted at two-week intervals in the Piedmont region with the 95 percent confidence interval.

season where survival was 100 percent except for day 56 (Jan. 2) and 126 (Mar. 13) where the survival percentages were 98 and 96 respectively. The survival percentages for 199596 range from 88-98 percent were due to a hunter who drove his vehicle on the study plot and damaged some of the seedlings. Precautions to prevent it from happening in future studies were made thus resulting in the almost 100 percent survival in the 1996-97 season. The seedlings lifted for the November planting (days zero and 14) were not hardened (table 2), however; the first year survival was high and comparable with other planting days when the seedlings were "dormant". These results are close to those published earlier where a survival of 89 percent was reported for the control of a loblolly pine study planted in the Ozarks to determine the effects of fertilization on seedlings survival and early growth (Pope and Voeller 1976). The findings of Boyd (1978) support the results of this study; he reported that in a normal winter, loblolly pine survival was high for deep planted seedlings for all seven months (December to June) of planting.

Survival in the Coastal Plain Region

Loblolly pine seedling survival-Figure 2 shows the loblolly seedling survival in the Coastal Plain region for two planting seasons. The survival percentages ranged from 60-96 and 76-98 for the 1993-94 and 94-95 planting seasons respectively. Although the seedlings broke dormancy and started new growth in April, the 126 day plantings for both years had very high survival percentages (94 and 96) indicating that extending the planting season might not be detrimental to plantation establishment.

Longleaf pine seedling survival-Longleaf pine seedlings either planted or naturally regenerated typically remain in the grass stage with no height growth for a period of five years or more. The first year survival data collection was hindered by the presence of grass and other similar weeds. However, extensive effort was made to find the terminal bud before recording the survival data. Figure 3 shows the results of survival measurements in the Coastal Plain region. In general, seedling survival percentage was higher in the 1993-94 than 1994-95 season, with ranges of 48-98 and 24-92 for the 1993-94 and 1994-95 planting seasons. The dates with least survival in the 1993-94 were February 16 and March 2. Late planting did not appear to affect survival of the longleaf seedlings in the 1993-94 season, contrarily to 1994-95 planting where late plantings (March and April) resulted in the lowest survival percentages (fig. 3). In a similar study in Florida, first year survival of 74 percent for the properly planted longleaf pine seedlings in Florida's droughty acid sands was reported. However, this survival was reduced to 35 percent at age five years (Burns 1974).

Environmental Factors

The survival results reported above might be related to common environmental factors that affect root growth and survival such as soil temperature and moisture content which are related to the weather conditions at the time of or in the following months after, planting. Table 3 shows the total monthly precipitation for the four years of planting at the two sites in comparison with the 30-year average (Perry 1996). The year total for the Coastal Plain region in the two planting years were very close to the 30-year average.

Table P-Temperatures in Fahrenheit F° (Celsius C°) for the Coastal Plain region (Whiteville Station) as they might affect seedlings hardening and dormancy in the nursery beds

	1993-94		1994-95		1995-96		1996-97	
Month	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Nov.	42(6)	67(19)	46(8)	71(22)	37(3)	62(17)	37(3)	64(18)
Dec.	31(-1)	56(13)	40(4)	61(16)	33(1)	57(14)	36(2)	62(17)
Jan.	29(-2)	53(12)	34(1)	56(13)	30(-1)	53(12)	34(1)	57(14)
Feb.	36(2)	60(16)	33(1)	54(12)	33(1)	57(14)	38(3)	61(16)
March	43(6)	70(21)	42(6)	70(21)	40(4)	66(19)	45(7)	74(23)
April	51(11)	79(26)	50(10)	78(26)	47(8)	74(23)	44(7)	72(22)

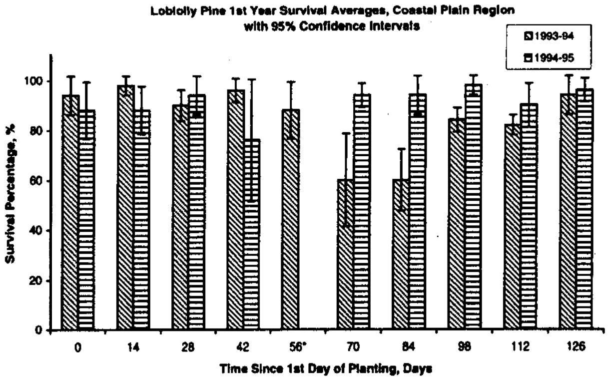

Figure P-First-year survival of loblolly pine planted at two-week intervals in the Coastal Plain region with the 95 percent confidence interval. The * indicates that the survival for day 56 in the 1994-95 season is not shown because the planting was performed on day 112 (March 31, 1995) using seedlings that were lifted on day 112, due to frozen soil condition at the nursery in February 1995.

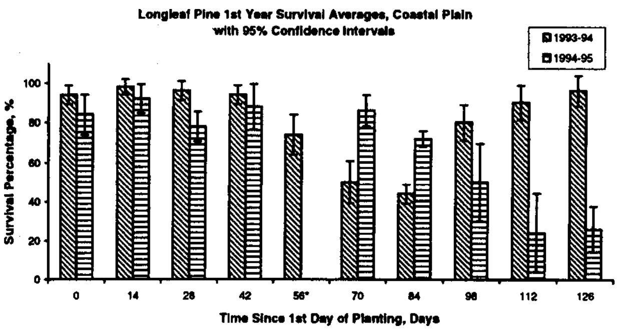

Figure 3-First-year survival of longleaf pine planted at two-week intervals in the Coastal Plain region with the 95 percent confidence interval. The . indicates that the survival for day 56 in the 1994-95 season is not shown because the planting was performed on day 112 (March 31, 1995) using seedlings that were lifted on day 112, due to frozen soil condition at the nursery in February 1995.

However, the March-August total for 1993-94 and 1994-95 were 758 mm and 583 mm respectively in comparison with the 30-year average of 711 mm. The 1993-94 planting season was very wet in comparison with the 1994-95 season, in other words the soil was saturated and aeration problems might have resulted in reduced oxygen needed for respiration, thus killing the root system and affecting survival of the loblolly pine seedlings (fig. 2). Although the total precipitation for 1995-96 was much higher than 1996-97 and the 30-year average in the Piedmont region (table 3), the loblolly pine seedling survival (fig. 1) was very high and the reported mortality was mainly due to the vehicle traffic incident.

Survival of the longleaf pine seedlings is still high, however, is variable and cannot be related to the weather patterns (table 3 and fig. 3). The high mortality was observed to be due to bed washaway because of the presence of stumps and logs which might have caused seedlings drowning in water.

Statistical Analysis and Models

Statistical analyses were conducted to determine the significance of extending the planting dates for loblolly and longleaf pines and in particular to determine the effects of planting date, year, and region on first-year survival of loblolly and longleaf pine seedlings.

The study dependent variable was the first year survival of pine seedlings. The independent variable was the time or planting date with time = 0 indicating the first day of planting in the season. The time (date) was then incremented by 14 days (two weeks) to make up the 10 visits comprising the 126-day planting season (table 1). Other variables used as control variables were pines (longleaf, loblolly), sites (Coastal Plain, Piedmont), years for each site (2 years) and blocks within the year (five blocks each).

SAS system release 6.12 and Microsoft Office 97 (Excel) were used for the statistical analysis and graphical presentation of the data.

Loblolly pine model-The analysis of variance (ANOVA) model for the first year survival of loblolly pine is represented by Eqn(1)

$$Y_{ijkl} = \mu + \rho_{k(l)} + t_i + s_j + (ts)_{ij} + \gamma_{l(j)} + (t\gamma)_{il} + \varepsilon_{ijkl} \qquad (1)$$

where:

Y_{ijkl} = the observed survival at the k^{th} block within the l^{th} year and j^{th} site and at the i^{th} time. $i=1,2,...,10$; $j=1,2$; $k=1,2,3,4,5$ and $l=1,2,3,4$

μ = overall unknown population mean

$\rho_{k(l)}$ = block effect within l^{th} year, assumed random

t_i = time of planting effect, assumed fixed

s_j = site effect, assumed fixed

$(ts)_{ij}$ = interaction effect, time vs site

$\gamma_{l(j)}$ = year effect within j^{th} site, assumed random

$(t\gamma)_{il}$ = interaction effect, time vs year

ε_{ijkl} = random error effect

Analysis of first year survival of loblolly pine seedlings planted two-weeks apart in an extended season for four years and two regions allowed the authors to conclude that there was no effect on seedling survival due to planting date. The lowest values of survival percentage (58 percent) were associated with the highest standard errors of 0.19 and 0.18 for planting day 70 and 84 respectively for the 1993-93 planting season (fig. 2).

Upon examination of the data set, there were some very low survival values for block 1 and 3 in 1993-94 which might be due to microsite conditions that resulted from site preparation and weather conditions (table 3).

Table 3-Total monthly precipitation in (mm) for the four planting seasons in comparison with the published 30-year averages

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Year total
					Coastal Plain region - Whiteville Station						
1993-94 planting	23	61	136	46	108	59	117	141	157	176	1282
1994-95 planting	60	83	216	120	83	18	129	165	107	81	1294
30-year average[a]	74	80	97	96	112	77	116	129	154	123	1238
					Piedmont region - Rougemont Station						
1995-96 planting	116	49	77	48	134	107	136	38	110	150	1307
1996-97 planting	83	103	82	82	82	149	24	156	85	64	1105
30-year average[a]	84	83	93	87	104	81	106	94	110	103	1118

[a] Perry (1996).

Longleaf pine model-Longleaf pine planting limited to the Coastal Plain region, resulted in a simpler ANOVA model (Eqn 2) than the loblolly pine model (Eqn 1).

$$Y_{ijk} = \mu + \rho_{k(j)} + t_i + \gamma_j + (t\gamma)_{ij} + \varepsilon_{ijk} \qquad (2)$$

where:

- Y_{ijk} = the observed survival at the k^{th} block within the j^{th} year, and j^{th} site and at the #*time. i=1,2,...,10; j=1,2; and k=1,2,3,4,5
- μ = overall unknown population mean
- $\rho_{k(j)}$ = block effect within j^{th} year, assumed random
- t_i = time of planting effect, assumed fixed
- γ_j = year effect, assumed random
- $(t\gamma)_{ij}$ = interaction effect, time vs year
- ε_{ijk} = random error effect

The results of the analysis indicated that the first year survival of the longleaf pine seedlings was lower and that the variability was higher than those for the loblolly pine seedlings. Very low survival values of 24 and 26 percent were observed for day 112 and day 126 in 1994-95 in comparison with 90 and 96 percent for the same planting times in 1993-94. These low values for the times 112 and 126 days resulted in a high standard error of 0.38 when the averages of the two years and five blocks were analyzed. Although the longleaf pine data exhibited more variability than the loblolly pine data, the longleaf pine survival percentage averages were still high indicating no effect of time (planting date). Hence, bare root longleaf pine seedlings can be planted in the Southern Coastal Plain region within the 126 day planting season tested.

Logistic regression analysis-The linear logistic regression model (Eqn 3) is an alternative approach for the ANOVA statistical analysis above (Agresti 1990). A model with time (day of planting) effect as the regressor variable allowing for different intercepts for blocks within years, and years was used for each pine as follows:

$$\pi(X\beta) = \frac{e^{X\beta}}{1+e^{X\beta}} \qquad (3)$$

where:

- $\pi(X\beta)$ = the probability that the seedling survived, where: Y_{ij}=1, if seedling survived and Y_{ij}=0, if seedling was dead at the i^{th} block and j^{th} year and for some Time value (planting date), and
- $X\beta$ = $\alpha+\beta_1 Time+\beta_{2i}Z_{2i(j)}+\beta_{3j}Z_{3j}+\varepsilon_{ij}$
- $Z_{2i(j)}$ = indicator variable of the i^{th} block within j^{th} year; i=1,...,5
- Z_{3j} = indicator variable of the j^{th} year, j=1,2,3,4 for loblolly pine and j=1,2 for longleaf pine
- ε_{ij} = random error
- a = common intercept parameter
- β_1 = logistic regression coefficient for Time (planting date) effect
- β_{2i},β_{3j} = specific intercept parameters for the I block and j year

The results of fitting the loblolly and longleaf data sets showed that the model (Eqn 3) was acceptable with standard errors of 0.0022 and 0.0020 for the loblolly pine and longleaf pine respectively. The results also showed that the regression coefficient estimates (6,) for the Time (planting date) effect were -0.0004 and -0.0169 for the loblolly pine and longleaf pine. These figures were very close to zero, hence it was concluded again that the tested Time (planting date) had no effect on seedling survival.

CONCLUSIONS

The planting dates which extended the season from 90 to 126 days appeared to have no effects on the first-year survival percentages of loblolly and longleaf pine seedlings. Survival of loblolly pine seedlings planted in the Piedmont region was higher than those planted in the Coastal Plain region. Similarly loblolly pine survival was higher than the longleaf pine survival in the Coastal Plain region. The experimental design of five blocks, IO planting dates per block repeated for two years for the longleaf pine and for two years at two regions for the loblolly pine provided enough repetitions for a good estimate of the error term and accordingly a high power associated to the statistical tests. The statistical analysis indicated that the planting date had no effect on the first-year survival of both pines and hence the planting season could be extended to four months.

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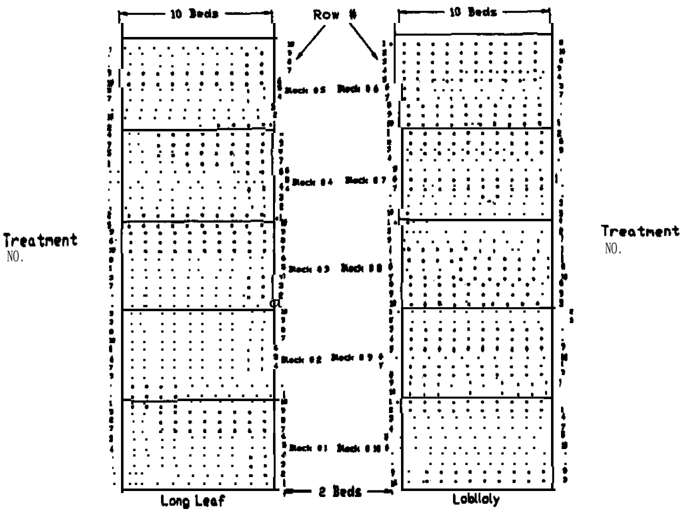
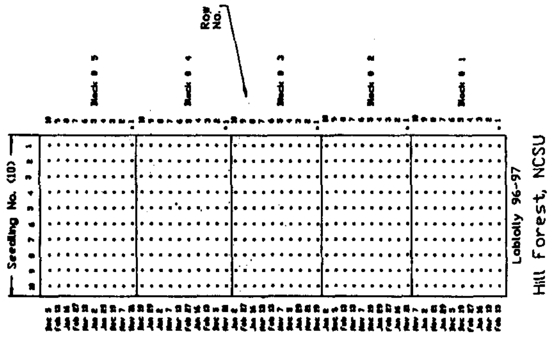
APPENDIX
Study Layout



(a) Coastal Plain Region



(b) Piedmont Region

WHICH LOBLOLLY PINE SEEDLING HAS A HIGHER SURVIVAL POTENTIAL -A DEEP PLANTED J-ROOT OR A SHALLOW PLANTED I-ROOT?'

David B. South[2]

Abstract-Two schools of thought exist regarding the planting of bare-root seedlings. One school favors the "pull-up" method where the seedling is pulled-up 3 to 10 cm after placing the roots in the planting hole. Although this action purportedly straightens the taproot, data are lacking to show this extra step actually improves field performance. Pulling up the seedling usually results in "shallow" planting (which could increase mortality on some sites). The "push-down" school advocates making a deep planting hole and placing the roots near the bottom of the hole. They say that shallow holes kill seedlings: bent roots do not. Planting guidelines should be rewritten to: (1) emphasize the "proper" depth of planting (to increase seedling survival); (2) de-emphasize intuitive beliefs that roots should look "normal" after planting; (3) eliminate unnecessary refinements in planting technique; (4) explain the advantages of machine planting; (5) explain the species/site/planting depth interaction for survival; and (6) cite references to support recommendations.

INTRODUCTION

In the South, many planted seedlings (40 to 80 percent) can be classified as having deformed roots (Gruschow 1959, Schultz 1973, Hay and Woods 1974a, Mexal and Burton 1978, Harrington and others 1989). However, just because a planted pine seedling has a bent taproot, this does not mean the performance will be less than seedlings that originate from direct seeding. In fact, sometimes 32 percent of loblolly pines (*Pinus taeda* L.) originating from seed have bent taproots (Harrington and others 1989). Therefore, bends in the taproot can be "natural" as well as "man-made." Even so, some claim that J-roots (table 1) will kill seedlings and that utmost care should be exercised during planting to ensure the taproot is straight. They claim that planting seedling roots deeply will bend the roots and, therefore, they say the "proper" planting depth is so the root-collar is slightly below groundline.

In my opinion, tree planting guidelines for loblolly pine overemphasize the dangers of both J-rooting and deep planting. Planting guidelines should be rewritten to eliminate the unimportant aspects of planting and to stress the important. Most data with loblolly pine indicate that bent roots, per se, do not affect early seedling survival or growth. On many sites, planting loblolly pine or slash pine (*Pinus elliottii* Englem.) deep in the hole increases survival (Slocum and Maki 1956, Malac and Johnson 1957, Malac 1965, Blake and South 1989).

This paper reviews the J-rooting L-rooting studies that have been conducted with bare-root pines in the southern United States. It does not cover root-strangulation occasionally caused by growing seedlings in containers or when twisting bare-root seedlings during planting. It reviews data mainly from the compression method planting where root systems are compressed into a vertical plane (also know as slit planting).

TWO SCHOOLS OF THOUGHT REGARDING THE PROPER PLANTING TECHNIQUE

Two schools of thought exist regarding the planting of loblolly and slash pine seedlings. The older-school favors the "pull-up" technique where the seedling is placed into the planting hole and then pulled up 3 to 10 cm (and the root-collar is about 1 to 5 cm below the soil surface). This action purportedly improves field performance by straightening out the roots. Several tree planting guides recommend this technique even though empirical trials by Wakeley (1954) show no advantage of this technique when compared to planting with a mattock. We even do not know if pulling the seedling up 3 cm is really enough to straighten out the roots. To avoid ψ-roots, members of this school allow some pruning of long fibrous roots by tree planters. "Graduates" of this school prefer straight taproots to deep planting. They claim the "correct" planting depth is to have the root-collar at or slightly below the groundline.

The other school recommends the "push-down" technique (which favors deep planting over straight taproots). Due to an increase in probability of success, members of this school prefer machine planting to hand planting (average planting hole depth for machine planting is about 30 cm and the root-collar is typically about 15 cm below the soil surface; this sometimes results in a high percentage of L-roots). On sites where hand-planting is required, leaders in this school recommend making a wide (15 to 18 cm) and deep (27 to 34 cm) planting hole. The roots are placed at the bottom of the hole and there they remain. As a result, the root-collar ends up at least 5 to 10 cm deeper than recommended by the "pull-up" school. For many sites, the "correct" planting depth for loblolly pine will result in the root-collar 15 cm below ground (and the bottom of the roots will be 25 to 34 cm deep). They allow J-roots, L-roots and r-roots but prohibit shallow planting holes (less than 25 cm deep) as well as pruning or stripping of roots by tree planters. However, due to a three-way interaction between species, site, and planing depth, members of this school do not recommend the same planting depth for all pine species or for all sites. Deep planting on sites where the water table is near the surface can decrease survival of loblolly pine (Switzer 1960). Therefore, the "correct" planting depth varies with site.

Because less time is required to make narrow, shallow holes, hand planters prefer recommendations from the "pull-up" school. Making a deeper planting hole by hand increases planting costs which is one reason those from the "push-down" school favor machine planting.

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Table I-Definitions of various root shapes at time of transplanting

Root shape	Definition
I-root	A **taproot** pointed straight down (o-20")
D-root	A bent **taproot** (1 cm or more) pointed down (21°-69°)
L-root	1 cm or more of the **taproot** pointed horizontally (70°–110°)
J-root	Less than half of the **taproot** in a J-shape pointed up (>110°)
N-root	Two bends in the **taproot** with the tip pointed down
P-root	A loop in the **taproot** with the tip pointed down
U-root	Half or more of the **taproot** pointed up (>110°)
ψ-root	A **taproot** pointed straight down ((0-20°) but with two or more first-order lateral roots pointed up (>110°)

Additional to the letter code, a number code can be added to provide more information on the planting depth, rooting depth, and **taproot** length. For example, an L-root **(3:13:15)** is planted with the root-collar 3 cm below the surface, it has a root depth of 13 cm, and the **taproot** is 15 cm long. A U-root **(8:15:16)** would have the root-collar 8 cm below the groundline, the roots are up to 15 cm below ground, and the **taproot** is 16 cm long. An I-root **(-1:18:15)** would have the root-collar 1 cm above the groundline, the lateral roots would extend to 18 cm below the surface, and the **taproot** is 15 cm long.

DEFINITIONS

Tree planting terminology can sometimes be confusing. For example, some from the "pull-up" school say the correct depth of planting should be 3 to 6 cm below the root-collar (Carlson and Miller 1990). Others define a seedling as being planted "deep" when the root-collar is just 3 cm below the soil surface (Brissette and Bamett 1969; Jones and Aim 1969). I offer the following definitions.

- Root depth = distance between groundline and bottom of roots after planting.
- Planting depth = distance between the root-collar and the groundline (negative values indicate the root-collar is aboveground).
- Correct planting depth = depth where survival and early growth are greatest.
- Shallow planting = depth where survival is increased when planting the root-collar deeper.
- Deep planting = planting seedlings with the root-collar 7 to 16 cm below the groundline.
- Excessively deep planting = depth where survival or growth would be increased if the root-collar was planted closer to the groundline.
- Shallow planting hole = hole less than 20 cm deep.
- Deep planting hole = hole greater than 25 cm deep.

HISTORY OF PLANTING RECOMMENDATIONS

The debate about proper planting techniques has been going on for more than a century. For example, Jarchow (1893) recommended shallow planting (a little higher than they stood in the nursery) and could not comprehend how Hough (1882) could recommend "setting the seedlings deeper than they stood before." Jarchow said the "experts in this matter agree in accepting the reverse to be true." Likewise, those in the "pull-up" school today probably can not comprehend how those in the "push-down" school can allow seedlings to be planted deeply (which results in J- and L-rooting). Debates on proper planting techniques will likely continue when data from empirical studies contradict intuition.

Regardless of the century, tree planting recommendations can be placed into three types: (1) recommendations based on intuition; (2) recommendations based on observations; and (3) recommendations based on experiments designed to test a hypothesis. Observational studies are good for formulating a hypothesis but are not good for testing one. Experiments carefully designed to minimize confounding are good for testing hypotheses. Little confidence should be placed in guidelines that rely only on 19th century intuition. Tree planting guides that cite only observational studies should also be viewed with caution. The greatest confidence should be placed on guidelines that cite results from actual planting method experiments.

SHALLOW PLANTING KILLS SEEDLINGS

Several tree planting guides state that root deformation will kill seedlings (Stephen 1928, Martin and others 1953). However, for loblolly pine or slash pine, there are no data proving this is true. Not only do most J-rooting trials show no significant effect on survival, but almost ail these trials confound root depth with root form. Therefore, the real cause of mortality in such trials could simply be due to shallow planting. Apparently, the idea that J-rooting can kill seedlings may have originated from a misinterpretation of a photo in a book by Tourney (1916). His figure 106 shows two L-rooted seedlings (one dead and one alive). Apparently some readers assumed the tree died because of the L-root as opposed to the shallow planting. However, the photo clearly shows the deeper planted L-root seedling in good condition. The cause of mortality was a shallow planting hole.

Brissette and Barnett (1989) established an empirical study where both root depth and J-roots were tested. Ail seedlings were placed into shallow holes (8 cm to 18 cm deep). A close examination of their data suggests that root depth (not J-rooting) was the primary factor affecting survival (fig. 1). in fact, when compared to tlie survival of i-roots **(-2:13:15)** placed in a **very** shallow hole (only 13 cm deep), J-roots **(3:13:15)** increased survival by 18 to 27 percent! Extrapolating the equations in figure 1 suggest that 90 percent survival could have been obtained if roots had been planted in a 22 cm to 28 cm deep hole. Unfortunately, the researchers made no holes this deep. Perhaps they were following recommendations that holes only be 15 cm to 20 cm deep (Martin and others 1953). in Virginia, planting holes using a OST bar are typically only 17 cm to 20 cm deep (Dierauf 1992).

A new OST planting bar can be used to make a 25 cm deep hole and a new Whitfield planting bar can help make a 34 cm deep hole. Ursic (1963) and Biian (1987) planted trees deep using a 45 cm bar. Malac (1965) recommends using a dibble with a 30 to 35 cm blade when planting Grade 1 seedlings but his recommendation is rarely followed. Therefore, when planting roots in holes only 8 to 19 cm

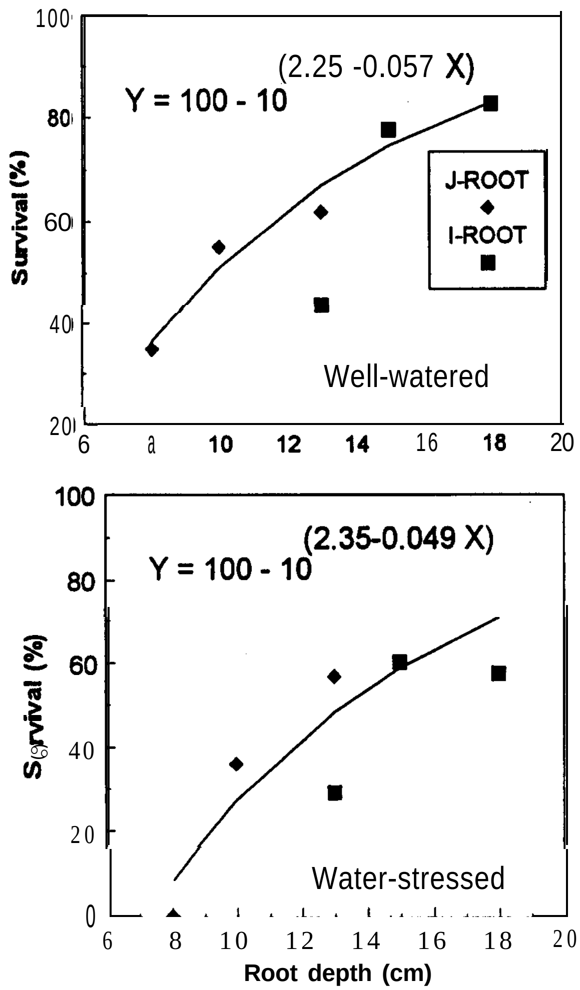

Figure l-The effects of root depth, water stress and root form on the survival of loblolly pine seedlings 12 weeks after planting in shallow holes (8 to 18 cm deep) in a greenhouse (adapted from Brissette and Barnett 1989). Each equation was derived using five means.

deep, tree planters should expect some mortality (even under well-watered conditions in a greenhouse).

Results from U-root and depth of planting trials caused Wakeley (1954) to conclude that in ordinarily well-conducted planting operations, planting depth probably reduces survival more often and more seriously than any and all other errors in planting combined. He said that U-rooting "usually has a negligible effect on initial survival." I have to assume those that claim U-roots reduce survival do not realize that shallow root depths kill seedlings, root form does not.

I agree with those who say a shallow planting hole is the main reason for increased mortality and not root deformation per se. Tourney (1916) states that "One of the most frequent defects in planting arises from crowding trees with large roots into shallow holes." After evaluating the performance of many operational plantings throughout the South, Xydias and others (1983) stated "Probably root deformation, per se, has no effect on survival. A too shallow planting slit results in root deformation, but the real cause of mortality is shallow planting." Seiler and others (1990) said "instructing planters to avoid J-roots by pulling back up on the seedlings when they are planted in the bottom of planting hole may do more harm than good since the end result could be shallower root placement."

Twenty studies that compared l-roots with bent roots of southern pines are listed in Table 2. On average, survival of seedlings with bent roots was about 0.8 percent less than seedlings with l-roots. However, in almost all cases, bent roots had less root depth than l-roots. Therefore, confounding exists between root depth and root form.

EFFECT OF BENT ROOTS ON SHORT-TERM GROWTH

According to Tourney (1916), Möller (1910) conducted a series of experiments with Pinus sylvestris on sandy soil in Prussia and concluded "that it does not matter apparently whether roots are bent to one side, tied together, or crowded into the planting hole. He found that if roots were not permitted to dry out, the above manner of treatment was not likely to kill the trees or even appreciably to check their growth." Tourney (1916) concluded that unnecessary refinements in planting technique should be avoided.

Gruschow (1959) excavated 2,005 loblolly pine seedlings three years after planting. He said it "was impossible to predict the condition of the roots from the above-ground development and appearance of the seedlings. The early growth did not seem to be related to the root classes." After excavating 183 slash pine seedlings, Schultz (1973) concluded that root deformation did not appear to be detrimental to tree growth. Hay and Woods (1974a) excavated 348 saplings and found a positive correlation between root deformation and size of seedlings four to six years after planting. On one site, loblolly seedlings with the most root deformation were more than twice as heavy as seedlings with l-roots. This apparent correlation may be simply due to more root deformation when planting seedlings with larger roots. However, Harrington and Gatch (1999) reported a growth benefit when size at planting was not confounded with root form.

Mexal and Burton (1978) excavated 100 seedlings two to four years after planting. As one might expect, they found a positive relationship between initial seedling size and early growth on all four sites but found no correlation between taproot deformation and height growth. However, on one site, they found a positive relationship between taproot deformation and volume growth (r^2 = 0.10). On a bedded site, they found a positive relationship between planting depth and height (r^2 = 0.14). Harrington and others (1987) excavated 192 loblolly pine seedlings (ages varied from three to nine years old). Half of the trees were from natural or artificial seeding. Although planted trees exhibited more root deformation, there was no difference in growth (i.e. past 3 years height growth) between planted and seeded trees. However, on four plots in Arkansas, they found a total of 3 planted trees that still had roots shaped like an L- or J- (root class #2). These 3 trees averaged 24 cm less growth than 14 planted trees with single taproots (root class #1). Likewise, in the Gulf Coastal Plain, they found a 12 cm difference in growth between l-roots (22 trees) and J-roots (7 trees). They conclude that root system deformation and orientation are factors in the long-term performance of loblolly pine plantations.

Table 2-Effect of root distortion on outplanting survival percent of bare-root pines in the southern United States (Wakeley 1984, Ursic 1983, Little 1973, Hay and Woods 1974b, Hunter and Maki 1980, Woods 1980, Dierauf 1992, Harrington and Howell 1998). In no case was a statistically significant difference reported

Year	Species	Straight roots	Bent roots	Root form	Difference
1954	Longleaf	86	86	U	0
1954	Longleaf	82	42	U	0
1954	Longleaf	62	88	U	+6
1954	Slash		69	U	+7
1954	Slash	96	56	U	-15
1954	Slash	87	94	U	-2
1963	Loblolly		75		-12
1963	Loblolly	89?[a]	89?	U	?
1963	Loblolly	94?	94?	U	?
1973	Loblolly	89	86	L+J	-3
1973	Loblolly	60	67	L+J	+7
1974	Loblolly	90	90	J	0
1980	Loblolly	89	91	Curl	+2
1980	Loblolly	70	78	L	+8
1980	Loblolly	55	51	L	-4
1992	Loblolly	95	82	ψ	+2
1992	Loblolly	95	100	ψ	+5
1992	Loblolly		97	ψ	+2
1998	Loblolly	87[b]	80[c]	J	-7
1998	Loblolly	76[d]	80[c]	J	+4

~-Questionable data.
Planted with shovel-roots not pruned.
[c] Planted with hoedad-roots not pruned.
[d] Planted with hoedad-roots lightly pruned.

Seiler and others (1990) found no difference in third-year height growth between J-roots and l-roots. Likewise, Dierauf (1992) found no difference in height growth between l-roots and w-roots. In contrast, Harrington and Gatch (1999) found better height growth for seedlings that were J-rooted.

EFFECT OF BENT ROOTS ON LONG-TERM GROWTH

An argument against bent taproots planted deeply is that something bad might happen to the stand after it reaches an age of 20 or 30 years. Stated another way, deep planting and the associated root deformation might be bad even if we cannot prove it to be so today. Indeed, observations from Europe suggest this might have occurred with pine and spruce in Germany and Austria (Tourney 1916). Since scientists cannot prove a null hypothesis, advocates of the "push-down" technique cannot prove that something bad will not happen in the future. They can only say that in one study, nothing bad happened for 24 years (Hunter and Maki 1980).

EFFECT OF BENT ROOTS ON TOPPLING

'Toppling" occurs when high winds blow over young (1 to 6 year-old) seedlings. Toppling is almost non-existent for slow-growing wildlings but it is a problem on planted trees in some countries, especially on sites with high water tables. However, even in areas with hurricanes, toppling of bare-root southern pines is rare. In a recent review, none of the 125 cited references dealt with the southern pines (Rosvall 1994). infrequent toppling has occurred on good sites between the ages of 3 and 5 (Klawitter 1969, Hunter and Maki 1980; Harrington and others 1989), especially when the foliage is loaded with ice or snow. Older loblolly pine trees tend to snap as opposed to lean (Fredericksen and others 1993). However, intuition suggests to some (Gruschow 1959) that when shallow planted seedlings are so cramped that they defy classification, high winds might cause toppling.

There are some who say that slit planting affects toppling more than J-rooting. For example, Schultz (1973) excavated five slash pine seedlings that had blown over. Although all five had deformed taproots, he concluded the primary reason for toppling was compression of the lateral root system as a result of slit planting (there was only one or no lateral roots on the windward side of the tree).

Intuition suggests that toppling might be negatively related to planting depth. Klawitter (1969) believed that toppling increased when roots were planted parallel to the surface (and on wet soils). The "ball-and-socket" effect that precedes toppling might be reduced when the stem above the root-collar is supported by 15 to 18 cm of firm soil. There is word from New Zealand that the "pull-up" method of tree planting results in more toppling than planting the seedlings deep. If toppling becomes a problem in the South when using intensive methods on old-field sites, this would be an interesting hypothesis to test.

EFFECT OF BENT ROOTS ON SINUOSITY

For pines, sinuosity of the stem (also known as speed-wobble) is related to genetics and growth rate. Slow growing provenances of loblolly pine have less sinuosity than fast growing provenances (Anonymous 1993). The heritability for bole sinuosity can range from 0.2 to 0.35 for loblolly pine and 0.2 to 0.55 for Pinus radiata D. Don (Bail and Pederick 1989, Anonymous 1993). If the bole is sinuous, the branches will also be sinuous (genetic correlation = 0.93 or greater). In Australia, sinuosity occurs on old-field sites with high fertility (Birk 1991, Touvey and others 1993).

Some believe that crooked stems can result from toppling. Some pines that have a 50° lean at age 2 will recover to a 5" lean by age 8 (Harris 1977). As seedlings gradually recover, compression wood forms on the underside of the lean. Although this enables the seedlings to recover, some of the seedlings develop a crook in the stem (Harris 1977).

If shallow planting results in toppling, this can cause crooked stems. Gatch and Harrington (1999) excavated 144 trees and observed stem sinuosity on trees with and without straight taproots. The amount of sinuosity on trees with bent taproots was about twice as great as trees with straight taproots. If a "ball-and-socket" results in toppling, then this might explain the apparent correlation between bent roots and sinuosity. Also, if fast-growing seedlings are planted on a lean, this might also result in the formation of compression wood and sinuosity. Examination of empirical trials (e.g. Harrington and Howell 1998) will confirm or fail to confirm the hypothesis that L-roots cause sinuosity.

CONCLUSIONS

For bare-root loblolly pine or slash pine, shallow planting (regardless of taproot form) can kill seedlings. Therefore, a loblolly pine seedling that has a bent taproot but is planted deeply (on a drained soil) will have a higher probability of survival than a shallow planted seedling with a straight taproot. Research needs to be conducted to determine if planting seedlings deep will reduce the frequency of toppling and subsequent butt-sweep.

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MANAGEMENT OF DROUGHN SITE: TYPIC QUARTZIPSAMMENTS, ECOLOGICAL CONSIDERATIONS'

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Abstract-Pine plantations on Typic Quartzipsamments in East Texas are difficult to establish. Forest management options following clearcutting are limited. A 12 year regeneration study of the growth and survival of loblolly, ***Pinus taeda*,** L. shortleaf, ***P. echinata*** Mill., slash, ***P. elliotii*** Engelm and longleaf pines ***P. palustris*** Mill. was conducted to determine optimum tree species and treatments for reforestation. With successful regeneration also comes insects and pathogens. Impacts of the Nantucket pine tip moth, *Rhyacionia* ***frustrana*,** (Comstock) and the Texas leaf-cutting ant, ***Atta texana*,** (Buckley) will be discussed in the context of droughty site management.

INTRODUCTION

In Nacogdoches and Rusk counties, sandhills are characterized by Quartzipsamments. The Tonkawa soil series is classified as thermic coated Typic Quartzipsamments, and accounts for approximately 5000 ha in Nacogdoches, Rusk, Panola, and San Augustine counties (Dolezel 1980). These soils are characterized by low fertility, rapid permeability and extreme acid reaction. The original vegetation on the sandhills was an association of longleaf pine (*Pinus palustris* Mill.), turkey oak (Quercus *laevis* Walt.) and bluejack oak (*Quercus incana* Barb.), commonly called scrub oaks and pineland three-awn (*Aristida stricta* Michx.), commonly known as wiregrass (Hebb 1957). The primary land use on Tonkawa soils today is pine and wildlife management although the potential for pine is low due to droughty and infertile nature of the sand. Watermelons can be grown, but potential is low for any other cultivated crops. Sandhills are resistant to erosion and are considered important ground water recharge areas.

From 1973 to 1975 approximately 1400 ha on Tonkawa were clearcut followed by extensive site preparation. Removal of all organic matter and surface litter from the site exposed the bare mineral soil to the sun and wind, which greatly decreased the moisture holding capacity of the soil and increased surface temperatures (Kroll and others 1985). Repeated attempts were made to regenerate the area without success. Intensive management on this sensitive site provided incentive for a regeneration study.

From 1983 to 1990 a study was conducted (Tracey and others 1991) on the site to determine the survival and growth of seven species/treatment combinations. Species/treatment combinations were: untreated loblolly pine *Pinus faeda,* L., Terra-Sorb® treated loblolly, kaolin clay slurry treated loblolly, untreated slash pine P. *elliotii* Engelm, Terra-Sorb@ treated slash, kaolin clay slurry treated slash, and containerized longleaf pine. The objectives of this study were to determine optimum tree species and treatments for reforestation: and to recommend practical alternative land uses and management strategies for Typic Quartzipsamments.

Containerized longleaf yielded the highest survival (> 50 percent) throughout the study, followed by loblolly Terra-Sorb@ treated pine (38 percent) all other treatments were unacceptable (below 30 percent by the end of the 12 year). Tracey and others (1991) recommended: 1) Encourage harvest systems that minimize site exposure and leave residual overstory; underplant pine; avoid clearcutting. 2) Site preparation on previously clearcut sites must be accomplished with minimal site disturbance and topsoil displacement. 3) Reforest droughty sites in East Texas with longleaf pine using container grown seedlings or loblolly pine treated with Terra-Sorb@. 4) Manage for non-timber resources, including wildlife, limited recreation, and groundwater protection.

With successful regeneration also comes insects and pathogens. Artificial monocrop systems in forestry are of recent origin and their effects on the emergence of new pests and diseases are more likely to be the direct result of environmental change (Way 1981). Heavy winter and spring precipitation followed by periods of drought during the summer for the past two years and characteristics of the soil has caused undue stress to trees. Minor impact caused by insect and pathogens on the Tonkawa series include the Nantucket pine tip moth (NPTM), ***Rhyacionia frustrana*,** (Comstock). The Nantucket pine tip moth (NPTM) is widely distributed throughout the eastern and southern United States. NPTM are larval feeders of meristematic tissue of young pines causing significant damage, particularly in areas where forest regeneration practices favor its proliferation (Yates and others 1981). Larval feeding severs the conductive tissue in the tip, causing it to turn brown and die. Infestations can result in growth loss, excessive branching, multiple terminals and deformed bushy trees and is of primary importance in even-age management of loblolly and shortleaf pines. While NPTM are a major forest insect pest in pine plantation management, on the Tonkawa study site they are secondary pests compared to the impacts caused by the Texas leaf-cutting ant, *Affa* fexana (Buckley).

Atta *fexana,* confined to Texas and Louisiana, is the northernmost representative of this most specialized genus of Attini, a New World tribe of fungus-growing myrmicine ants. The range of the ant occupies much of the area of Texas and Louisiana lying between 92.5 and 101 degrees of longitude. In Texas, the range extends from near the Oklahoma border to the extreme southern border,

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with an extension into northeastern Mexico as far south as Vera Cruz.

Atta ***texana*** shows a decided preference for nesting in sandy or sandy loam soils, but is also capable of nesting in heavy soils and those of limestone origin (Smith 1963). These nesting areas (mounds) are most often found on the tops and sides of ridges where the water table is deep and nests can reach depths of 6 m (Moser **1967,1984).** ***Atta texana*** overturn the soil in excavating their tunnels and chambers. In building these tunnels and chambers, materials transported to the surface by ants are mixed with body fluids to form uniform pellets of soil (Weber 1966). The tunnels and chambers that *A.* ***texana*** construct in the soil are numerous and extend deeper than those of vertebrate animals. The nest area is usually marked by crescent shaped mounds about 15 to 30 cm in height and about 30 cm in diameter. Nests are conspicuous and abundant, reach sizes of 15 to 25 m across, and have a decided impact on the forest landscape.

Atta texana shows a decided preference for grasses, weeds, and hardwood leaves. These leaf parts are gathered and used to cultivate their fungus. They prune the vegetation, stimulate new plant growth, break down vegetable material rapidly and in turn enrich the soil **(Hölldobler** and Wilson 1990). ***Atta texana*** is a forest pest because it cuts the needles from both natural and planted pine seedlings. The pines usually escape destruction as long as there is other green vegetation, but in the winter pine needles satisfy the ants' need for green plant material (Moser 1967). Spatial distribution of *A.* ***texana*** is based on suitable habitat availability. The clearcutting disturbance of the study site quickly became a matrix (the most extensive and most connected landscape element type present, which plays the dominant role in landscape functioning) of ideal ant habitat. Ant densities are normally higher in secondary than in primary vegetation (Haines 1978). Nest dimensions are significantly correlated with distances foraged by various species of leafcutters (Fowler and Robinson 1979). ***Atta*** foraging patterns are influenced by the availability and locations of preferred plant species in its territory (Waller 1982). Adaptations in their pattern of the nest distribution enables ants to use the food available in the habitat more effectively and to reduce the unfavorable results of competition among societies, which limit their reproduction and numbers (Cherrett 1968).

OBJECTIVES

The objectives are to:

1. Determine the overall effects of ***Atta texana*** on soil texture, and organic matter within the mound and adjacent areas;
2. Estimate the landscape area affected by ***Atta texana*** on different sites on an area on the Tonkawa soil series of thermic coated Typic Quartzipsamments; and

METHODS

The study area is located along the FM 1078 road corridor (right of way) and an area of regeneration north of the Tonkawa camp, located in northern Nacogdoches and southern Rusk counties, IO km west of Garrison, Nacogdoches Country, Texas. ***Atta texana*** show a decided propensity for the Tonkawa soil series of thermic coated Typic Quartzipsamments for their mounds.

Soil samples were collected from 30 *A.* ***texana*** mounds found on the Tonkawa soil series. Samples were taken on the surface, and at depths of 15 and 50 cm on the *A.* ***texana*** mounds (an area currently being impacted by *A.* ***texana*).** This procedure was replicated on the inter-mound area (an area once effected by *A.* ***texana***) and from a control area of similar physical characteristics away from the area of influence for a total of nine samples per mound. All soil samples were **catalogued,** oven dried, and sifted with a IO gauge soil sieve. Loss on ignition methodology of each soil sample was processed in a muffle furnace at a temperature of 500 **°C.** This determines the percent of organic matter lost to the nearest 0.01 percent. Bouyoucos analysis (Bouyoucos 1962) was performed on 100 grams of each soil sample to determine the percent clay, percent silt and percent sand.

Using aerial photographs and ground truthing, all mounds and foraging openings were located in the regeneration study area. All nesting mounds and created forage openings were measured in the four cardinal directions (north, south, east, and west). This was done to measure the overall impacts of the nesting and foraging territories on the forest landscapes.

RESULTS AND DISCUSSION

Regeneration studies on the Typic Quartzipsamments indicate the best survival with Terra-Sorb@ treated loblolly pine followed by **longleaf** pine. Impact of leaf-cutting ants was greatest on loblolly pine. Currently there are 52 openings found throughout the study area. The total area of the study is 78 ha or 78,000 sq. m. Total defoliation attributed to *A.* ***texana*** accounts for 16,380 square m or 21.5 percent of the total landscape area. The immediate nesting areas or mounds account for 1.25 percent of the total area affected by *A.* ***texana.*** Not all disturbance areas contain mounds due to natural mound mortality or chemical treatment with methyl bromide. ***Atta texana*** in overturning the soil in excavating their tunnels and chambers has an effect on organic matter and texture of the Tonkawa soil series. In building these tunnels and chambers materials transported to the surface by ants are mixed with body fluids to form uniform pellets of soil. ***Atta texana*** significantly increases the percent clay; the percent clay in the pellets of nest mound craters was statistically more significant than at the intermound surface and the control surface at the a = **.05** percent level. In comparing percent clay by depth, the mound surface was statistically more significant (5.6 percent clay for the pellets of the nest mound crater compared to 3.9 and 3.6 percent for 50 cm depths and the internest surface, respectively. at the a = **.05** level).

Soil brought to the mound surface by *A.* ***texana*** is significantly lower in percent organic matter than the percent organic matter present in the soil at the intermound and control surfaces. Organic matter for the mound at 15 cm. and 50 cm. is statistically higher than the same depths at the intermound and the control at a = **.05** percent confidence interval.

Atta texana uses created openings and disturbances (an event or events that causes a significant change from the normal pattern in an ecological system, **Forman** 1997) to create nesting areas and benefit from the use of corridors (a narrow strip of land that differs from the matrix on either side) in their expansion. *Atta texana* reacted to the monocultural habitat and dispersed in all directions loss to the **loblolly** plantation in the area.

The relationship of *A.* ***texana*** to topography and depth above the water table are being examined to develop a landscape model to ascertain the effects of both terrain and location of the ant mounds and the influence of *A. fexana* on the forest landscape. Each central nest mound of A. fexana are being located use GPS systems and transferred to rectified photography for the area. Each mound is located in relation to the topography of the site. Generally, *A. fexana* is located more that 1.5 m and less than 8 m from the water table. Vegetation on active ant mounds are generally dominated by species not preferred by A. *fexana.* Our current research indicates a predominance of post oak, **bluejack** oak, sumac, yucca, hickory, sassafras, grape vine and dog fennel on the sites. This vegetation flourishes following the colonization of the site by *A. fexana.* Educational activities for the area include use in teaching forest entomology, landscape ecology, environmental science and teacher education in environmental science. The importance of teaching in the area includes the inclusion of management of a forest resource; ecology of an organism; and inclusion of teaching constructs from environmental science. Evaluation of the influence of A. *fexana;* on the landscape includes using the components of structure, function and change to evaluate corridors, patch dynamics and the influence on the matrix in long-term evaluation of a droughty landscape. The measurement of change on the forest matrix by *A. fexana* gives a graphic example of the influence of social insects on the landscape.

Atta fexana serves an important ecological function of soil amelioration and increases biodiversity, especially on the very sensitive ecosystem of the Tonkawa study area. *Atta fexana* is unique in regards to soil preference, its nesting mounds, foraging areas and spatial distribution. Repeated efforts at regeneration and control of *Atta* fexana in certain areas of the study area has failed. Therefore, recommendations include 1) native vegetation be allowed to grow in the openings created by *Atta fexana 2)* the area be managed for wildlife and limited recreation 3) *Atta fexana* be allowed to continue their biological function of soil improvement and 4) the area could be utilized as an important teaching aid for forest pest management and forest entomology laboratories because of the unique nature of the area in regard to the pathogens and insects present.

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STEM SINUOSITY, TREE SIZE, AND PEST INJURY OF MACHINE-PLANTED TREES WITH AND WITHOUT BENT TAPROOTS: A COMPARISON OF LOBLOLLY AND SLASH PINE[1]

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Abstract-Twenty-four machine-planted stands each of slash (*Pinus elliottii* Engelm.) and loblolly pine (*Pinus taeda* L.) (between ages 3 to 10 years) were randomly selected in the Coastal Plain and Piedmont of Georgia, respectively. Ten points per site were located along a transect and two planted trees within a 10-m radius of each point were selected to best represent high and low levels of stem sinuosity (240 pairs per species). All trees were measured for size, pest injury, and a visual index of stem sinuosity. Three pairs were excavated to characterize taproot shape. When comparing trees with high versus low levels of sinuosity, paired t-tests revealed trees from both species were slightly smaller in size and pest injury was greater for loblolly pine. Levels of stem sinuosity were medium to high for 73 percent and 77 percent of slash and loblolly pine with bent taproots, respectively.

INTRODUCTION

Published research on the planting of southern pines indicates mixed beliefs on the possible long term effects of establishing seedlings with bent taproots. Several studies have found no effect from bent taproots on survival and growth of southern pines (Gruschow 1959, Hay and Woods 1974a and 1974b, Hunter and Maki 1980, Schultz 1973, Woods 1980). Even fewer studies have identified negative effects on the survival and growth of southern pines planted with bent taproots(Harrington and others 1987, Harrington and Howell 1998). Research on other conifer species have shown these same mixed results (Haase and others 1993, Lacaze 1968).

An association was identified for radiata pine (*Pinus radiata* D. Don) in which restricted vertical development of the taproot was associated with stem sinuosity (Balneaves and De La Mare 1989, Mason 1985). Mason (1985) estimated for radiata pine that the number of top quality clear logs produced per hectare could be reduced by up to 36 percent in the presence of high levels of stem sinuosity. After field observations throughout Georgia indicated a possible association between stem sinuosity and the presence of bending in the taproot, we initiated a retrospective study to compare stem sinuosity, tree size, and levels of pest injury of loblolly pine with bent versus straight taproots (Gatch and others [in press]). If reductions in the level of stem sinuosity could be made by modifying planting practices to avoid bending the taproot, such modifications could prove cost-effective due to the potential for large reductions in quality sawtimber crop trees resulting from increased stem sinuosity. Therefore, we designed a follow-up study, similar to that of the loblolly pine study, to investigate slash pine with and without bent taproots. The goal of this paper is to present the slash pine results and compare these with the results from the previous loblolly pine research.

METHODS

Study Sites

For the original loblolly pine study, twenty-four plantations were randomly selected in the Piedmont of Georgia from Conservation Reserve Program plantations. Most of these Piedmont sites have clay subsoil horizons that typically occur at or near the soil surface due to heavy erosion from past agricultural practices (Morris and Campbell 1991). The Conservation Reserve Program (CRP) was a federal program designed to remove a portion of these highly erodible lands from agricultural production by providing financial assistance for reforestation to qualifying landowners. Likewise, twenty-four slash pine plantations were randomly selected in the Coastal Plain of Georgia from lands owned by the Georgia Pacific Corporation and the Union Camp Corporation.

All sites were established through machine planting 1-O bare-root seedling stock. Selections for both species were stratified such that three plantations were chosen within each of eight, one-year age classes between 3 to 10 years. In the Piedmont, loblolly pine sites were selected so that approximately half of the plantations had received a subsoiling treatment and half had not. In the Coastal Plain, slash pine sites were selected so that one plantation in each age received either a single bedding, single bedding with discing, or a double bedding site preparation treatment. Transects were then established across each plantation with ten sample points located at 20-m intervals.

Vegetation Measurements

All vegetation measurements were conducted from late June to early August 1996 and 1998 for loblolly and slash pine, respectively. A visual index was used for measuring sinuosity that combined the frequency and intensity of stem oscillations into a 0- to g-point scale (Gatch and others [in press]). This index was used to make estimates of sinuosity on all trees with a 3.59-m radius of each sample point in order to determine the overall level of stem sinuosity for the 24 study sites per species. Branch sinuosity also was estimated for each tree using a similar approach.

A paired-tree sample was used to locate two planted trees within a 1 O-m radius of each point to represent high and low levels of stem sinuosity (n=240 pairs per species). Each tree

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was measured for diameter at breast height (dbh, mm), height (cm), and crown density (percent, after Belanger and Anderson **1992),** and visual estimates were made of the level of stem and branch sinuosity. Estimates also were made visually of current year pest injury from fusiform rust **(*Cronartium quercum* f. sp. *fusiforme*)** branch cankers, Nantucket pine tip moth **(*Rhyacionia frustrana*** Comstock), and southern pine, black turpentine, and **Ips** bark beetles **(*Dendroctonus*** and ***Ips*** spp.) as a percentage of the bole or crown affected (10 percent classes, after **Tallent-Halsell** 1994). The presence of fusiform rust stem cankers was avoided during tree selection due to possible stem deformities associated with this injury.

At each site three sample points (usually points three, six, and nine) were excavated for **taproot** characterization (72 pairs per species). All excavations were performed using hand equipment and were started approximately 1 m from the base of the tree to preserve its root configuration. Excavation was carried to the depth needed to determine the shape of the **taproot** up to a maximum of 60 cm. Upon extraction, **taproot** configuration was assigned into one of four categories: straight and single, bent and single, straight and multiple, or bent and multiple. If bending or branching were present then the depth at which the injury occurred was measured (cm). The basal area **(m^2/ha)** of competing trees was calculated by measuring the dbh (mm) of each tree within 3.59 m of the excavated tree.

Statistical Analysis

All statistical test were performed at the 95 percent significance level using SAS (1989). Paired t-test were used to determine significant difference in dbh, height, crown density, and current year pest injury between high and low levels of sinuosity on the 240 pairs of trees per species. A likelihood ratio chi-square (G) test was used on the 144 excavated trees per species to test the null hypothesis that the frequency of trees with bent versus straight **taproots** was independent of stem sinuosity index (Sokal and Rohlf 1981). For some cells the frequency of trees with bent versus straight **taproots** for each value of stem sinuosity index was less than five. To ensure validity of the test (Sokal and Rohlf **1981),** stem sinuosity index values were lumped into low, medium, and high values (0 to **2=Low,** 3 to **5=Medium,** and 6 to **9=High).** Analysis of variance **(ANOVA)** also was used on the data from the 144 excavated trees per species to identify significant differences in size, current year pest injury, and stem and branch sinuosity levels among **taproot** configurations. In the **ANOVA, taproot** configuration was specified as a two-by-two factorial design (bent versus straight **taproots** x single versus multiple taproots), stand was included as a blocking factor, and basal area of competing trees was used as a covariate when significant **($P<0.10$).** In order to normalize their distributions, dbh and height were log transformed and all percentage values were converted to proportions and subjected to an arc-sine square root transformation (Snedecor and Cochran 1980). When the interaction term in the **ANOVA** was significant, multiple comparisons of means were conducted with Bonferroni probabilities (Snedecor and Cochran 1980).

RESULTS

Results of the paired t-test for slash pine revealed that dbh, height, and crown density were 3 percent, 5 percent, and 7 percent smaller, respectively, for trees with high versus low levels of sinuosity **($P<0.02$).** Similar results from loblolly pine indicate that trees with high levels of sinuosity were 8 percent, 8 percent, and 14 percent smaller for dbh, height, and crown density, respectively **($P<0.001$).** However, where injury from fusiform rust, tip moths, and bark beetles were significantly higher in the presence of high levels of stem sinuosity for loblolly pine **($P<0.05$),** no significant differences were found in injury level for slash pine.

For slash pine, only the main effect of bent versus straight **taproots** was found significant for any response variable in the **ANOVA.** For loblolly pine, however, not only was the main effect of bent versus straight **taproots** significant for all response variables, but the main effect of single versus multiple **taproots** was also found significant for branch sinuosity. Height proved to be the only size variable significantly smaller (9 percent, **$P<0.001$)** in the presence of **taproot** bending for slash pine. Though not significant, means for both dbh **($P=0.126$)** and crown density **($P=0.076$)** were 3 percent smaller in the presence of bent taproots. Dbh, height, and crown density were 9 percent, 7 percent, and 8 percent smaller, respectively, in the presence of bent **taproots** on loblolly pine **($P<0.01$).** Average stem sinuosity index for both loblolly and slash pines with bent **taproots** was found to be over two to three times greater, respectively, than that of trees with straight **taproots ($P<0.001$).** Difference in branch sinuosity index were similar, but smaller in magnitude (1.5 to 2 times greater for slash and loblolly, respectively). The only significant response for an injury variable was a slight, but significant increase in **tipmoth** injury for loblolly pine in the presence of bent **taproots ($P=0.009$).**

Results of the chi-square (G) test for slash pine **($G=29.3$; $P=0.001$)** were similar to those for loblolly pine ($G= 35.3$; **$P=0.001$)** indicating that the frequency of trees with bent **taproots** was not independent of stem sinuosity index for either species. Seventy-three percent of slash pine trees with bent **taproots** had medium to high levels of stem sinuosity (77 percent for loblolly pine), while 78 percent of trees with straight **taproots** had low levels of stem sinuosity (71 percent for loblolly pine).

Average sinuosity index values of all 24 sites for both species indicated that the overall level of stem sinuosity was medium for both slash (3.2, **s.e.=0.05, n=1496)** and loblolly pine (2.6, **s.e.=0.03, n=1327).** A frequency distribution of trees per stem sinuosity index value indicated that 57 percent of slash pine and 49 percent of loblolly pine had medium to high levels of stem sinuosity.

DISCUSSION AND CONCLUSIONS

A comparison of the results of this retrospective analysis of slash pine with the previous research on loblolly pine reveals many similarities. For both species, trees with high levels of stem sinuosity were somewhat smaller in stem size and crown density. An association between high levels of stem sinuosity and higher levels of pest injury was found for loblolly pine, but was not evident for slash pine. After excavation of a subset of trees, presence of bending in the **taproot** was found to have a significant effect on both slash and loblolly pine. Slash pine height was significantly shorter in the presence of bent **taproots** while both dbh and crown density were smaller, although these differences were not statistically significant. Similarly, all size variables were significantly smaller in the presence of bent **taproots** for loblolly pine. In addition to size differences, trees with bent **taproots** had two to three times the mean value of stem sinuosity index as those with straight taproots. It was found that a large majority of trees for both species with bent **taproots** (73 percent for slash, 77 percent for loblolly) had medium to high levels of stem sinuosity, while 78 percent and 71 percent of slash and loblolly pines, respectively, with straight **taproots** had low levels of stem sinuosity.

Results from both southern pine species are quite similar to those found by Balneaves and De La Mare (1989) for radiata pine. Their research indicated that stem sinuosity of radiata pine increased with decreasing depth of subsoiling and penetration and with decreasing straightness of the **taproot.** Although Balneaves and De La Mare (1989) found no significant differences in tree size with increasing stem sinuosity of radiata pine, our results indicate a similar response in which a small reduction in tree height was detected slash pine and relatively small reductions were found in all size variables for loblolly pine, although differences were statistically significant.

Although the biological mechanism involved in the association between bent **taproots** and increased stem sinuosity has not been identified, the results of this research indicate an association between the establishment of southern pines with bent **taproots** and reduced stem quality that may prove to be problematic for land managers. Since a retrospective approach was used in this research and no biological mechanism has been identified, a direct causal link between bent **taproots** and increased stem sinuosity cannot be inferred. However, these studies indicate a need for further research into the possible mechanisms driving this relationship and a need for research on how modifying planting practices and planting machine specifications could affect the frequency and intensity of **taproot** bending during planting.

ACKNOWLEDGMENTS

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THE Y-LT REVISITED: LOOKING BACK AFTER 10 YEARS[1]

Larry M. Bishop and Clair H. Redmond[2]

Abstract-This assessment surveys the changes in the softwood timber resource of the former Yazoo-Little Tallahatchie Flood Prevention Project (Y-LT) area between 1985, when the project closed, and 1995, when the latest Forest Inventory was completed. Economic and forest inventory data for the area were compared with similar data for the State of Mississippi to evaluate parity. During the lo-year period in the Y-LT counties, total softwood timberland area increased; total softwood volume decreased; the number of 2" to 6" DBH class live softwood trees increased substantially. The Y-LT economy also increased significantly in terms of population, employment, per-capita income, value added, and total industrial output. Although softwood removals exceeded softwood growth in 1994 for both the Y-LT counties and the State, softwood growth will likely exceed softwood removals in the near future if harvesting does not increase materially above 1994 harvesting levels. Y-LT stumpage prices increased considerably over the IO-year period. The data suggest that the forest economy of the Y-LT counties has reached relative parity with the State of Mississippi.

INTRODUCTION

During its heyday, the Yazoo-Little Tallahatchie Flood Prevention Project (Y-LT) was the largest tree planting project that the United States had ever undertaken. It was the result of federal legislation that ensued after nearly one hundred years of exploitative logging, land clearing, and farming in north Mississippi. By the 1940's, much of the highly-erodible loessial soils, and the underlying sands, of the Yazoo and Little Tallahatchie River watersheds had washed from fields and forests into the stream channels and fertile bottomlands. Sixty-five percent of the bottomland fields suffered annual flooding and large depositions of sterile sand. The land — and the people — had become impoverished.

Congress was convinced that a federal flood control program was needed. It passed the Flood Control Act of 1944. This Act was the most important piece of federal flood control legislation in the nation's history. It explicitly committed the Federal government to massive flood control work — including erosion control work on privately-owned lands. As a result, the Y-LT Flood Prevention Project was officially launched in 1947. Its major objectives were: reduction of flood water and sedimentation damage, proper land use, channel stabilization, and improvement of the affected local economies. Congress appropriated funding for the program to the USDA Soil Conservation Service (SCS), which then allocated funds for forestry activities to the USDA Forest Service (USFS). .

All or parts of 19 counties were included in the Y-LT Project area (Map 1). Its boundaries included all of Calhoun, Grenada, Lafayette, Panola, and Yalobusha counties; most of Carroll, DeSoto, Holmes, Marshall, and Tate counties; substantial acreages in Benton, Pontotoc, Tallahatchie, and Union counties: and small portions of Chickasaw, Montgomery, Tippah, Webster, and Yazoo counties.

The Y-LT was a multi-agency project. Along with the SCS and the USFS, other federal agencies involved included the Agricultural Stabilization and Conservation Service (ASCS), the U.S. Army Corps of Engineers, and the Farmer's Home Administration. State cooperating organizations included the Mississippi Forestry Commission, Mississippi Cooperative Extension Service, and the Mississippi Forestry Association.

The SCS was assigned the overall program responsibility, as well as authority, to plan programs for open land, structures, road banks, and stream channel improvements.

The primary role of the USFS was to plant trees for erosion control. During 1959, the peak year for tree planting, over 50 million seedlings were planted. In 1960, 46 million seedlings were planted by well over 1,000 tree planters (including vendor crews). Other USFS duties included: controlling gullies, providing forest management planning and assistance to landowners, providing hydrologic stand improvement (HSI), and promoting good forest management through an information and education program.

Over a period of 35 years of tree planting, a grand total of 835,893 acres were successfully reforested within the Y-LT counties utilizing over 918 million tree seedlings. The Project was completed and closed out in 1985 (Williston 1988).

Within a short time after the Project closed, word spread that a large inventory of merchantable timber would soon be available. Several forest industries located new plants in the former Y-LT Area, and harvesting increased at an astonishing rate. By 1994, many began to wonder if the supply of softwood timber would be sustainable. One factor did help: from 1986 through 1994, an additional 134,000 acres in the 19 Y-LT counties had been reforested, mostly to loblolly pine, under the Conservation Reserve Program (CRP).

OBJECTIVES

The purpose of this assessment was to evaluate the 1995 condition of the forest resources of the former Y-LT Project, and to assess the contribution of forest resources to the local and regional economy. The following questions were to be addressed:

1. What was the status of the forest resources when the Y-LT Project closed in 1985, and what were they in 1995, using the most recent data available?

2. What did the 1995 forest resources contribute to the local and regional economies in terms of employment, personal income, total industrial output and value added?

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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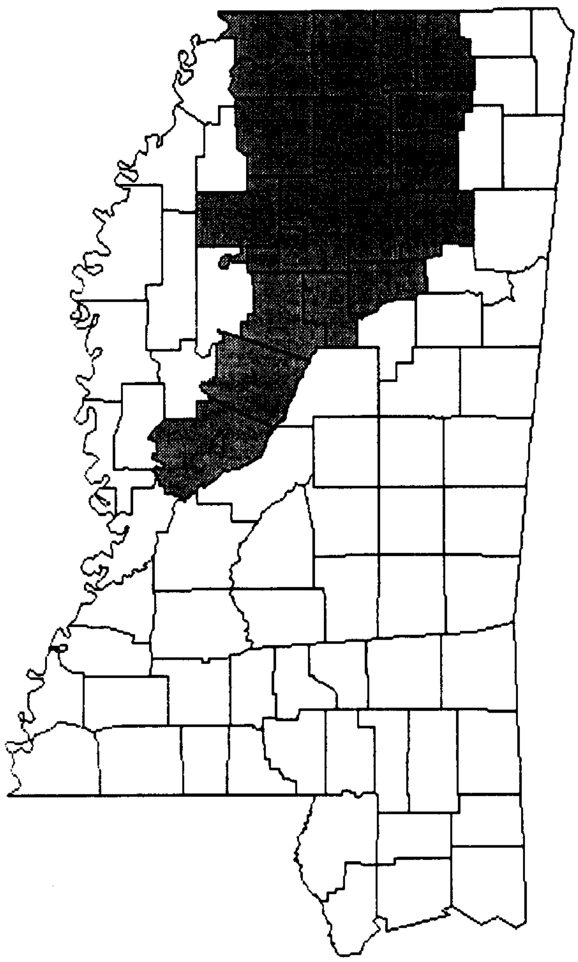
3. What were landowners doing with their forestlands after harvest; i.e., were they converting them to agricultural or other uses?

4. What special actions, if any, are needed by the USDA Forest Service, the Mississippi Forestry Commission, or others to ensure continued stewardship and protection of the forest resources of the former Y-LT Project area?



Map I-Y-LT Counties.

PROCEDURE

Methods

A three-part process was used to address the above questions. The first part was to interview forestry and other experts working in, residing in, or familiar with the forest resource situation in the former Y-LT area, and the State of Mississippi. Next, economic questions were addressed using IMPLAN — an input/output model to describe the local timber economy to estimate impacts of timber sales from forest lands. Statistics from the Mississippi Employment Security Commission were used to show changes in economic variables over time. The third part was to use USFS Forest Inventory and Analysis (FIA) data for survey years 1987 and 1994 in the 19 Y-LT counties and the State.

Persons Interviewed-Twenty seven people were interviewed, either in person or by telephone. These included representatives from: the Mississippi Forestry Commission, the Mississippi Cooperative Extension Service, the USDA Soil Conservation Service (now the Natural Resources Conservation Service), USDA Forest Service; forest industry; private forestry consultants, and nonindustrial private landowners.

Level of decision-Even though the Y-LT included only portions of several of the 19 counties, for the purpose of this assessment the county was the lowest level used. The reason is because the county is the primary level for input and output for both IMPLAN and FIA statistical data (see map). The assumption was made that the Y-LT area was not a closed system but an integral part of a larger forest resource area.

Strategy--A basic three-part strategy was used to: 1) determine the changes in timberland attributes in the 19 Y-LT counties and the State between the 1987 and 1994 FIA survey years, 2) determine the changes in the loblolly-pine forest type in the Y-LT counties and the State between the same survey years (because loblolly was the primary species planted during the Project), and 3) compare economic and forest inventory data between the Y-LT counties and the State of Mississippi to evaluate parity.

RESULTS

Personal Interviews

Personal interviews were conducted during June through October, 1994. At that time, the 1994 FIA survey had been completed and published for all of the Y-LT counties except for Holmes, Tallahatchie, and Yazoo counties. Opinions ranged from mild concern to outright alarm. Most of the consultants were quite satisfied with the present situation, one stating that it was a good time to be a consultant in North Mississippi because there was plenty of work for everybody. Since the FIA data at that time had only recently been published, most of the interviewees had not had time to digest the information. All persons interviewed, though, were concerned about the increased harvesting levels — especially the industry foresters.

Forest Inventory and Analysis

Area-Based on the FIA data, between the 1987 and 1994 forest survey years, total softwood timberland area in the Y-LT counties increased about 346,000 acres or 11 percent, and the loblolly-shortleaf pine forest type area increased about 128,000 acres or 20 percent A major shift occurred from the sawtimber stand-size class area to the sapling-seedling stand-size class area (fig. 1). The ratio between planted and naturally regenerated pine timberland area increased significantly in favor of planted pine timberlands (from 42 percent to 74 percent). These changes were due in large part to the conversion of former agricultural lands to timberland under the CRP mentioned above. The Federal Forestry Incentive Program (FIP) and the Mississippi Forest Resource Development Program (FRDP) also contributed to this increased reforestation.

Likewise, for the State of Mississippi, pine timberland area increased about 20 percent (including longleaf and slash pine), and the percentage ratio between planted and naturally regenerated pine timberland area changed significantly in favor of planted timberlands (from 32 percent

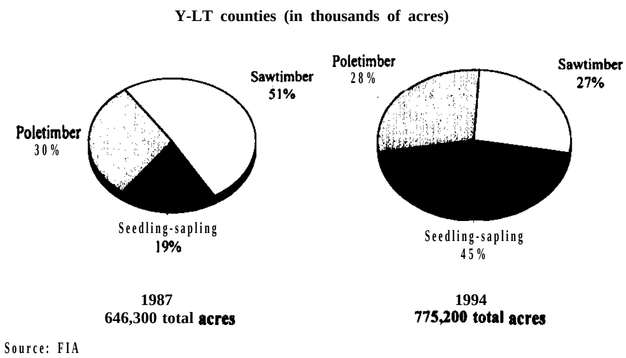


Figure I-Area of loblolly-shortleaf pine timberland by stand-size class.

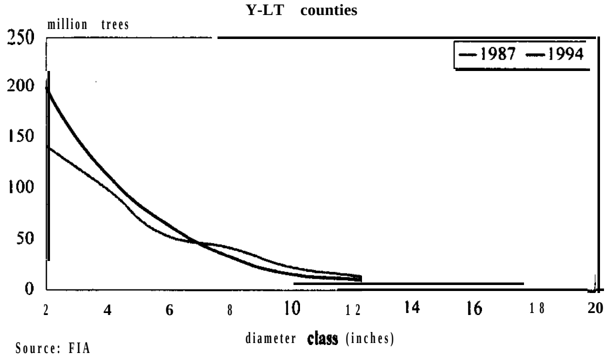


Figure 3-Number of live softwood trees on timberland, by diameter class (2"-20").

to 51 percent). Much of these gains, also, can be attributed to the CRP, FIP and FRDP.

Volume-In the Y-LT counties, total softwood volume was about 246 million cubic feet less in 1994 than in 1967, but the percentage ratio between shortleaf and loblolly pine volume reversed. In 1987, shortleaf comprised 55 percent of the total volume of the pine growing stock while loblolly comprised 45 percent. By 1994, loblolly had increased to 56 percent of the total pine growing stock and shortleaf had dropped to 44 percent.

In 1994, softwood removals exceeded softwood growth for both the Y-LT counties and the State. Both the Y-LT counties and the State sustained considerable harvesting activity between 1987 and 1994. Based on growth to removal ratios (G/R), the Y-LT counties were harvested at a somewhat higher, but comparable, rate than the State (fig. 2).

Number of Trees-The number of 2" to 6" DBH live softwood trees was considerably greater in 1994 than in 1987 for both the Y-LT counties and the State. Again, these increases, in large part, can be attributed to the CRP, FIP and FRDP (figs. 3 and 4).

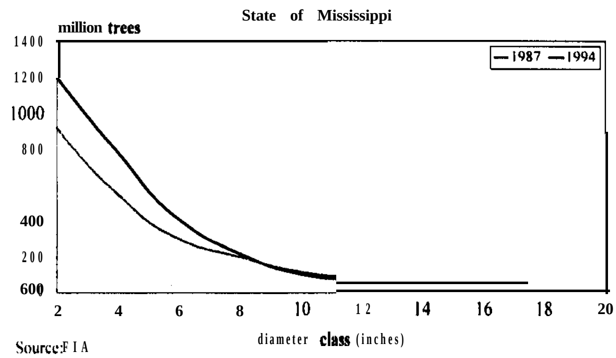


Figure 4—Number of live softwood trees on timberland, by diameter class (T-20").

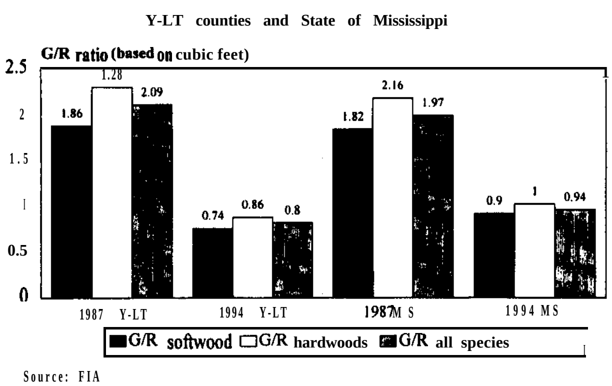


Figure P-Growth to removal ratios (G/R) on timberland.

ECONOMY

IMPLAN

In the Y-LT counties, the forest-based industries share of the total economy was greater in 1990 than in 1977 in terms of total industrial output, value added, and employment. Oriented strand board, particle board, and paper are now the major forest products in the Y-LT counties, in terms of impact on income, total industrial output, and value added. Lumber, sawtimber export, and cordwood export comprise a much lesser share of the impacts (fig. 5). Nearly $71 million of 1992 stumpage in the Y-LT counties led to $483 million in industrial output, $166 million in labor income, $180 million in value added, and 4,456 jobs.

Economic activity in the Y-LT counties has increased significantly. From 1959 to 1990, population increased 18 percent in the Y-LT counties, compared with 20 percent with the State, and 40 percent for the U.S. From 1961 to 1990, employment surprisingly grew an average of 3.7 percent annually compared with 1.8 percent for the State, and 2 percent for the U.S. Per capita income (adjusted for inflation) in the Y-LT counties grew substantially from $4,400 in 1959 to $11,800 in 1990, a 3.2 percent average annual increase, compared with 2.8 percent, for the State, and 2.1 percent for the U.S. (fig. 6).

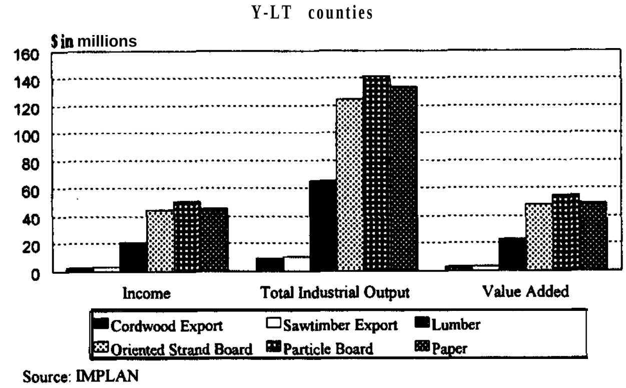


Figure 5—Estimated impacts of 1992 timber harvest.

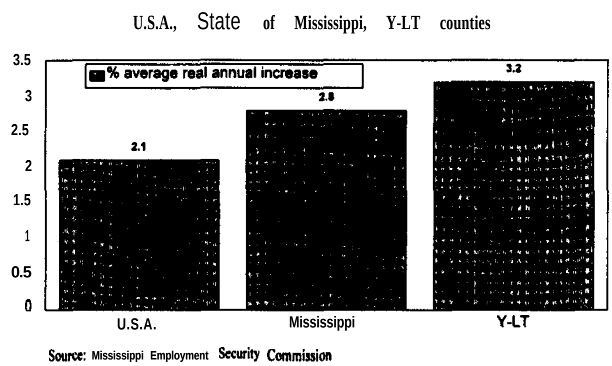


Figure 6—Per capita income growth, 1959-1990.

The Y-LT counties have also become less dependent on agriculture and more diversified with services, trade and government employment. The agricultural share (excluding forestry) of total industrial output decreased almost 31 percent from 1977 to 1990.

Stumpage Prices

From 1985 to 1995, Y-LT standing pine sawtimber stumpage prices and standing pine pulpwood prices nearly doubled, even when adjusted for inflation. This is a direct reflection of the increased demand for the stumpage needed to support the growing consumption of the wood products industry in the Y-LT counties.

CONCLUSIONS

The Conservation Reserve Program (CRP) will have a major impact on the future timberland resources in both the Y-LT counties and the State of Mississippi. Presently, softwood removals exceed softwood growth in the Y-LT counties; however, 45 percent of the loblolly-shortleaf pine timberland area is in the seedling-sapling stand-size class. Softwood growth will likely exceed removals in the near future, unless harvesting increases substantially above 1994 levels. While harvesting activities in the Y-LT counties have increased for both softwoods and hardwoods, they also have for the State. In fact, they are closely comparable.

Based on personal interviews with forestry experts familiar with forestry activities within the Y-LT counties and the State, it appears that most harvested timberland is not being converted back into agriculture. In fact, the opposite appears to be happening. As pine timberlands are harvested, most are regenerated back to pine, either by planting or natural regeneration, and mostly to loblolly pine. The FIA data tend to bear this out.

Forest industry has made some significant gains in utilization of wood residues which, in effect, has extended the available wood supply. A substantial small roundwood/small sawtimber forest products market has developed in the Y-LT counties to produce oriented strand board, particle board and paper. Stumpage prices have increased considerably for both pine sawtimber and pine pulpwood, which has likely served as an incentive for private landowners to reinvest in growing timber on their harvested timberlands. As a result, the economy has increased significantly in terms of employment, income, and regional output, which was one of the primary objectives of the original Y-LT Project.

Generally, the forest economy of the Y-LT counties has reached relative parity with the forest economy of the State of Mississippi. Current government programs appear to be sufficient to sustain the present forest resources situation in the Y-LT counties. Hence, no special program specifically designed for the Y-LT area is needed.

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Natural Regeneration of Pines

Moderator:

LARRY WALKER
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SEEDBED REQUIREMENTS FOR REGENERATING TABLE MOUNTAIN PINE WITH PRESCRIBED FIRE'

Thomas A. Waldrop, Helen H. Mohr, Patrick H. Brose, and Richard B. Baker[2]

Abstract-High-intensity, stand-replacement fires have been recommended to regenerate stands of Table Mountain pine (*Pinus pungens* Lamb.) because its seeds require mineral soil to germinate and seedlings are intolerant of shade. Early prescribed fire efforts resulted in poor regeneration success where crown fires created seedbeds with abundant insolation and thin duff. This study examined regeneration success over a range of shading and duff depth conditions in the field and in a greenhouse. In both trials, stem densities that would adequately regenerate Table Mountain pine stands were found on seedbeds with abundant insolation and thin duff. However, stem density was significantly higher under moderate shade and on duff up to 3 in. thick. These findings suggest that prescribed fires of sufficient intensity to eliminate shade and expose mineral soil are unnecessary to successfully regenerate Table Mountain pine.

INTRODUCTION

Southern Appalachian ecosystems evolved with and are adapted to lightning- and human-caused fires (Van Lear and Waldrop 1989). For 7 to 8 decades fire suppression policies on public lands have probably reduced diversity in Southern Appalachian ecosystems and may threaten the continued existence of some plants. One species likely declining due to lack of fire is Table Mountain pine (*Pinus pungens* Lamb.), a species that is endemic to xeric Appalachian sites from central Pennsylvania to northeast Georgia (Zobel 1969). Throughout the region, stands of this species are entering later seral stages, in which dying pines are replaced by oaks and hickories (Turrill and others 1997). Table Mountain pine has serotinous cones and this suggests that fire may be needed to regenerate the species. Williams (1998) stated that Table Mountain pine stands are in decline as a result of fire suppression and inadequate understanding of the species' regeneration biology.

Research on regenerating Table Mountain pine stands is limited and sometimes contradictory. Zobel's (1969) monograph emphasizes the need for intense fire. He found that serotinous cones opened in lightly burned areas but that seedlings survived only where fire killed the overstory and erosion exposed mineral soil. Williams and Johnson (1992) found that seeds were abundant in lightly disturbed stands where no fire occurred but seedlings did not become established because suitable microhabitat (high insolation and bare soil) was extremely limited. By contrast, Waldrop and Brose (1999) found fewer seedlings where a stand-replacement fire killed all trees than where some trees remained alive to cast shade. They also found that roots of l-year-old seedlings penetrated duff (the 0, and 0, horizons below freshly fallen leaf litter but above mineral soil) up to 3 in. thick, suggesting that bare soil is not necessary for seedling establishment.

This study examined the microsite conditions (shade level and duff depth) where Table Mountain pine was successfully established in two burn units described by Waldrop and Brose (1999). Because the range of shade and duff conditions created by each fire was limited and effects of slope and aspect were confounded, a greenhouse study was conducted to examine the relationship of seedling establishment to a wider range of shade and duff conditions. Results provide an indication of the fire regimes that could be prescribed for successful regeneration of Table Mountain pine.

METHODS

Field Study

A total of 99 sample plots was established in two bum units, one in northeastern Georgia and another in northwestern South Carolina. Plots were 0.05 acre in size and distributed throughout each Table Mountain pine stand to include as much of the stand and, therefore, as many microsite conditions as possible. Fires were prescribed for both areas that would be of sufficient intensity to kill overstory trees and allow abundant regeneration. The Georgia unit was burned in April 1997 and the South Carolina unit in March 1998. Flame heights ranged from 6 to 100 ft in Georgia and from 3 to 40 ft in South Carolina. Waldrop and Brose (1999) give a detailed description of site and burning conditions.

Postburn regeneration and microsite conditions were measured in 28 subplots, each measuring 6 x 6 ft and spaced systematically throughout the 0.05-acre sample plots. All measurements were completed at the end of the first growing season after burning (late August through early September). On each subplot, counts of pine seedlings and cones and the amount of insolation on the forest floor were recorded. Insolation was estimated between 10:00 and 14:00 on sunny days and described as one of the following categories:

1. full shade: no direct sunlight reaching the forest floor,
2. high shade: 1 to 30 percent of the area receiving direct sunlight,
3. medium shade: 31-60 percent of the area receiving direct sunlight, or
4. low shade: 61-100 percent of the area receiving direct sunlight.

Full shade was rarely seen in either bum unit so this category was dropped from analysis. Duff deoth was measured at 10 randomly selected locations immediately

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, IA, February 16-18, 1999.

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outside each of the 99 sample plots. Numbers of cones in crowns were estimated for each Table Mountain pine in each sample plot.

Differences among treatment means were analyzed using a 3 x 3 factorial arrangement of treatments. Factors included the three shade categories described above and three categories of duff depth (0.5 to 1.5 in., 1.6 to 3.0 in., and > 3.0 in.). Pine regeneration density was compared with a one-way analysis of variance using the total number of cones on the ground and in tree crowns as a covariate to adjust for seed source differences. Mean separation was by linear contrast (a = 0.05).

Greenhouse Study

The greenhouse study used a set of shade and duff treatment combinations like the field study but with an additional shade treatment. Duff depths were 0, 2, and 4 in.: shade levels were 0, 30, 63, and 85 percent shade. Although 0 percent shade was never observed in the field, this category was added to the greenhouse study to test seedbed conditions recommended by Turrill and others (1997). Duff depth categories represent the range of post-burn conditions reported by Waldrop and Brose (1999).

Treatments were arranged in a split-plot design with shade as the main plot effect and duff depth as the subplot effect. Soil and duff were collected from the South Carolina bum unit. Soil was placed in 6-in. square pots and duff was added to depths of 2 or 4 in. The desired shade levels were obtained by placing commercial shade cloth over a set of 24 pots, 8 pots (subsamples) for each of the three duff categories. All treatment combinations were replicated three times in a randomized complete block design.

On November 1, 1998, a total of 25 seeds was placed in each pot. Seeds had been collected from 12 trees that were felled in an area adjacent to the Georgia burn unit. Viability was found to be 90.4 percent in a laboratory test using seeds placed on moist paper in petri dishes. Greenhouse temperatures approximated summer conditions with nightly lows of 65 to 70 °F and afternoon highs of 90 to 95 °F. A watering schedule was selected that would roughly approximate the observed rainfall pattern that occurred on the Georgia burn unit during the first growing season after burning. Rainfall at the closest weather station (Clayton, GA) was abundant during the first half of the growing season but infrequent during the second half. From May 15 through June 30, 1997 a total of 18.4 in. of rain was recorded. The maximum period without rain was 4 days. Rainfall from July 1 through August 15, 1997 was only 4.5 in. and there were periods of 12 and 14 days with no rain. To approximate this pattern, pots were watered every 2 to 3 days during the first 45 days of the study and every 7 to 10 days during the second 45 days.

Germination, mortality, and seedling height were measured periodically through January 29, 1999 (90 days after sowing). Differences among treatment combinations for germination, survival, seedling density, and height were detected by analysis of variance with mean separation by linear contrast (a = 0.05).

RESULTS AND DISCUSSION

Duff Depth

Even though seed viability was over 90 percent in the laboratory test, fewer than 70 percent of the greenhouse seeds germinated. Germination varied somewhat by duff depth, with a significantly lower rate on 4-in. duff than on 2-in. duff or on bare soil (table 1). Survival rates for those seedlings that emerged also varied by duff depth. The best survival over the 90-day study was on bare soil (57 percent), which was significantly higher than survival on the 2-in. duff (42 percent) but not significantly higher than survival on the 4-in. duff (50 percent).

The total number of seedlings in each pot at the end of the 90-day study was a function of both germination and survival. It also indicated the relative density of seedlings that could become established under similar field conditions. Seedling density was significantly higher in 2-in. duff than on bare soil or in 4-in. duff in the greenhouse (table 1). Pots with bare soil dried quickly and the seedlings could not benefit from the mulching effect that was probably available to seedlings growing in 2-in. duff. Low stem numbers in 4-in. duff were caused by a lower germination rate and, although it was not measured here, the inability of roots to penetrate duff layers of 23 in. (Waldrop and Brose 1999). The lower

Table l-Germination, survival, and stem density by duff depth in greenhouse and field studies

Greenhouse				Field	
Duff depth	Germination[a]	Survival[b]	Density	Duff depth	Density
Inch	*Percent*		*Stems/pot*	*Inch*	*Stems/acre*
0	64.9a[c]	57.3a	5.7b	*0.5-l .5*	3,749.4a
2	63.0a	41.9b	9.9a	1.6-3.0	5,152.8a
4	56.6b	49.9ab	6.5b	over 3.0	1,338.0a

[a] Percentage of 25 seeds that germinated at any time throughout the 90-day study.
[b] Percentage of germinants that survived to the end of the 90-day study.
[c] Means followed by the same letter within a column are not significantly different at the 0.05 level.

germination and survival on thicker duff likely would not constitute regeneration failure under field conditions. On the thickest duff layer (4 in.), germination and survival were over 50 percent.

The pattern of stem density by duff depth in the field was similar to that in the greenhouse (table 1). Although not statistically significant, stem density in medium duff (1.6 to 3.0 in. thick) was greater than in thin (0.5 to 1.5 in.) or thick duff (> 3.0 in.). Although density was higher in thin and medium duff layers, almost 2,000 seedlings per acre were present in thick duff layers. If most were to survive, those seedlings would produce a stand dominated by Table Mountain pine.

Shade

Differences in germination and survival were more pronounced among shade categories than among duff depths. In the greenhouse study, germination rates were significantly higher under all levels of shade than under no shade (table 2). The best germination occurred under 63-percent shade. Shade also affected the survival rates of germinants. Over 70 percent of germinants growing under 30-percent shade survived throughout the 90-day study (table 2). This survival rate was significantly higher than for germinants growing without shade or under the two highest shade levels.

survival rates under high shade in the greenhouse and low density under high shade in the field emphasize the lack of shade tolerance of Table Mountain pine. The species may be unable to survive without some direct sunlight. Moderate levels of shade, represented by 30-percent shade cloth in the greenhouse or 30- to 60-percent insolation in the field, may provide the best balance of moisture and light. Waldrop and Brose (1999) found that a prescribed fire that was of sufficient intensity to kill understory trees and shrubs but leave the overstory alive would create insolation levels similar to the moderate shade categories. This pattern suggests that high-intensity crown fires are not necessary for Table Mountain pine regeneration.

Duff and Shade Interactions

Figure 1 shows the total number of seedlings per pot at the end of the 90-day greenhouse study for all combinations of duff and shade. Stem density was typically greater in 2-in. duff than in bare soil or 4-in. duff. This pattern remained constant for all shade categories except 0 shade. In 0 shade, stem densities in pots with 2 in. of duff were equal to stem densities in pots without duff. Without shade, the mulching effect of a 2-in. duff layer may not have been adequate to prevent moisture deficit and seedling death.

Lack of shade reduced seed germination and the survival of germinants, while heavy shade reduced survival. These

Table 2-Germination, survival, and stem density by shade level in greenhouse and field studies

Greenhouse				Field	
Shade level	Germination[a]	Survival[b]	Density	Shade category	Density
- - - - -	*Percent*	- - - - -	*Stems/pot*	*Percent*	*Stems/acre*
0	49.9c[c]	51.8b	8.5b		
30	64.0ab	71.3a	10.2a	Low (l-39)	3,942.3ab
63	69.8a	31.2c	6.0c	Medium (40–69)	6,665.2a
85	62.2b	44.4bc	4.7c	High (70-99)	232.6b

[a] Percentage of 25 seeds that germinated at any time throughout the 90-day study.
[b] Percentage of germinants that survived to the end of the 90-day study.
[c] Means followed by the same letter within a column are not significantly different at the 0.05 level.

Differences in greenhouse germination and survival rates caused significant differences in pot seedling density after 90 days (table 2). At the end of the study, pots placed under 30-percent shade had significantly more seedlings than did pots without shade or those under higher levels of shade. This pattern closely resembled the pattern observed in the field (table 2). There, stem density under medium shade was higher than under low shade and significantly higher than under high shade. Stem density at low and medium shade was probably higher than necessary for successful stand regeneration. However, areas under high shade had only 233 seedlings per acre, a stocking level that would probably not generate Table Mountain pine dominance.

Reduced germination and survival rates observed without shade were likely caused by less available moisture. Poor

factors typically allowed more seedlings to become established under 30-percent shade than under full light or higher levels of shade. This pattern was constant among pots with 2 and 4 in. of duff but differed among pots with no duff (fig. 1). With no duff, fewer seedlings per pot occurred under 30-percent shade than under no shade, although this difference was not significant. Without the mulching effect of duff, 30-percent shade may not be adequate to prevent moisture deficit.

If germination and survival under field conditions follow the same patterns as in the greenhouse, these data provide a partial description of seedbed conditions necessary to establish Table Mountain pine. Because of differences in study designs, field results shown here do not provide a direct comparison to greenhouse results. However, results

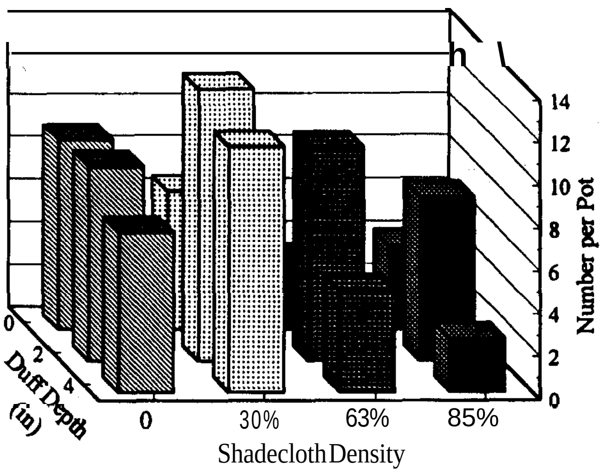

Figure l--Seedling density per pot by shade level and duff depth after the **90-day** greenhouse study.

Table 3—Seedling height after 90 days by duff and shade level in the greenhouse study

Duff depth	Height
	Inch
0	**1.6b**
2	**2.4a**
4	**2.1a**

Shade level	Height
Percent	*Inch*
0	**2.3a**
30	**2.3a**
63	**1.7b**
85	**1.8b**

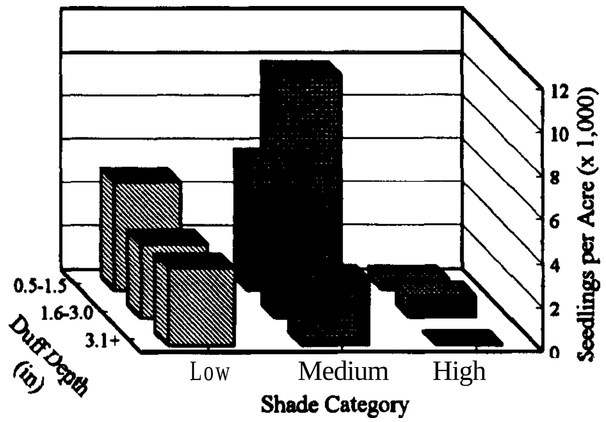

Figure **2—Seedling** density by shade level and duff depth at the end of one growing season in Georgia and South Carolina burn units.

of the two studies are similar. in the field, stem numbers did not vary significantly at different duff depths within a shade category (fig. 2). Seedling numbers were not significantly different between low- and medium-shade categories but both had significantly more stems than did the high-shade category. Under high shade, stem density was less than 1,000 seedlings per acre at ail duff depths. These seedlings are probably too few to adequately regenerate a stand. Stem numbers in medium and low shade ranged from 3,024 per acre for medium shade with > 3 in. of duff to over 11,000 stems per acre under medium shade and 1.6 to 3.0 in. of duff. Each of these stem densities probably exceeds the minimum needed to regenerate the stand.

Seedling Height

Height growth of seedlings in the greenhouse was affected by duff depth and shade levels (table 3). Seedlings growing in bare soil were significantly shorter than those growing in 2 or.4 in. of duff. in addition, seedlings were significantly shorter when grown under 63 or 85 percent shade than those grown under 30 percent shade or without shade. These patterns give additional evidence that seedlings endure moisture stress without a duff layer and light stress under shade levels over 60 percent.

CONCLUSIONS

Previous research indicated that successful regeneration of Table Mountain pine required a thin forest floor (Williams and Johnson 1992) and abundant insolation (Zobell969). Results of the greenhouse and field studies verify these findings and indicate that high-severity, stand-replacement fires, which was the goal of the prescription for fires studied, will produce those **seedbed** conditions. Such fires provide abundant sunlight by killing ail overstory trees and they consume the duff to expose mineral soil. This study showed adequate stem density for regeneration when the duff was thin or missing and shade levels were low.

This study also suggests that fires of lower intensity than crown fires can produce as many or more seedlings. Stem density was highest where moderate levels of shade **(30-** percent shade in the greenhouse and **30-** to **60-percent** insolation in the field) were combined with a duff layer less than 3 in. thick. Also, seedling growth was reduced where there was no duff. Moderate levels of shade and duff may help prevent moisture stress in young seedlings. Duff > 3 in. thick appears to reduce seedling survival. Shade levels > 60 percent may inhibit photosynthesis. At high shade levels, seedlings were fewer in number and height growth was reduced.

Additional research is needed to document the relationship of fire intensity to **postburn** shade level and duff depth over a range of conditions in Table Mountain pine stands. Also, seedling survival must be followed for more than one growing season. During the second growing season, pine numbers may increase with additional germination or decrease if that season is dry. Nonetheless, this study indicates that fires of extreme intensity, such as crown fires, may not be necessary to regenerate the species. One fire of moderate intensity or a series of low-intensity fires may be adequate. Such fires would maintain a duff layer to prevent erosion on steep slopes and help to reduce risks. Because of the limited number of days with weather conditions appropriate to produce controllable crown fires, prescriptions for lower-intensity fires would help expand the burning window. This would not only make burning less risky but allow more areas to be treated for regeneration of Table Mountain pine.

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TREE GROWTH AND RESOURCE AVAILABILITY IN RESPONSE TO SIMULATED CANOPY GAPS IN MATURE SLASH PINE FOREST[1]

Timothy B. Harrington and Ronald L. Hendrick[2]

Abstract-In a 44-year-old, natural stand of slash pine (*Pinus elliottii* Engelm.) near Cordele, GA, three 25-m radius canopy gaps were created in October 1995 by girdling trees to simulate patch mortality from bark beetles. Mortality and growth of trees growing near gaps and light, soil water, and temperature within gaps were studied for two years. These responses also were monitored in three adjacent, undisturbed plots of equal area. Bark-beetle induced mortality of pines within 12.5 m of gap edge (3.1 m^2 ha^{-1} yr^{-1}) was greater than that of trees in undisturbed stands (0.1 m^2 ha^{-1} yr^{-1}). Second-year crown area of individual pines was 22 percent greater for trees near gaps versus those in undisturbed plots. Availability of light was greater in gap plots versus plots in undisturbed stands, while availability of soil water increased with proximity to gap center.

INTRODUCTION

Attack of southern pines by bark beetles is stimulated by factors such as declining tree vigor, stand density, and disturbance (Goyer and others 1998). For example, bark beetle attack becomes increasingly likely as pines mature because of age-related reductions in their growth rate and vigor. Excessive stem densities in pine plantations that result from recruitment of volunteer pines can stimulate bark beetle epidemics because of the large, continuous food source these stands provide. Disturbances such as soil compaction from harvesting equipment or stem injury from lightning also can hasten attack by bark beetles.

Previous research has been conducted on the effects of canopy gaps on availability of light and soil water and on stand dynamics in deciduous forests of the eastern United States (Clinton and Boring 1993, 1994, Dahir and Lorimer 1996, Phillips and Shure 1990, Runkle 1981). In general, if the ratio of gap diameter to surrounding canopy height is two or greater for forested sites in the middle latitudes of the northern hemisphere, the northern half of the gap is fully illuminated with direct sunlight for most of the day throughout the growing season (Smith and others 1997). Increased amounts of diffuse sunlight occur in a large area of intact forest surrounding the gap. Generally, soil water availability increases with proximity to gap center until roots of invading vegetation or peripheral trees recolonize the newly available growing space.

Limited research information exists regarding effects of canopy gaps on resource availability and stand dynamics in southern pine forests. An improved understanding of such responses has potential application in the management of mature pine forests for timber production, wildlife, and aesthetics. Therefore, gap dynamics research was initiated in 1994 to determine influences of canopy gaps, simulated as those induced by bark beetles, on mortality and growth of stands and individual trees of mature slash pine and on growing conditions (light, soil water, and temperature).

METHODS

Study Sites and Treatments

The study was conducted at the Wheatley Tract, a 1010-ha, mixed-aged forest dominated by slash, longleaf (*Pinus palustris* Mill.), and loblolly pines (P. *taeda* L.) located near Cordele, GA and managed by the Daniel B. Warnell School of Forest Resources, University of Georgia, Athens, GA. The study area supported an old-field origin stand of slash pine that had never been thinned. Soils are well to moderately-well drained loamy sands of the Fuquay series (Arenic Plinthic Kandiudults) (Pilkinton 1978). In winter 1994-95, six circular plots (r=37.5 m) were located with a minimum of 25 m separating each plot. Diameter at breast height (d.b.h. in cm at 1.37 m above ground) and distance (m) and azimuth (°) from plot center were measured for each pine of d.b.h. greater than 2.5 cm. Measurements of height (m) and crown width (m in each of north-south and east-west dimensions) were taken in June 1995 on 30 trees per plot randomly selected from those located between 25 m and 37.5 m distance from plot center. From the 30 trees per plot, ten were randomly selected and their breast-height age (yr) was determined with an increment bore in September 1995. Pre-treatment averages for d.b.h., height, crown area, and stand basal area were 24.9 cm, 22.7 m, 23.4 m^2, and 29.5 m^2/ha, respectively. Initial tree age varied from 18 to 44 years, with 72 percent of the trees of age 35 years or greater.

On three randomly selected plots, all pine trees located within 25 m of plot center were girdled with chainsaws in October 1995. Girdling was done during a period of low bark beetle activity to minimize the attack of adjacent ungirdled trees. By May 1996, all girdled trees were dead or strongly declining in vigor, and by the end of the year, all girdled trees were dead. Girdling created canopy openings 0.2 ha in area with a ratio of gap diameter to canopy height equal to 2.2. Each gap plot had a 12.5-m wide annulus of ungirdled trees surrounding the gap for monitoring pine mortality and growth. Measurements of pine d.b.h., height, and crown width were repeated in winter 1997-98, two growing seasons after gap formation.

Light, Soil Water, and Temperature Measurements

Gap fraction (proportion of unobstructed sky), an index of light availability, was measured with the LAI-2000 plant canopy analyzer (LI-Cor, Inc, Lincoln, NB) at plot center and at points located at 12.5-m intervals along north, south, east, and west transects radiating outward from plot center (n=13 per plot). Readings were taken at breast height above each

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sample point facing south during diffuse light conditions (sunrise, sunset, or overcast sky) in August 1995 (pre-treatment), 1996, and 1997. This timing of gap fraction measurements was selected to coincide with peak annual leaf area of slash pine. Another LAI-2000 plant canopy analyzer located nearby within a large opening (unobstructed sky 15" above the horizon) logged readings simultaneously. Readings from the two plant canopy analyzers were merged according to the nearest time interval and gap fraction was calculated with LI-Cor software.

Volumetric soil water content (percent, O-45 cm depth) was measured at plot center and at points located at 12.5-m intervals along north and south transects radiating outward from plot center (n=7 per plot). Readings were taken monthly from March to October of 1996 and 1997 with a Trase time domain reflectometry sensor (SoilMoisture Equipment Corp., Goleta, CA).

Air temperature (°C) at ground surface was recorded hourly with Hobo temperature sensors (Onset Computer Corporation, Pocasset, MA) at the same sample points used for the soil water measurements (n=7 per plot). Soil temperature at 15 cm below ground was recorded similarly but only at plot center and at points located at 12.5-m intervals along the south transect (n=4 per plot). Air and soil temperatures were recorded from August 1995 to August 1997.

STATISTICAL ANALYSIS

The study has a completely-randomized, split-plot design with three replications of each main-plot treatment (i.e., gap plots versus plots in undisturbed stands). Periodic (1996-97) annual mortality and growth in stand basal area (m^2 ha") were calculated for each of eight groups of trees per plot: four quadrants (centered on the north, south, east, or west transects) x two distances (trees located between 25 and 31.25 m and those located between 31.25 and 37.5 m from plot center). Basal area variables were subjected to analysis of variance (ANOVA) with two levels of the main-plot treatment and two levels of the split-plot treatment (i.e., two distances from plot center). Initial stand basal area (1995) *was* included as a covariate to adjust for pre-treatment differences in stand density.

Second-year (1997) values of individual tree height, basal area, and crown area were regressed against pre-treatment (1995) values of these variables. An indicator variable was specified to account for potential differences in regression intercepts and slopes between gap plots and plots in undisturbed stands. The extra-sums-of-squares approach was used to test the significance of gap effects on the regression parameters (Neter and others 1989).

For analyses of light, soil water, and temperature, split plots were designated according to the following distances from plot center: 0, 12.5, 25, and 37.5 m. Gap fraction values for each measurement year (n=78) were subjected to ANOVA with two levels of the main-plot treatment and four levels of the split-plot treatment. Initial gap fraction (1995) was included as a covariate to adjust for pre-treatment differences in light availability. Daily minimum, average, and maximum values of air and soil temperature were calculated and then averaged to provide monthly means for each variable. Temperature and soil water data for each month (n=42 for air temperature and soil water: n=24 for soil temperature) were subjected to a split-plot ANOVA, as described for gap fraction.

Multiple comparisons of least-squares treatment means were conducted with a Bonferroni-adjusted probability (Snedecor and Cochran 1980). All analyses were conducted with SAS (1989) at the 95 percent significance level.

RESULTS

Stand Mortality and Growth

Periodic annual mortality was significantly greater for trees growing near gaps (3.1 m^2 ha-' yr') versus those growing in undisturbed plots (0.1 m^2 ha" yr^{-1}). However, the interaction of gap treatment and distance from gap edge was not significant, indicating that mortality did not vary between trees close versus those farther away from gap edge. Periodic annual growth in stand basal area did not differ significantly between gap plots and plots in undisturbed stands, averaging 0.4 m^2 ha^{-1} yr^{-1}.

Individual Tree Size

The largest response in individual tree size to gap formation was for crown area. Second-year (1997) crown area of trees near gaps averaged 5.8 m^2 more than that of trees in undisturbed plots. Pines near gaps averaged 0.4 m taller than those in undisturbed plots. Average stem basal area of pines near gaps was approximately equal to that of trees in undisturbed plots.

Light, Soil Water, and Temperature

First- (1996) and second-year (1997) values of gap fraction at plot center and at 12.5 m and 25 m from plot center each were significantly greater in gap plots versus plots in undisturbed stands. Gap fraction ranged from 0.6 to 0.8 within gap plots, while it ranged from 0.4 to 0.6 in undisturbed plots. At 37.5 m from plot center, gap fraction did not differ significantly between gap plots and plots in undisturbed stands. Although gap fraction was somewhat higher at gap center versus elsewhere in the gap, this difference was not statistically significant.

Throughout the 1996 growing season, soil water content within gaps was 4 percent to 7 percent greater (in absolute units) than values observed for undisturbed plots. The interaction of gap treatment and distance from plot center was significant because soil water availability was consistently highest at or near gap center. A similar magnitude of soil water increases was observed several times in the 1997 growing season, but these differences disappeared during periods of high rainfall.

In gap plots, monthly values of maximum daily air temperature averaged up to 4°C higher than those of undisturbed plots, while monthly values of minimum daily air temperature averaged as much as 2°C lower. These differences occurred throughout the year. The interaction of gap treatment and distance from plot center was not significant for any of the temperature variables, indicating that daily temperature regimes did not vary with distance from gap center. None of the soil temperature variables, or average daily air temperature, differed significantly between gap plots and plots in undisturbed stands.

CONCLUSIONS

Simulated canopy gaps in a mature slash pine forest resulted in additional bark-beetle induced mortality of trees growing on the periphery of the gap. However, mortality rates were similar for trees located 0 to 6.25 m versus those >6.25 to 12.5 m from gap edge. Growth in stand basal area and individual-tree height and basal area differed little between gap plots and plots in undisturbed stands. However, second-year crown area of individual trees growing near gaps averaged 22 percent greater than that of trees growing in undisturbed plots.

Second-year results indicate that mature slash pine responded to gap formation largely by increasing their crown area. Trees growing on the edge of a gap had very little change in their height or stem girth. Probably the high degree of measurement error associated with the larger sample trees, as well as the short duration of the study, limited detection of subtle responses in stand and individual-tree growth.

Availability of light and soil water was greater in gap plots versus plots in undisturbed stands. Because increases in soil water content were significantly greater at or near gap center versus elsewhere in gap plots, it appears that pines growing along the edge of a gap exerted an influence on soil water availability 12.5 m or more from where they were centrally rooted. Increases in light availability within gaps did not vary spatially as observed for soil water, perhaps because the large sample area of the LAI-2000 plant canopy analyzer resulted in overlapping measurements. Temperature extremes were higher in gap plots versus plots in undisturbed stands. Continued monitoring of these plots will provide further insight into whether mature slash pines are capable of responding in a substantial way to changes in growing conditions that accompany gap formation.

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REGENERATION OF SOUTHERN PINE STANDS UNDER ECOSYSTEM MANAGEMENT IN THE PIEDMONT[1]

James W. McMinn and Alexander Clark III[2]

Abstract-Ecosystem-oriented management is being used on southern National Forests to conserve biodiversity, improve the balance among forest values, and achieve sustainable conditions. This paper reports on the regeneration phase of a study to identify the implications of ecosystem management practices on loblolly pine (*Pinus taeda* L.) and shortleaf (? *echinata* Mill) pine stands in the Piedmont. Naturally regenerated stands are likely to have less diverse seedling populations 1 year after harvest than preharvest and will be comprised of more hardwoods-especially sweetgum--than the original overstory stands.

INTRODUCTION

European settlement was accompanied by clearing of virtually the entire Piedmont Physiographic Region of the Southeastern United States for cotton and other row-crop production. By the time of the Great Depression most topsoil had eroded away and productive cultivation was difficult. In the 1930's the Federal government purchased some of the most severely-eroded farmland, which was later incorporated into the National Forest System. This land now supports productive forests. Currently, Piedmont national forests have 58 percent of their growing stock in pine, 3 percent in other softwoods, 18 percent in soft hardwoods, and 21 percent in hard hardwoods. The majority of stands are natural even-aged pine or pine-hardwood.

Piedmont national forest lands have been managed under the multiple-use concept since the 1980's with one primary objective being to improve the health, quality, and volume of pine stands. Older pine stands were clearcut and planted back to pine or harvested using seed tree cuts to establish pine regeneration. Younger stands were thinned to stimulate pine sawtimber growth.

In the early 1990's an ecosystem approach to managing national forests was introduced to conserve biodiversity, improve the balance among forest values, and achieve sustainable, healthy conditions while retaining the esthetic, historic, and spiritual qualities of the land. Under ecosystem management, pine and pine/hardwood stands on national forests in the Piedmont are being converted from evenaged monocultures to unevenaged or two-aged pine and mixed-species stands.

This paper reports preliminary results of the regeneration phase of a study to determine the implications of ecosystem management practices on loblolly and shortleaf pine stands in the Piedmont.

PROCEDURES

A series of permanent measurement plots have been established in loblolly/shortleaf pine stands on the Oconee, Sumter, and Uwharrie National Forests to monitor the response to an array of ecosystem management practices. The management practices include: (1) partial cuts, (2) group selection cuts, (3) seed tree cuts and (4) reserve areas. Included in the partial cuts are single tree selection, salvage cuts, stand improvement cuts, and shelterwood cuts. Reserve areas are stands in which no human disturbance is planned. Each monitoring plot is a cluster group comprised of three IA-acre circular plots and is randomly located within each stand selected for monitoring. Cluster groups are inventoried at establishment, then prior to and following harvest treatments, as well as, every 5 years and following any natural disturbance. Cluster groups were established in stands representing five 20-year age classes (1, 20, 40, 60, 80) and two broad site-index (SI) classes (SI<80 and SI≥80) for each management practice.

On each IA-acre plot all trees ≥5.0 in. diameter at breast height (d.b.h.) are located by azimuth and distance from plot center. Species, d.b.h., total height, merchantable height, crown class, tree grade, and defect indicators are recorded for both live and dead trees. Five 1/300-acre microplots are located 30 ft from plot center at 72-degree intervals within each IA-acre plot to tally seedlings and saplings. Seedlings (woody plants up to 1 .O-in. d.b.h.) are tallied by species. Saplings (woody plants 1 .O to 4.9 in. d.b.h.) are tallied by species, d.b.h., and total height. Softwoods 5.0 to 8.9 in. d.b.h. and hardwoods 5.0 to 10.9 in. d.b.h. are classified as pole timber. Softwoods ≥9.0 and hardwoods ≥11 .O in. d.b.h. are classified as sawtimber if they contain one or more 16-ft sawlogs. Pine sawtimber trees are classified using a tree classification system for natural pine developed by Clark and McAlister (1998) and hardwood sawtimber trees are classified using USDA Forest Service hardwood tree grades (Hanks 1976). Increment cores are also extracted from four trees in each 1/5-acre plot for wood properties determination.

Species diversity and evenness were calculated using Shannon's indices of diversity and evenness based on stem counts by species (Magurran 1988)

RESULTS

Natural Stands

Average preharvest characteristics for the natural stands that were harvested are presented by harvest method in tables 1 and 2. Preharvest species richness, diversity, and evenness for the overstory and midstory are generally low, as would be expected. However, the seedling component exhibited generally higher values for these characteristics, averaging more than twice the number of species as the

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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Table l-Average stems per acre, species richness, diversity and evenness for seedlings, saplings, and pole and sawtimber by harvest method for natural pine stands in the Piedmont before harvest

	Harvest method		
Characteristic	Partial cut	Group selection	Seed tree
Stands sampled	12	2	4
Seedlings			
Stems/acre	12,765	12,200	14,470
Richness	20	16	20
Diversity	2.0	1.8	2.0
Evenness	.7	.7	.7
Saplings			
Stems/acre	505	520	215
Richness	6	4	2
Diversity	1.3	.8	.6
Evenness	.8	.6	.4
Pole and sawtimber			
Stems/acre	170	115	90
Richness	9	6	8
Diversity	1.1	1.0	1.1
Evenness	.5	.6	.5

overstory and midstory. Pine comprised over one-half of the overstory stems and were well-represented in the seedling component, which averaged more than 12,000 stems per acre in all cases. Sweetgum had the most consistent representation of the hardwoods in the seedling and sapling components, followed by dogwood.

One year after harvesting, seedling species richness, diversity, and evenness were ail lower than at the preharvest measurements and sweetgum was the consistent major constituent (tables 3 and 4). Although loblolly pine was a major constituent on the partial cut and seed tree areas, it comprised only 3 percent of the seedlings on group selection areas. Red maple was the third most consistent constituent.

Planted Stands

Although natural stands are more prevalent, five planted stands were old enough to have also been harvested (tables 5-8). Preharvest species richness, diversity, and evenness of the overstory and seedling components were all lower than in the natural stands. The planted stands also had fewer seedlings than the natural stands. In the partial cut stands, which were ail "purchaser select" improvement cuts, pines comprised 93 percent of the overstory stems, 27 percent of saplings, and 13 percent of seedlings. On the one group selection area, pines comprised 84 percent of the overstory stems, but only 2 percent of the saplings and none of the seedlings. The group selection stand was only 23 years old (too young for substantial seed production), whereas the partial cut stands ranged in age from 18 to 37. Sweetgum was again a prevalent constituent of the seedling component.

Table 2-Proportion of stems per acre (percent) by species and harvest method for seedlings, saplings, and pole and sawtimber for natural pine stands in the Piedmont before harvest

Harvest method		
Partial cut	Group selection	Seed tree
Seedlings		
Red maple (23)	Dogwood (24)	Loblolly pine (30)
Loblolly pine (16)	Loblolly pine (22)	Red maple (18)
Sweetgum (12)	Sweetgum (20)	Sweetgum (10)
Dogwood (7)	Water oak (15)	Dogwood (6)
Winged elm (5)	Red maple (4)	Black cherry (3)
Water oak (3)	Winged elm (3)	Water oak (3)
Black cherry (3)	Black cherry (3)	Sourwood (2)
Saplings		
Sweetgum (29)	Sweetgum (63)	Lobiolly pine (42)
Lobloliy pine (17)	Dogwood (24)	Sweetgum (31)
Dogwood (14)	Loblolly pine (7)	Yellow-poplar(11)
Red maple (10)	Yellow-poplar (3)	Black cherry (8)
Black cherry (10)	So. red oak (1)	Sourwood (6)
Hackberry (4)	Water oak (1)	So. red oak (1)
Sourwood (4)		Shortleaf
Pole and sawtimber		
Loblolly pine (61)	Loblolly pine (53)	Loblolly pine (69)
Shortleaf pine (10)	Sweetgum (31)	Sweetgum (10)
Winged elm (5)	Shortleaf pine (9)	Yellow-poplar (3)
Sweetgum (5)	Yellow-poplar (3)	Sour-wood (3)
Scarlet oak (3)	Dogwood (2)	Dogwood (1)
Blackgum (2)	E. redcedar (1)	Shortleaf pine (1)
Yellow-poplar (2)	Winged elm (1)	Red maple (1)

As in the natural stands, most postharvest indicators of seedling diversity were lower 1 year after harvesting than prior to the harvests. On the partial cut areas red maple, black cherry, sweetgum, and lobioily pine shared dominance, with each comprising no more than 13 percent. Sweetgum and dogwood comprised 87 percent of the seedlings on the group selection area, and pines were not represented at all.

CONCLUSIONS

Although the data are preliminary, including less than one-half the stands that will eventually be harvested, some strong trends are already evident. Naturally regenerated pine and pine-hardwood stands in the Piedmont will generally exhibit a less diverse seedling population 1 year after harvesting than prior to harvesting. In the absence of additional techniques to influence species composition, sweetgum is likely to comprise a major component of the regenerated stands, regardless of the harvest method.

Table S-Average stems per acre, species richness, diversity, and evenness for seedlings by harvest method for natural stands in the Piedmont 1 year after harvest

	Harvest method		
Characteristic	Partial cut	Group selection	Seed tree
Stands sampled	12	2	4
Seedlings			
Stems/acre	10,372	14,310	13,754
Richness	15	14	19
Diversity	1.8	1.3	2.0
Evenness	.7	.5	.7

Table 4-Proportion of stems per acre (percent) by species for seedlings by harvest method for natural pine stands 1 year after harvest

Harvest method		
Partial cut	Group selection	Seed tree
	Seedlings	
Sweetgum (22)	**Sweetgum** (23)	**Sweetgum** (25)
Lobioily pine (20)	Dogwood (23)	Lobiolly pine (21)
Red maple (13)	Water oak (17)	Red maple (12)
Dogwood (6)	Lobioliy pine (3)	Sumac (6)
Yellow-poplar (5)	So. red oak (2)	Dogwood (5)
Black cherry (5)	Winged elm (2)	Black cherry (5)
Winged elm (2)	Red maple (1)	Sour-wood (3)
So. red oak (2)	Post oak (1)	Water oak (2)

Table 5—Average stems per acre, species richness, diversity and evenness for seedlings, saplings, and pole and sawtimber by harvest method for iobioiiy pine planted stands in the Piedmont before harvest

	Harvest method	
Characteristic	Partial cut	Group selection
Stands sampled	4	1
Seedlings		
Stems/acre	**9,335**	2,440
Richness	17	14
Diversity	2.0	2.1
Evenness	.7	.8
Saplings		
Stems/acre	600	1,180
Richness	7	14
Diversity	1.6	1.8
Evenness	.8	.7
Pole and sawtimber		
Stems/acre	335	322
Richness	6	8
Diversity	.3	.7
Evenness	.2	.3

Table S-Proportion of stems per acre (percent) by species for seedlings, saplings, and pole and sawtimber by harvest method for planted iobioiiy pine stands in the Piedmont before harvest

Harvest method		
Partial cut		Group selection
	Seedlings	
Lobioliy pine (13)		**Sweetgum** (33)
Sweetgum (10)		Dogwood (18)
Dogwood (9)		Red maple (10)
Winged elm (7)		Beech (8)
Biackgum (7)		White oak (7)
Black oak (6)		Black cherry (5)
Red maple (5)		Water oak (2)
Black cherry (4)		**Blackgum** (2)
	Saplings	
Lobioiiy pine (27)		Dogwood (39)
Biackgum (15)		**Sweetgum** (27)
Winged elm (12)		Water oak (10)
Black cherry (10)		So. red oak (6)
Sour-wood (5)		White oak (3)
Sweetgum (4)		Lobioliy pine (2)
Red maple (4)		Red maple (2)
	Pole and sawtimber	
Lobloliy pine (93)		Lobloily pine (84)
Sweetgum (1)		**Sweetgum** (9)
Chestnut oak (1)		Black cherry (2)
Red maple (1)		Yellow-poplar (2)
Scarlet oak (1)		Shortleaf pine (1)
Winged elm (1)		Water oak (1)

Table 7—Average stems per acre, species richness, diversity, and evenness for seedlings by harvest method for planted iobioiiy pine stands in the Piedmont 1 year after harvest

Characteristic	Harvest method: Partial cut	Group selection
Stands sampled	4	1
Seedlings		
Stems/acre	7,250	6,920
Richness	13	9
Diversity	1.7	1.2
Evenness	.7	.6

Table (E-Proportion of stems per acre (percent) by species for seedlings by harvest method for planted iobioiiy stands 1 year after harvest

Harvest method: Partial cut	Group selection
Seedlings	
Red maple (13)	Sweetgum (44)
Black cherry (13)	Dogwood (43)
Sweetgum (10)	Black cherry (3)
Lobioliy pine (9)	Water oak (3)
Dogwood (5)	Red maple (2)
Biackgum (5)	White oak (2)
Water oak (4)	Biackgum (2)
So. red oak (2)	Persimmon (1)

Seasonal timing of harvests strongly influenced the predominance of pine in naturally regenerated Upper Piedmont oak-pine stands (McMinn 1992) and could possibly be employed to influence the relative mix of pines, sweetgum, and other species. However, that would depend on the extent to which seedfali timing is distinct among species and whether the respective species regenerate primarily via seedlings or sprouts.

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NONLINEAR PROGRAMMING MODELS TO OPTIMIZE UNEVEN-AGED LOBLOLLY PINE MANAGEMENT[1]

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Abstract-Nonlinear programming models of uneven-aged loblolly pine (*Pinus taeda* L.) management were developed to identify sustainable management regimes which optimize: 1) soil expectation value (SEV), 2) tree diversity, or 3) annual sawtimber yields. The models use the equations of SouthPro, a site- and density-dependent, multi-species matrix growth and yield model that recognizes three species groups (loblolly pine and other softwoods, soft hardwoods, and hard hardwoods) and 13 P-inch diameter-at-breast-height size classes. The regimes for optimal diversity almost obtain their theoretical maximum Shannon diversity indices, but have low SEV's. The optimal economic and production regimes each involve a guiding maximum diameter for softwoods and complete hardwood control, with the optimal maximum diameter a function of site productivity. Constrained optimizations in which SEV is maximized subject to increasing constraints on diversity show the tradeoffs between economic return and diversity objectives.

INTRODUCTION

Although interest in uneven-aged management has grown considerably in recent years, information to guide it toward specific objectives is frequently lacking as our scientific knowledge of, and experience with, uneven-aged silviculture remain far behind that of even-aged. In this country, the longest continuous research on uneven-aged forest management comes from studies of loblolly (*Pinus* taeda L.)-shortleaf pine (*P. echinata* Mill.) stands in the west Gulf coastal plain of southern Arkansas, particularly at the Crossett Experimental Forest, where research was initiated in 1937 (e.g., Baker and others 1996, Reynolds and others 1984).

Over the years, several researchers have proposed uneven-aged management regimes for loblolly-shortleaf pine (Baker and others 1996, Farrar 1996, Farrar and others 1984, Hotvedt and others 1989, Reynolds 1959, Williston 1978). The effects of these and other regimes on timber production, economic returns, and structural and species-group diversity are examined by Schulte and Buongiorno (1998). Because these regimes were based either on the personal experiences of the researchers who proposed them or on simulation studies, rather than mathematical optimization, other regimes are likely to prove better suited for specific objectives. The purpose of this paper is to develop mathematical programming models to identify management regimes that maximize tree diversity, economic returns, or annual sawtimber production in uneven-aged loblolly pine and loblolly pine-mixed hardwood stands.

METHODS

Growth and Yield Model

A number of growth and yield models exist for uneven-aged stands of loblolly-shortleaf pine (Baker and Shelton 1998; Murphy and Farrar 1982, 1983, 1988), loblolly pine (Murphy and Shelton 1994, 1996), and loblolly pine-mixed hardwoods (Farrar and others 1989, Lin and others 1998). The model used in this study is the density- and site- dependent, multi-species matrix model of Lin and others (1998, Schulte and others 1998). It was chosen because: 1) its reproduction and mortality equations make it possible to identify sustainable, steady-state management regimes, 2) it can simulate management over the widest range of site productivity, 3) it recognizes the greatest number of species groups and size categories, and 4) its calibration data set covered the largest geographic area, making its results more broadly applicable.

The data set used to calibrate the model contains 991 mixed-aged, naturally regenerated, loblolly pine re-measurement plots of the Southern Forest Inventory and Analysis data base. In the model, trees are categorized into thirteen two-inch diameter-at-breast height (d.b.h.) size classes, ranging from two to twenty-six inches, and three species groups: loblolly pine and other softwoods, soft hardwoods, and hard hardwoods. In matrix notation, the general form of the model is:

$$y_{t+1} = G_t(y_t - h_t) + I_t \qquad (1)$$

where the matrix G_t contains the growth and mortality parameters for year t, the vector $y_t = [y_{ijt}]$ contains the number of live trees per acre of species group i (i = 1, 2, 3) and size class j (j = 1, ... 13) at the beginning of year t, the vector $h_t = [h_{ijt}]$ contains the number of trees cut from each species-size category at the start of year t, and the vector I_t contains the ingrowth parameters for year t.

Sawtimber and pulpwood cubic-foot volumes are estimated using equations (Lin and others 1998) based on the stem volume tables of Clark and Souter (1994). Pulpwood is potentially available from poletimber trees (hardwoods 5 to less than 11 inches d.b.h. or softwoods 5 to less than 9 inches d.b.h.) and from the tops of sawtimber trees (hardwoods 11 inches d.b.h. and larger or softwoods 9 inches d.b.h. and larger). Tree volumes, the ingrowth vector, I_t, and the growth matrix, G_t, all vary as a function of site productivity and residual stand basal area.

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Optimization Models

Maximizing soil expectation value-While obtaining economic returns certainly is not the only reason forest landowners in the South own their land (Lentz and others 1989), it is an important consideration, in part because it makes other pursuits possible, such as wildlife conservation, recreation, aesthetics, and hunting. In addition, knowing the maximum economic return that can be expected from a particular site provides a valuable baseline for judging the economic performance of alternative management strategies. A stand's soil expectation value, the present value of ail future harvests, net of ail costs, including the opportunity cost of the growing stock, is the preferred criterion for measuring economic performance. The model for maximizing SEV is:

$$\max_{y,h} SEV=\frac{s'h-F}{(1+r)^{C}-1}-s'(y-h) \qquad (2)$$

subject to:

$$y_1 = G_0(y_0-h_0)+I_0 \qquad (3)$$
$$y_2 = G_1(y_1)+I_1$$
$$y_c = G_{C-1}(y_{C-1})+I_{C-1}$$
$$y_c = y_0 \qquad (4)$$
$$y_0-h_0 \geq 0 \qquad (5)$$
$$h_0 \geq 0 \qquad (6)$$

where C is the number of years in the cutting cycle, the vector $h = [h_{ij}]$ contains the number of live trees harvested per acre each cutting cycle from of species *I* and sizej, and vectors = $[s_{ij}]$ contains the stumpage values of a standing live tree in each species-size category.

The stumpage values of individual trees are obtained by multiplying their pulpwood (cords) and sawtimber (board-feet) volumes by the corresponding stumpage prices. The pulpwood stumpage prices used in this analysis are the 1996 average prices for the Southeastern United States (table 1, Timber Mart-South 1997). For sawtimber, a premium for larger trees is assumed whereby the stumpage price of each sawtimber diameter class is three percent greater than that of the next smaller class, while the average price across diameter classes is the 1996 southeastern average. Pulpwood cubic-foot volumes are converted to cords assuming 72 cubic feet per cord for softwoods and 79 cubic feet for hardwoods. Koch's conversion table (Koch 1972) is used to convert cubic-foot sawlog volumes to board-foot measures (Scribner log rule for softwoods and Doyle log rule for hardwoods). Harvesting costs not already reflected in the stumpage prices, *F,* such as administration and hardwood control, are assumed to total $80.00 per acre, while the real rate of interest, *r,* is set at 4 percent, the value used by the USDA Forest Service.

Equations (3) are the growth equations. There is one equation for each year of the cutting cycle. Equation (4) is the steady-state constraint, which ensures sustainability by requiring the stand to return to the same pre-harvest distribution each cutting cycle. Equation (5) guarantees that the number of trees harvested from the stand does not exceed the number of trees present; whereas equations (4) and (5) together ensure that the number of trees in, and harvested from, each species-size category is nonnegative.

Maximizing tree diversity-Forest landowners are also increasingly interested in managing for biological diversity. Because the distribution of trees by species and size largely determines a stand's structure and, thus, the ecological niches available to other organisms, tree diversity is a key component of a stand's overall diversity (Wilson 1974, Rice and others 1984). One of the most widely used and accepted diversity indices is Shannon's index . The model for maximizing Shannon's index of tree diversity, *H,* is:

$$\max_{y,h} H=-\sum_{i}\frac{b_{ij}}{b+e}\ln\left(\frac{b_{ij}+e}{b+e}\right) \qquad (7)$$

subject to: (3), (4), (5) and (6) where b_{ij} is the residual basal area of trees of species *I* and size j, *b* is the residual basal area of all trees, and e is a small, positive constant (0.001) used to avoid division by zero and natural logarithm of zero errors. As defined here, Shannon's index reaches its maximum value of 3.66 when the residual basal area is distributed evenly among each of the thirty-nine species-size categories. By defining Shannon's index in terms of the

Table 1—Stumpage prices used to calculate soil expectation values

Species group	Pulpwood	Sawtimber by d.b.h. class (in.)									
		10	12	14	16	18	20	22	24	26+	Avg.
	$/cord	$/Mbf[a]									
Softwoods	23.73	210	216	223	229	236	243	251	258	266	237
Soft hardwoods	13.73	—	112	115	118	122	126	129	133	137	124
Hard hardwoods	13.73	—	178	183	189	195	200	207	213	219	198

[a] Sawtimber prices are Scribner log rule for loblolly pine and other softwoods and Doyle log rule for hardwoods.

distribution of basal area rather than individual trees, greater weight is given to larger diameter trees.

Maximizing annual sawtimber yields-Another common concern of southern forest landowners is knowing the average annualvolume of lobioliy pine sawtimber that can be produced sustainably from a given stand. The model for maximizing the sustainable annual iobioiiy pine sawtimber yield, V_s, is:

$$\max_{y,h} V_s = \frac{\sum_{js} v_{js} h_{js}}{C} \qquad (8)$$

subject to: **(3), (4),** (5) and (8) where, v_{js} is the board-foot volume of a iobioiiy pine of sawtimber size class j_s.

Competing objectives-While it is certainly possible to manage a stand for multiple objectives, it is generally not possible to maximize a stand's performance in terms of more than one objective at a time. When two or more objectives are less than completely complementary, mathematical programming models can help quantify tradeoffs between competing objectives. To illustrate, we add a constraint to the model for maximizing SEV that requires tree diversity to be at least a given percentage of its maximum sustainable value, H':

$$\max_{y,h} SEV = \frac{s'h - F}{(1+r)^C - 1} - s'(y-h) \qquad (2)$$

subject to: **(3), (4), (5),** (8) and

$$H \geq (Z/100) * H' \qquad (9)$$

where Z is an integer from zero to 99. Then, the opportunity costs of improving tree diversity are determined by solving the model for increasing levels of Z.

Ail the optimization problems examined in this study have non-concave response surfaces. These non-concave response surfaces, which result from 1) the recursive nature of the growth equations (Eq. (3)) when the cutting cycle exceeds one year, 2) the nonlinearity of the growth model (Lin and others 1998) and 3) the use of Shannon's index to quantify tree diversity, necessitate the use of nonlinear programming techniques. The problems were coded in the GAMS programming language and solved with the **GAMS-MINOS** solver for cutting cycles of 1 to 20 years to determine which is optimal and for each of three site productivity categories: low (iobioiiy pine site index of 80 to 79 feet, age **50),** medium (80 to 94 feet) and high (95 to 109 feet). Because nonlinear programming techniques were used, it is not possible to know whether the optimal solutions identified by the solver are global optima or local optima.

RESULTS AND DISCUSSION

Soil Expectation Value

Table 2 gives the steady-state management regimes that maximize SEV on low, medium, and high productivity sites. The optimal cutting cycles are 11, 15, and 13 years, respectively. in ail three cases, the hardwoods are completely controlled at each harvest and the iobioiiy pines and other softwoods are cut back to a guiding maximum diameter of 13 inches d.b.h. on low sites and 11 inches on medium and high sites. The regimes give **SEVs** of $989, $1,085, and $1,207 per acre, while producing 357, 346, and 395 **b.f./acre/year** of iobioiiy pine and other softwood sawtimber, respectively. Although more trees are harvested from medium sites than high sites, high sites have a greater SEV because trees of a given diameter are taller and have larger volumes on the better sites (Lin and others 1998). Similarly, whereas low sites produce a greater annual volume of sawtimber than medium sites, medium sites have the greater SEV because their longer cutting cycle reduces the frequency at which harvesting costs are incurred. The small diameters of softwoods and the absence of hardwoods in the residual stands result in relatively low Shannon indices of tree diversity of 1.67, 1.50, and 1.50 for low, medium and high sites, respectively.

Tree Diversity

The steady-state management regimes that maximize Shannon's index of tree diversity are in Table 3. The nearly even distribution of basal area across ail species-size categories results in Shannon indices of tree diversity very near the theoretical maximum. For each site, the optimal cutting cycle is one year, but few trees are cut with each harvest. Thus, the average annual iobioiiy pine sawtimber yields are a mere 57, 65, and 74 **b.f./acre/year** for low, medium, and high sites, respectively. Due to their short cutting cycles, low yields, and large investments in growing stock, these regimes have very low **SEVs** of $2,726, **$-2,735,** and $2,756 per acre, respectively. However, these values could be raised to $-870, $-886, and $-896 per acre, respectively, while leaving tree diversity essentially unchanged at 3.66, by adopting instead the regimes which maximize Shannon's index of tree diversity for a IO-year cutting cycle.

Sawtimber Production

Table 4 shows the optimal management regimes for producing iobioily pine and other softwood sawtimber. Again, the optimal cutting cycle for each site is 1 year. As was the case for the SEV-maximizing regimes, the optimal sawtimber regimes each involve complete hardwood control at each harvest and a guiding maximum diameter for iobioiiy pine and other softwoods: 19 inches d.b.h. on low sites and 17 inches on medium and high sites. These regimes produce 426,472, and 520 **b.f./acre/year** of iobioiiy pine and other softwood sawtimber on low, medium, and high sites, respectively. By leaving more large diameter softwoods in the residual stand than the SEV-maximizing regimes, Shannon's index of tree diversity improves to 1.99 on low sites and 1.90 on medium and high sites. in contrast, the **SEVs** are only **$-1**,590, **$-1**,088, and **$-1**,071 per acre, respectively, due to the short cutting cycles. if the regimes which maximize annual softwood sawtimber yields for a **10-**year cutting cycle were adopted instead, the **SEVs** would improve to $445, $431, and $425; whereas the softwood sawtimber production would decline by only 1.7, 1.9, and 2.3 percent, respectively.

Competing Objectives

Figure 1 shows the effect of increasingly restrictive tree diversity constraints on the maximum sustainable **SEVs** of different sites. **SEVs** remain at their maximum levels until tree diversity is constrained to be at least 42 percent of its sustainable maximum for low sites or 46 percent for medium

Table 2—Steady-state management regimes that maximize soil expectation value, by site

Site[a]	Time	Species group[b]	Diameter-at-breast height (inch) 2	4	6	8	10	12	14	16	18	20	22	24	26+
			Trees per acre												
Low	Pre-harvest	SW	124.1	57.4	35.2	25.8	21.4	19.3	12.7	5.5	1.6	0.3	—	—	—
						—	—		—	—	—	—	—	—	—
		SH HH	90.4	11.4	1::	.1	—	❑	—	—	—	—	—	—	—
	Post harvest	SW	124.1	57.4	35.2	25.8	21.4	19.3	—	—	—	—	—	—	—
		SH	—	—	—	—	—	—	—	—	—	—	—	—	—
		HH	—	—	—	—	—	—	—	—	—	—	—	—	—
		Cycle[c] = 11 yr, SEV = $989/ac, sawtimber = 357 bf/ac/yr, H = 1.67													
Medium	Pre-harvest	SW	132.8	63.3	39.2	28.9	24.0	17.5	9.8	4.1	1.3	.3	—	—	—
		SH	88.4	14.8	2.3	.3	.0	—	—	—	—	—	—	—	—
		HH	80.1	14.7	2.7	.5	.1	—	—	—	—	—	—	—	—
	Post-harvest	SW	132.8	63.3	39.2	28.9	24.0	—	—	—	—	—	—	—	—
		SH	—	—	—	—	—	—	—	—	—	—	—	—	—
		HH	—	—	—	—	—	—	—	—	—	—	—	—	—
		Cycle[c] = 15 yr, SEV = $1,065/ac, sawtimber = 346 bf/ac/yr, H = 1.50													
High	Pre-harvest	SW	136.2	64.6	40.1	29.6	24.6	17.0	8.7	3.2	.9	.2	—	—	—
		SH	77.7	13.3	2.0	.3	—	—	—	—	—	—	—	—	—
		HH	83.0	10.8	1.8	.3	—	—	—	—	—	—	—	—	—
	Post-harvest	SW	136.2	64.6	40.1	29.6	24.6	—	—	—	—	—	—	—	—
		SH	—	—	—	—	—	—	—	—	—	—	—	—	—
		HH	—	—	—	—	—	—	—	—	—	—	—	—	—
		Cycle[c] = 13 yr, SEV = $1,207/ac, sawtimber = 395 bf/ac/yr, H = 1.50													

[a] Loblolly pine site index: Low = 60-79, Medium = 80-94, High = 95-109 feet.
[b] SW = pines and other softwoods, SH = soft hardwoods, HH = hard hardwoods.
[c] Cycle = cutting cycle, SEV = soil expectation value, Sawtimber = annual loblolly pine sawtimber yield, and *H* = Shannon's index of tree diversity.

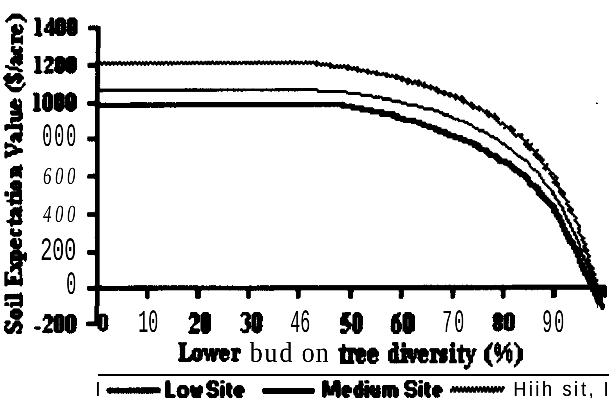

Figure l-Maximum soil expectation value, by site, under increasingly restrictive tree diversity constraints, expressed as a percentage of the maximum sustainable diversity.

and high sites. After that, they drop at increasingly rapid rates as tree diversity requirements increase. For example, requiring tree diversity to be at least 65 percent of its maximum reduces the maximum SEVs by 12, 11, and 10 percent for low, medium and high sites, respectively; whereas requiring it to be at least 85 percent of its maximum reduces the maximum SEVs by 43, 39, and 38 percent, respectively.

Being able to quantify the tradeoffs between competing objectives greatly facilitates the identification of acceptable compromises. One potential compromise might be to adopt the management regime which maximizes SEV while requiring tree diversity to be at least 75 percent of its sustainable maximum. In this case, the maximum SEVs on low, medium, and high productivity sites would be $752, $846, and $960 per acre, or 76, 79, and 79 percent of their unconstrained sustainable maxima, respectively.

Table 3—**Steady-state** management regimes that maximize the Shannon index of tree diversity, by site

Site[a]	Time	Species group[b]	2	4	6	6	10	12	14	16	18	20	22	24	26+
			Diameter-at-breast height (inch)												
			Trees per acre												
Low	Pre-Harvest	SW	89.7	23.9	10.3	5.8	3.7	2.6	1.9	1.4	1.1	0.9	0.8	0.6	0.5
		SH	94.8	23.2	10.2	5.7	3.7	2.5	1.9	1.4	1.1	1.0	.8	.6	.5
		HH	96.4	23.5	10.2	5.7	3.7	2.5	1.9	1.4	1.1	.9	.7	.6	.5
	Post-Harvest	SW	89.7	22.5	10.0	5.6	3.6	2.5	1.8	1.4	1.1	.9	.7	.6	.5
		SH	90.0	22.5	10.0	5.6	3.6	2.5	1.8	1.4	1.1	1.0	.8	.6	.5
		HH	90.0	22.5	10.0	5.6	3.6	2.5	1.8	1.4	1.1	.9	.7	.6	.5
		Cycle[c] = 1 yr, SEV = $-2,726/ac, sawtimber = 57 bf/ac/yr, H = 3.66													
Medium	Pre-harvest	SW	89.3	23.9	10.3	5.8	3.7	2.6	1.9	1.4	1.1	.9	.8	.6	.5
		SH	94.2	23.6	10.2	5.7	3.7	2.5	1.9	1.4	1.1	.9	.8	.6	.5
		HH	93.0	23.5	10.2	5.7	3.7	2.5	1.9	1.4	1.1	.9	.7	.6	.5
	Post-harvest	SW	89.3	22.5	10.0	5.6	3.6	2.5	1.8	1.4	1.1	.9	.7	.6	.5
		SH	89.9	22.5	10.0	5.6	3.6	2.5	1.8	1.4	1.1	.9	.8	.6	.5
		HH	89.9	22.5	10.0	5.6	3.6	2.5	1.8	1.4	1.1	.9	.7	.6	.5
		Cycle[c] = 1 yr, SEV = $-2,735/ac, sawtimber = 65 bf/ac/yr, H = 3.66													
High	Pre-harvest	SW	89.1	23.9	10.3	5.8	3.7	2.6	1.9	1.4	1.1	.9	.8	.6	.5
		SH	93.6	23.8	10.3	5.7	3.7	2.5	1.9	1.4	1.1	.9	.8	.6	.5
		HH	91.7	23.5	10.2	5.7	3.7	2.5	1.9	1.4	1.1	.9	.7	.6	.5
	Post-harvest	SW	89.1	22.4	10.0	5.6	3.6	2.5	1.8	1.4	1.1	.9	.7	.6	.5
		SH	89.7	22.4	10.0	5.6	3.6	2.5	1.8	1.4	1.1	.9	.8	.6	.5
		HH	89.7	22.4	10.0	5.6	3.6	2.5	1.8	1.4	1.1	.9	.7	.6	.5
		Cycle[c] = 1 yr, SEV = $-2,756/ac, sawtimber = 74 bflaclyr, H = 3.66													

[a] Loblolly pine site index: Low = 60-79, Medium = 80-94, High = 95-109 feet.
[b] SW = pines and other softwoods, SH = soft hardwoods, HH = hard hardwoods.
'Cycle = cutting cycle, SEV = soil expectation value, Sawtimber = annual loblolly pine sawtimber yield, and H = Shannon's index of tree diversity.

Table 4—Steady-state management regimes that maximize annual iobioiiy pine sawtimber production, by site

Site[a]	Time	Species group[b]	2	4	6	8	10	12	14	16	18	20	22	24	26+
			Diameter-at-breast height (inch)												
			Trees per acre												
Low	Pre-Harvest	SW	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.8	1.1	—	—	—
		SH	6.0	—	—	—	—	—	—	—	—	—	—	—	—
		HH	9.3	—	—	—	—	—	—	—	—	—	—	—	—
	Post-Harvest	SW	89.1	38.5	23.0	16.6	13.6	12.2	11.6	11.6	11.8	—	—	—	—
		SH	—	—	—	—	—	—	—	—	—	—	—	—	—
		HH	—	—	—	—	—	—	—	—	—	—	—	—	—
		Cycle[c] = 1 yr, SEV = $-1,590/ac, sawtimber = 426 bf/ac/yr, H = 1.99													
Medium	Pre-harvest	SW	104.7	46.2	27.9	20.3	18.7	15.0	14.2	14.1	1.4	—	—	—	—
		SH	6.4	—	—	—	—	—	—	—	—	—	—	—	—
		HH	6.5	—	—	—	—	—	—	—	—	—	—	—	—
	Post-harvest	SW	104.7	46.2	27.9	20.3	16.7	15.0	14.2	14.1	—	—	—	—	—
		SH	—	—	—	—	—	—	—	—			—	—	—
		HH	—	—	—	—	—	—	—	—	—	—	—	—	—
		Cycle[c] = 1 yr, SEV = $-1,088/ac, sawtimber = 472 bf/ac/yr, H = 1.90													
High	Pre-harvest	SW	104.4	46.1	27.9	20.3	16.7	15.0	14.2	14.0	1.4	—	—	—	—
		SH	6.4	—	—	—	—	—	—	—	—	—	—	—	—
		HH	5.5	—	—	—	—	—	—	—	—	—	—	—	—
	Post-harvest	SW	104.4	46.1	27.9	20.3	16.7	15.0	14.2	14.0			—	—	—
		SH	—	—	—	—	—	—	—	—	—	—	—	—	—
		HH	—	—	—	—	—	—	—	—	—	—	—	—	—
		Cycle[c] = 1 yr, SEV = $-1,071/ac, sawtimber = 520 bf/ac/yr, H = 1.90													

[a] Loblolly pine site index: Low = 60-79, Medium = 80-94, High = 95-109 feet.
[b] SW = pines and other softwoods, SH = soft hardwoods, HH = hard hardwoods.
[c] Cycle = cutting cycle, SEV = soil expectation value, Sawtimber = annual loblolly pine sawtimber yield, and H = Shannon's index of tree diversity.

CONCLUSIONS

Deciding how best to manage forestlands to meet specific objectives requires a clear understanding of what is possible on different sites. The nonlinear programming models presented here help define these limits for uneven-aged loblolly pine stands by identifying sustainable steady-state management regimes that maximize either the soil expectation value, Shannon's index of tree diversity, or the average annual sawtimber production on low, medium and high productivity sites. As illustrated above, mathematical programming models can also be used to quantify tradeoffs between competing objectives and thus help identify potential compromise management regimes. Nevertheless, because tree growth, reproduction, and mortality are highly stochastic processes, our ability to model them accurately is limited. Therefore, the optimal regimes presented in this paper should be interpreted as tentative recommendations and not as proven strategies to be adopted unquestioningly.

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HARDWOOD CONTROL TREATMENTS TO ENHANCE NATURAL REGENERATION AND GROWTH OF LOBLOLLY-SHORTLEAF PINES IN AN UNEVEN-AGED STAND: 12-YEAR RESULTS'

Michael D. Cain[2]

Abstract-To facilitate natural regeneration of loblolly (*Pinus taeda* L.) and shortleaf pines (*P. echinata* Mill.) in an overstocked, uneven-aged pine stand in southeastern Arkansas, hardwoods were controlled by either basal injection of TordonQ 101 R, soil application of **Velpar®** L, or rotary mowing followed by a broadcast spray of TordonQ 101 applied over the hardwood stubble. After hardwood control, an improvement cut reduced merchantable pine basal area from 97 to 70 ft^2 per acre, just before a better-than-average pine seed crop. Two subsequent improvement cuts in July 1987 and June 1991 left 55 and 48 ft^2 per acre, respectively, in merchantable pine basal area. Twelve years after hardwood control, all plots had an adequate density of pine regeneration for uneven-aged stands, but dominant pine regeneration on treated plots averaged 16 ft taller and 2.2 in. larger in groundline diameter than the dominants on untreated plots.

INTRODUCTION

Although much forest acreage in the South is stocked with pine sawlogs in the overstory, little or no pine regeneration is present in the understory, even when overstory basal area is optimum (<60 ff per acre) for such regeneration. Hardwood trees, shrubs, vines, and brambles invade pine sites and shade out many pines of smaller size during the early years of pine development. To compound this problem, many private nonindustrial forest landowners tend to periodically harvest their merchantable sawlog pines without controlling the hardwood component. Such harvesting practices are especially detrimental in uneven-aged pine silviculture because there must be a progression of trees from the smaller to the larger and more valuable size classes.

Private nonindustrial forest landowners are often aware of the hardwood problem on pine sites, but frequently have the misconception that hardwood control involves high-cost, intensive treatments, requiring the use of heavy mechanical equipment. As a result, productive pine sites can become dominated by low-quality hardwoods that may have little commercial value as a timber resource.

The objectives of this study were to assess the effects of low-cost hardwood control on the establishment of natural pine regeneration and to monitor the development of that regeneration to merchantable size. This paper reports the efficacy of three hardwood control treatments for enhancing pine establishment and growth 12 years after treatments were applied.

METHODS

The study was initiated in southeastern Arkansas in a mature, overstocked stand of loblolly (*Pinus taeda* L.) and shortleaf pines (P. *echinata* Mill.) that averaged 20 in. d.b.h. and contained 97 ft^2 of pine basal area per acre. The stand did not have a well-defined uneven-aged structure but did have potential for uneven-aged management. Submerchantable (<3.6 in. d.b.h.) pine density was only 63 stems per acre compared to a hardwood density of 2,350 stems per acre.

Soil on the study area is Bude (Glossaquic Fragiudalf) silt loam (USDA 1979). Sixteen contiguous plots of 0.25 acre each were established in spring 1983 with interior subplots measuring 66 by 68 ft (0.1 acre). The experiment was a randomized complete block design with four replications of each treatment. Blocking was based on merchantable pine basal area before the first improvement cut. Preharvest treatments for controlling hardwoods were assigned at random within blocks.

Hardwood control treatments were applied to plots only once, as follows:

(1) Untreated check-There was no preharvest control of hardwoods.
(2) Basal injection-All hardwoods having a groundline diameter (g.l.d.) of ≥ 1 in. were injected with TordonQ 101 R (picloram at 0.27 lb acid equivalents (a.e.) per gal and 2,4-D at 1 .O lb a.e. per gal) at the rate of 0.03 oz per incision and one incision per inch of groundline diameter Injection was accomplished in late March 1983 with Jim-Gem® tree injectors.
(3) Soil-applied herbicide—Velpar® L (hexazinone) was dispersed using spotgun applicators at the rate of 4 lb active ingredients (a.i.) per acre on a 4- by 4-ft grid. A 50150 solution of water/hexazinone was applied as 0.19 oz spots. Because soil texture and soil moisture affect the efficacy of hexazinone, the herbicide was dispersed in early April 1983, when there was adequate soil moisture to ensure uptake by target plants.
(4) Mow and herbicide spray-All hardwoods 14 in. d.b.h. were mulched using a rotary mower attached to a wheel tractor; hardwoods >4 in. d.b.h. were cut with chain saws then mulched with the mower so that no hardwoods were left standing. Plots were mowed in late May and early June 1983. Tordon 101 was applied over the hardwood stubble as a broadcast spray at the rate of 2 lb a.e. per acre in 60 gal of water per acre as soon as mowing was complete.

The initial improvement cut was completed in summer 1983 by harvesting the poorest quality trees so that residual pine

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basal area averaged 70 ft^2 per acre. A second improvement cut was completed in summer 1987, leaving 55 ft^2 per acre of merchantable pine basal area. Residual pine basal area averaged 48 ft^2 per acre following a third improvement cut in June 1991. All three improvement cuts were done operationally using rubber-tired tractors and skidding log lengths no longer than 38 ft. The objectives of the improvement cuts were to provide openings for natural pine regeneration, remove trees of poor form and quality, and improve spacing of residuals.

Pine seed crops were monitored during the first three winters after hardwood control. Pine regeneration, hardwood reestablishment, and percent ground cover were measured within nine systematically spaced circular quadrats (5.27-ft radius) per interior O.l-acre subplot. Twelve years after hardwood control, pine seedlings (<0.6 in. d.b.h.) and saplings (0.6 to 3.5 in. d.b.h.) were counted within each sample quadrat. The two tallest (dominant) stems of pine regeneration (seedlings or saplings) per quadrat were measured for total height to 0.1 ft and g.l.d. to 0.1 in. and were assessed as being either overtopped by nonpine competition or free-to-grow. Percent ground cover of vegetative components was visually estimated on each quadrat to the nearest 10 percent. Hardwoods of seedling and sapling size were identified by species, and rootstocks were counted within each sample quadrat. A rootstock was comprised of seedling-sized single or multiple stems (clump) which obviously arose from the same root system. Hardwoods >3.5 in. d.b.h. were identified as *Acer rubrum* L. (red maple), *Comus florida* L. (flowering dogwood), *Ilex opaca* Ait. (American holly), *Liquidambar styraciflua* L. (sweetgum), *Quercus* spp. (red oaks or white oaks), and *Sassafras albidum* (Nutt.) Nees (sassafras). All merchantable-sized pines and hardwoods were counted by l-in. d.b.h. classes within each 0.25acre gross plot.

Data were analyzed by analysis of variance. Percent values were analyzed following arcsine transformation, but only nontransformed values are presented. Orthogonal contrasts were used to partition mean differences among treatments as follows: (1) untreated checks versus competition control treatments; (2) effects of herbicides applied by basal injection and herbicides applied to soil versus mowing and herbicide spray; and (3) effects of herbicides applied by basal injection versus herbicides applied to soil. Treatment differences were judged significant at a = 0.05.

RESULTS AND DISCUSSION

During winter 1983-84, following hardwood control and the first improvement cut, a better-than-average pine seed crop averaged more than 1 ,000,000 potentially viable seeds per acre (Cain 1988). Twelve years after hardwood control, density of pine regeneration established from that seed crop or subsequent seed crops, averaged 1,81 1 stems per acre on hardwood control plots, which was 307 percent more (P = 0.03) than occurred on check plots (table 1). Quadrat stocking of these pines averaged 42 percent on check plots versus 78 percent on treated plots, and that difference was statistically significant (P = 0.05).

Based strictly on density and quadrat stocking, the untreated check plots were adequately regenerated with enough pines to perpetuate uneven-aged management. However, when size of pine regeneration was considered, the untreated check plots become a less-favorable option. After 12 growing seasons, saplings accounted for more than 70

Table 1—Status of pine regeneration 12 years after hardwood control in a southeastern Arkansas uneven-aged pine stand

Hardwood control and orthogonal contrasts	Density	Quadrat stocking[a]	Total height	Groundline diameter[b]	Free-to-grow[b]	Ground cover from pine regeneration
	No./acre	Percent	Feet	Inches	- - - - - - - Percent	- - - - - -
1. Check	445	42	3.61	0.51	20	2
2. Injection	2,167	84	19.94	2.88	80	31
3. Soil-applied herbicide	1,139	64	15.85	2.16	65	17
4. Mow-and-spray	2,126	86	23.08	3.06	90	37
Mean square error	819,049	.15	34.02	.73	.25	.02
P>F[c]	.07	.12	.01	.01	.06	.03
			Probabilities of a greater F-ratio			
1 vs 2+3+4	.03	.05	< .01	< .01	.02	.01
2+3 vs 4	.42	.36	.18	.32	.26	.17
2 vs 3	.14	.22	.35	.27	.47	.19

[a] (Number of occupied quadrats/total number of quadrats) x 10.
[b] Based on the tallest 250 stems per acre on sample quadrats.
[c] The probability of obtaining a larger F-ratio under the null hypothesis.

percent of pine regeneration density on treated plots but only 22 percent of pine regeneration on check plots. On the mow-and-spray plots, more than 1,900 pines per acre grew to sapling size in 12 years as compared to a range of from 778 to 1,488 pine saplings per acre on the soil-applied herbicide plots and injection plots, respectively.

For the tallest 250 stems per acre of pine regeneration, total heights averaged from 12 to 19 ft taller (P <0.01) on hardwood control plots compared to untreated check plots (table 1). Similarly, dominant pine regeneration on hardwood control plots averaged 2.2 in. larger (P <0.01) in g.l.d. compared to dominants on check plots (table 1).

After 12 growing seasons, only 20 percent of dominant pine regeneration was free-to-grow on untreated check plots compared to an average of 78 percent on hardwood control plots, and that difference was significant (P = 0.02) (table 1). Likewise, ground cover from pine regeneration was consistently higher (P = 0.01) on hardwood control plots (28 percent) versus check plots (2 percent).

When the study was initiated, the number of pines by diameter class did not exhibit the reversed-J distribution (Smith 1988) that is characteristic of uneven-aged stands, because there was no pine regeneration. However, the release of midstory pines by three improvement cuts and the ingrowth of pine regeneration during the 12-year period, resulted in a stand with an irregular uneven-aged structure (fig. 1).

Density of submerchantable-sized (<3.6 in. d.b.h.) nonpine woody competition averaged 9,035 rootstocks per acre with no differences (P = 0.49) among treatments (table 2). *Cornus florida* L., *Callicarpa americana* L. (American beautyberry), *Vaccinium* L. spp. (huckleberry), and *Acer rubrum* L. accounted for 70 percent of submerchantable-sized woody rootstock density. *Cornus florida* was the dominant species on check, inject, and soil-applied herbicide plots; Veccinium was dominant on mow-and-spray plots.

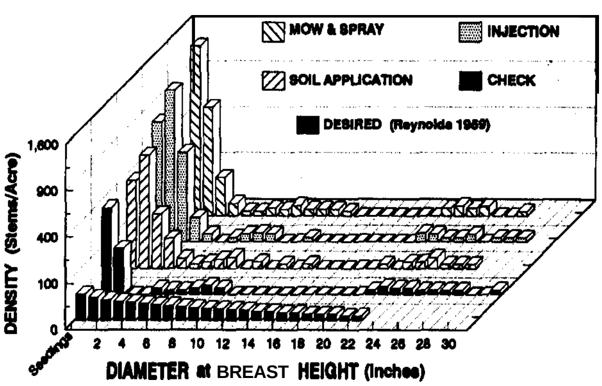

Figure l-Diameter distribution of loblolly and shortleaf pines in a southeastern Arkansas uneven-aged pine stand, 12 years after hardwood control. Scale of the Y-axis is a square-root transformation.

Species richness (number of different species) of submerchantable-sized woody nonpine rootstocks was similar across all treatments. Actual counts of species by treatments were 21 on check plots, 23 on injection plots, 24 on soil-applied herbicide plots, and 21 on mow-and-spray plots. Ground cover from these submerchantable-sized woody plants averaged 57 percent with no differences (P = 0.84) among treatment means (table 2). These data suggest that diversity of plant species was not greatly compromised by applying herbicides 12 years earlier.

For merchantable-sized hardwoods (≥3.6 in. d.b.h.), hardwood control plots averaged 87 percent fewer(P <0.01) stems (22 per acre) compared to check plots (table 2). Some hardwoods in these merchantable size classes on inject and soil-applied herbicide plots were residuals that survived control treatments 12 years earlier.

On mow-and-spray plots where all hardwood stems were cut at groundline, *Liquidambar styraciflua* and *Cornus florida* were the only species to attain merchantable size in 12 years. On check, inject, and soil-applied herbicide plots, the dominant hardwood species in merchantable d.b.h. classes in order of prevalence were *Cornus florida*, *Acer rubrum*, and *Liquidambar styraciflua.* These species as a group accounted for 88 percent of merchantable-sized hardwoods on check plots, 95 percent on inject plots, and 85 percent on soil-applied herbicide plots. The only treatment with merchantable-sized *Quercus* spp. was the untreated check, where oaks comprised 11 percent of total stems.

Percent ground cover from merchantable-sized hardwoods ranged from only 4 percent on injection plots to 45 percent on check plots (table 2). Twelve years after treatment, all three hardwood control treatments had less (P <0.01) ground cover from merchantable-sized hardwoods when compared to check plots.

Because the forest floor was shaded by pines on mow-and-spray plots and by hardwoods on check plots, these two treatments averaged the lowest (P = 0.03) ground cover from herbaceous vegetation at 53 percent (table 2). Herbaceous ground cover on injection and soil-applied herbicide plots did not differ (P = 0.75) and averaged 76 percent.

Costs for hardwood control in this investigation were as follows (Cain 1988): Check (no cost), injection ($64 per acre), soil-applied herbicide ($100 per acre), and mow-and-spray ($105 per acre). These costs were based on $3.50 per hour minimum wage, retail prices of herbicides in 1983, and USDA Forest Service operating and replacement costs for fleet equipment (rubber-tire tractor used in mowing).

SUMMARY AND CONCLUSIONS

Density and quadrat stocking of natural pine regeneration that becomes established after an improvement cut in an uneven-aged stand may appear to be adequate without hardwood control. Nevertheless, under hardwood shade, dominant pine seedlings lingered in a suppressed condition with low vigor for 12 years. In contrast, all three methods of hardwood control compared in this study resulted in dominant pine regeneration that averaged larger in size and exhibited a more vigorous appearance when compared to dominant pine regeneration on plots without hardwood control. From 65 percent to 90 percent of dominant pine

Table 2—Status of nonpine competition 12 years after hardwood control in a southeastern Arkansas uneven-aged pine stand

Hardwood control and orthogonal contrasts	Density of stems <3.6 inches d.b.h.	Ground cover from stems <3.6 inches d.b.h.	Density of stems ≥3.6 inches d.b.h.	Ground cover from stems ≥3.6 inches d.b.h.	Ground cover from herbaceous species[a]
	No./acre	*Percent*	*No./acre*	*Percent*	*Percent*
1. Check	9,570	63	163	45	54
2. Injection	6,056	52	20	4	77
3. Soil-applied herbicide	9,000	55	30	25	74
4. Mow-and-spray	9,514	58	15	IO	52
Mean square error	2,274,155	.04	159	.01	.03
P>F[b]	.49	.84	< .01	< .01	.03
			Probabilities of a greater F-ratio		
1 vs 2+3+4	.43	.44	< .01	< .01	.07
2+3 vs 4	.31	.73	.23	.44	.01
2 vs 3	.40	.84	.29	.02	.75

[a] Herbaceous vegetation included grasses, sedges, forbs. vines, and semi-woody plants.
[b] The probability of obtaining a larger F-ratio under the null hypothesis.

regeneration was judged as free-to-grow on treated plots compared to only 20 percent on check plots. During a better-than-average seed year, any method of hardwood control combined with a pine improvement cut will facilitate the establishment of natural loblolly-shortleaf pine regeneration on silt loam soil, as long as residual overstory pine density and basal area are within recommended guidelines for uneven-aged management (Baker and others 1996).

Twelve years after establishment, density of natural pine regeneration was excessive (>1 ,400 stems per acre) when compared to published recommendations (Cain 1991, Reynolds 1959) for optimum postharvest density of submerchantable-size pines in uneven-aged stands (100 to 200 stems per acre). Nevertheless, on treated plots, where pine densities were highest and midstory hardwood densities were lowest, dominant pine regeneration exhibited a 12- to 19-ft height gain in 12 years when compared to dominant pines on check plots. Consequently, intraspecies competition among pines was less detrimental to growth of pine regeneration than the presence of overtopping hardwoods. Private nonindustrial forest landowners who wish to increase pine growth and yield would likely benefit from the low-cost hardwood control treatments tested in this study.

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FIRE ECOLOGY OF SEEDS FROM *RUBUS* SPP.: A COMPETITOR DURING NATURAL PINE REGENERATION'

Michael D. Cain and Michael G. Shelton'

Abstract-Air-dried blackberry (*Rubus* spp.) fruits were placed at three depths in a reconstructed forest floor and subjected to a simulated prescribed summer burn. Within the forest floor, fruits were placed on the L layer, at the upper-F/lower-F interface, and at the lower-F/mineral-soil interface. Wind for a headfire was generated by electric box-fans. Extracted seed viability was assessed during each of six 30- or 60-day germination tests that alternated with 30 or 60 days of cold stratification over a period of 18 months. As depth within the forest floor increased, germinative capacity of blackberry seeds increased. For blackberries placed on the L layer and at the upper-F/lower-F interface during prescribed burning, cumulative seed germination averaged only 0.03 and 0.33 percent, respectively. At the lower-F/mineral-soil interface, mean seed germination did not differ (*P* = 0.74) from the 23 percent achieved by unburned control seeds.

INTRODUCTION

Forestry benefits from prescribed burning include: site or seedbed preparation, control of unwanted vegetation, disease control, thinning of dense young pine stands, increased growth and yield of pines, and improvement of wildlife habitat (Crow and Shilling 1980, Davis 1959). Therefore, prescribed burning continues to be widely used in southern pine management.

Prescribed burning can have positive and negative effects on wildlife habitat by increasing certain essential nutrients and palatability of forage, initially reducing leafy biomass followed by increases, and initially decreasing fruit yields followed by increases (Landers 1987). Consequently, it is important to determine the effects of prescribed fire on early successional plant species that both hinder natural pine regeneration and contribute wildlife habitat.

Blackberry (*Rubus* spp.) was chosen for this investigation because it occurs throughout the Southeastern U.S., is a predominant herbaceous vegetation component in naturally regenerated pine stands (Cain 1991, Shelton and Murphy 1994), and is an important food source for wildlife (Landers 1987, Matthews and Glasgow 1981). Because blackberry seeds have hard, impermeable seedcoats, germination has been improved when seeds are scarified with concentrated sulfuric acid for 20 to 60 minutes (Brinkman 1974). Sumorization, or heat pretreatment of seeds before they germinate (Barbour and others 1987), may also enhance germination of blackberry seeds.

The purpose of the present investigation was to experimentally determine if germination of seeds from air-dried blackberry fruits might be enhanced when subjected to a simulated prescribed summer burn, depending upon vertical stratification of the fruits in a reconstructed forest floor.

METHODS

The study was located in southeastern Arkansas. The soil, a Sacul loam (clayey, mixed, thermic, Aquic Hapludult), is described as a moderately well drained upland soil with a site index of 80 ft for loblolly pine (*Pinus taeda* L.) at age 50 years (USDA 1976).

Within a pine seed-tree stand, an area was cleared of vegetation down to mineral soil and a 5- by 7-ft burn bed was framed with steel railings. Soil was leveled within the bed and allowed to settle 6 months at which time a forest floor was reconstructed on the bed using procedures developed by Shelton (1995).

In early July 1996, 7 days before burning, undisturbed forest floor material was obtained from beneath a closed forest canopy 300 ft from the burn site, where pine basal area averaged 90 ft^2 per acre. The forest floor was typical of similar stand conditions found elsewhere in the South (Switzer and others 1979). To facilitate reconstruction on the burn bed, forest floor material was collected in three layers - L, upper F, and lower F - using 1.3 ft^2 sampling frames. The L layer refers to the litter layer consisting of unaltered dead remains of plants (Pritchett 1979). The fermentation (F) layer was immediately below the L layer and consisted of fragmented, partly decomposed organic materials that were sufficiently preserved to permit identification as to origin (Pritchett 1979). For this experiment, the F layer was subdivided into upper and lower zones based on visual evidence of decay. The undisturbed L layer averaged 0.24 in. in thickness; the upper F layer averaged 0.18 in.; and the lower F layer averaged 0.65 in. Each layer was removed separately; then layers were transferred from the undisturbed forest floor in paper bags and reconstructed on the burn bed during the day of removal. Within the burn bed, a 3- by 5.2-ft interior plot was subdivided into twelve 1.3 ft^2 cells (replications) for placement of the reconstructed forest floor and blackberry fruits. A reconstructed forest floor ensured uniform fuel conditions for burning (Hungerford and others 1994) and uniform litter layers for placement of blackberry fruits.

Fresh blackberry fruits for the study were obtained in late June 1996 from forested pine stands in southeastern Arkansas, north-central Louisiana, and southwest Mississippi. Fruits were collected from a minimum of 25 blackberry canes per geographic location. These fruits were air-dried on wire screen at room temperature from the time of collection until the burn date. For each replicated cell in the burn bed, 12 blackberry fruits were used, with four fruits taken from each of the three geographic areas. To relocate

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all fruits per treatment cell after burning, the fruits were glued at l-in. intervals onto fiberglass cord with high-temperature silicone. This process was done 24 hours before the scheduled burn to permit the glue to cure. At the time of burning, fruit moisture content averaged 16 percent (oven-dry basis).

Just before fire ignition, three fiberglass cords containing four blackberry fruits each were transferred to the center of 12 burn cells at one of three randomly assigned litter depths in the reconstructed forest floor. Fruits were placed on the L layer, at the upper-F and lower-f interface, or at the lower-f and mineral-soil interface (fig. 1).

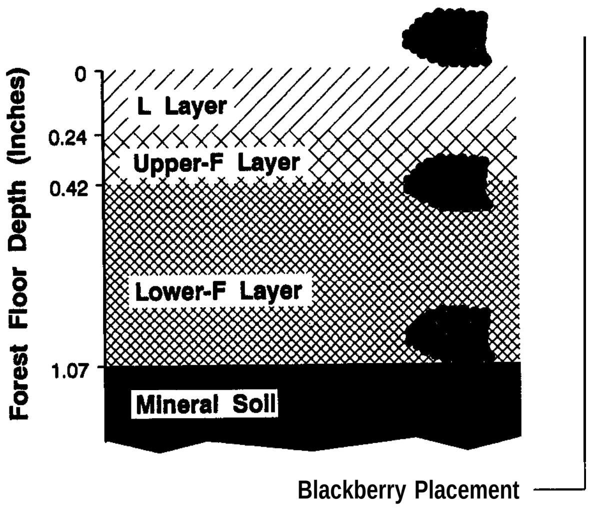

Figure l-Before prescribe burning, blackberry fruits were placed at three depths within the forest floor-on the L layer, within the F layer, and at the lower-F and mineral-soil interface.

Prescribed burning was conducted on July 8, 1996 (table 1). Wind for the simulated fire was provided from two 20-in. electric box-fans positioned side-by-side at ground level. Fan-blade rotation was varied during burning to maintain a constant wind speed at the fire front. Fuel burned with the wind (headfire), and wind speed was determined using an electronic Turbo-Meter@ wind speed indicator. While burning was in progress, flame lengths were ocularly estimated to the nearest 0.5 ft. Fireline intensity was calculated from flame lengths (Byram 1959).

To accurately measure temperatures generated by the fire, Tempil® temperature indicator pellets with known melting points were placed atop the burning litter. The melting temperature for these pellets ranged from 119 to 1490 "F.

To determine fuel moisture, a separate 3-ft^2 subplot containing a reconstructed forest floor was set up at the burn site. Immediately after burning, three unburned litter samples were taken from this subplot within each of the three litter layers in proportion to the weight of each layer. Moisture determination was on an oven-dry basis. After the burn, four 1-ft^2 samples of residual litter were taken from within the burn bed to determine the weight of this unburned material on an oven-dry basis.

For each treatment (fruit location) and replication, blackberry fruits were removed from the fiberglass cords after burning

Table l-Fuel and weather conditions during a simulated prescribed summer burn in southeastern Arkansas

Fuel and weather variables	Values
Date of burn	July 8, 1996
Days since last precipitation	2
Amount of most recent precipitation (inches)	1.10
Time of burning (hours DST)	1,020
Dry bulb temperature ("F)	96
Relative humidity (percent)	49
Wind direction	From the South
Wind speed[a] (mph)	5.5
Forest floor moisture (percent)	
L layer[b]	18
Upper F	16
Lower F	26
Forest floor weight (tons/acre)	
L layer	.9
Upper F	.7
Lower F	3.7
Mean fire line intensity[c] (Btu/ft-sec)	6.4
Rate of spread (Wmin)	3.2

[a] Wind speed generated by two electric box fans positioned side-by-side at ground level.
[b] Fine-fuel moisture.
[c] $I = 5.67L_f^{2.17}$, where L_f = Ocular estimates of flame length.

and placed in de-ionized water along with four replications of unburned control fruit to soak overnight. After burning, blackberry fruit recovery was 94 percent from the L layer, 98 percent from the F layer, and 100 percent from the lower-F/mineral-soil interface. Soaked fruits were macerated by hand in running tap water on 0.02-in. sieves to separate seeds from the pulp. The pulp mass was allowed to air dry at room temperature overnight; then seeds and pulp were forced through 0.08-in. sieves to remove the larger pulp. Percent germination was based on the number of sound blackberry seeds per replicate, which was estimated from air-dried weight of the fruit. The average air-dried fruit weighed 0.009 oz. There was an average of 7,560 seeds per oz of air-dried fruit with 89 percent of seeds being judged sound by float testing (Brinkman 1974). Residual seeds and pulp were dispersed onto moist, sterile-sand flats for germination tests.

The germination phase of the study lasted 18 months during which six germination tests were conducted. From July through October 1996, 30-day germination tests alternated with 30 days of stratification at 39 "F. Germination periods of 30 days each were retained through March 1997, but stratification time was increased to 60 days for the remainder of the study. From June through December 1997, 60-day germination tests were used.

The first germination test was conducted without stratification using 10 hours of full-spectrum fluorescent light and 14 hours of darkness during each 24 hours. Light exposure during the remaining germination tests was increased to 16 hours per day to simulate summer day length. Temperature in the germination room was maintained at 70 °F. Germination was considered complete when the radicle had emerged from the seedcoat and was at least 0.1 in. in length (Doucet and Cavers 1996).

The experiment was a randomized complete block design with four replications of three litter depths. Blocking was based on distance from the fans. Analysis of variance was used to compare germinative capacity of seeds relative to their location within the forest floor (SAS 1989). Germination percent was analyzed following arcsine square-root proportion transformation, but only nontransformed percentages are reported. Orthogonal contrasts were used to partition mean differences among seed locations within the forest floor as follows: $L+F_UF_L$ versus F_LS, and L versus F_UF_L (L is the L layer, F_U is the upper-F layer, F_L is the lower-F layer, and S is mineral soil). A second analysis of variance was used to compare the germinative capacity of seeds from the F_LS interface to that of unburned control seeds. Significance was accepted at the a = 0.05 probability level.

RESULTS AND DISCUSSION

The headfire completely traversed the burn bed, leaving no unburned gaps. Forest floor weight averaged 5.3 tons per acre before burning and 3.5 tons per acre after burning. Consequently, the fire consumed all of the L and upper-F layers and a portion of the lower-f layer. Subsequent germination of blackberry seeds varied directly with litter consumption. Blackberry fruits on the L layer and at the F_U/F_L interface were badly charred, yielding only 0.03 and 0.33 percent seed germination, respectively, during the next 18 months. Germinative capacity of blackberry seeds did not differ (P = 0.64) between these upper litter layers (table 2).

During the 18 months following the burn, cumulative germination of blackberry seeds from fruit placed at the lower-F/mineral-soil interface averaged 23.43 percent. This significant improvement (P <0.01) in seed germination over the mean from the L and upper-F/lower-F interface (table 2) was attributed to the heatshield provided by unburned litter at that lower depth. Moisture content of the lower F layer was 26 percent (table 1) at the time of burning, and residual forest floor litter weight after burning averaged 3.5 tons per acre. So, only 0.2 tons per acre of the lower F layer burned. Wade and Lunsford (1989) reported that when fine-fuel moisture approaches 30 percent, fires tend to burn slowly and irregularly, which may explain why litter at the lower depth did not burn in the present study. According to Alexander (1982), responses by minor vegetation following a fire are directly influenced by depth of the burn.

Table P-Analysis of variance for germinative capacity of blackberry seeds by fruit location within the forest floor

Source of variation	Degrees of freedom	Mean square	P>F
Block	3	0.0074	0.38
Fruit location in the forest floor[a]	2	.2994	< .01
($L+F_uF_L$ vs F_LS	1)	.5973	< .01
(L vs F_uF_L	1)	.0015	.64
Error	6	.0061	

[a] L is the litter layer, F_uF_L is the upper-F/lower-F interface, and F_LS is the lower-F/mineral-soil interface.

During 18 months of germination cycles in this investigation, the mean germinative capacity of control seeds from unburned blackberry fruits averaged 23.49 percent. That proportion of germination was no different (P = 0.74, MSE = 0.0162, ANOVA not presented) than the 23.43 percent germination from seeds at the lower-F/mineral-soil interface. Cumulative germination for these two groups of seeds is illustrated in figure 2. Following each period of stratification, there was a pulse of germination from control seeds and seeds placed at the lower-F/mineral-soil interface. Within the first 300 days of germination testing, less than 5 percent of these seeds had germinated. Yet, within the next 200 days, seed germination increased by 20 percentage points (fig. 2). Similarly, Heit (1967) found that seeds from cultivated hybrid blackberries germinated over a period of several years without special treatment and maximum delayed germination was obtained in the third year.

At 184 days after the germination tests began, seeds at the lower-F/mineral-soil interface averaged somewhat better germination over unburned controls, and that trend continued for the next 300 days (fig. 2). However, t-tests comparing germination of those two groups for each germination date produced nonsignificant results (P >0.05). Still, the consistent trend toward more rapid germination suggests that heating blackberry fruit by fire might enhance seed germination.

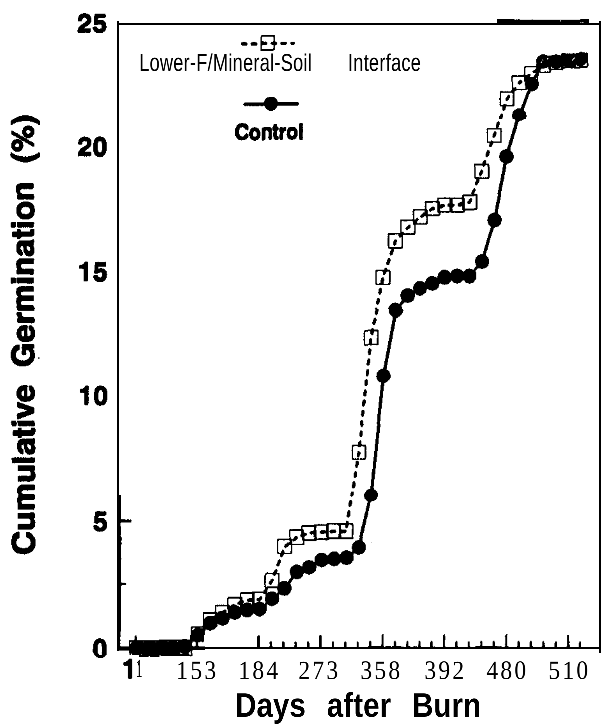

Figure P-Cumulative germination of blackberry seeds taken from unburned control fruit and fruit placed at the lower-F and mineral-soil interface during a simulated prescribed summer burn.

In this experimental prescribed burn, blackberry fruit placed at the lower-F/mineral-soil interface (fig. 1) produced the highest germination of seeds, which did not differ from unburned control seeds. Viability of seeds at this depth was mainly attributed to the fact that the lower-F layer was not completely consumed by fire. Although killing of plant tissue has been reported to occur at about 120 °F (Davis 1959), both temperature and its duration are important. On these 7- by 5-ft beds, melting of Tempil® pellets indicated that temperatures ranged from 550 to 750 °F during this summer burn.

MANAGEMENT IMPLICATIONS

In operational prescribed winter burns (Cain 1993) conducted on sites similar to those described here, fireline intensities were greater (47 to 134 Btu per sec per ft), fine-fuel moisture was lower (6 to 15 percent) and wind speeds were higher (3 to 13 mph) than reported in the present simulated burn. Under those environmental conditions, it is unlikely that blackberry fruits with a moisture content of 16 percent will remain intact during prescribed burns if they are located on the litter layer or in the upper-F layer of the forest floor.

Whether heat pretreatment or cracking of the impermeable seedcoat by fire can enhance the establishment of blackberries from seed was not answered in this investigation because the air-dried blackberry fruits tended to be charred by the fire when placed in the upper litter layers of a forest floor, apparently destroying the seeds. In contrast, seeds from fresh blackberry fruits that are exposed to fire might exhibit an entirely different response, because the high moisture content of fresh fruit should protect seeds from complete consumption by fire. Operationally, such burning would be limited to a narrow window during late spring or early summer when blackberries ripen in the Southeastern U.S. Additionally, fruits eaten by animals may be embedded in an entirely different matrix, altering seed response to fire.

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EVALUATION OF THE EFFECT OF THINNING LEVELS, AGE AND SITE INDEX ON SHORTLEAF PINE REGENERATION AND HARDWOOD UNDERSTORY[1]

Jean Nkouka, Thomas B. Lynch, Michael M. Huebschmann, and Paul A. Murphy[2]

POSTER SUMMARY

Effects of thinning levels, age and site index on shortleaf pine (*Pinus echinata* Mill.) advance regeneration and hardwood understory stems were evaluated in natural, even-aged shortleaf pine stands which had thinning and hardwood control treatments 10 years previously. Plots 0.2-acres in size for measurement of overstory trees were established 10 years prior to understory evaluation as part of a growth and yield study of natural, even-aged shortleaf pine conducted cooperatively by the USDA Forest Service and the Department of Forestry at Oklahoma State University. Overstory plots were established on the Ozark and Ouachita National Forests in eastern Oklahoma and western Arkansas. Each overstory plot with a surrounding 33-foot buffer zone was thinned to one of four residual basal area classes: 30, 60, 90 or 120 ft^2/acre (class midpoints listed). Overstory plots were located in four age classes: 20, 40, 60 or 80 years and four site index classes: 50, 60, 70, or 80 feet at 50 years. Chemical herbicide was used to control hardwoods present on each overstory plot at the time of plot establishment.

Ten years after the establishment of overstory growth and yield plots, pine regeneration and the hardwood understory were inventoried on two 0.005acre understory plots in each 0.2-acre overstory plot. All shortleaf pine regeneration and understory hardwood stems 4.5 feet and taller were tallied by species and l-inch d.b.h. class. Data were summarized to provide number of trees per acre and basal area per acre of shortleaf pine regeneration and hardwood understory stems associated with each overstory growth and yield plot.

Regression models were fitted to the plot data to predict number of trees per acre and basal area per acre of both shortleaf pine regeneration and hardwood understory stems. These analyses show that the number of pine regeneration stems is negatively correlated with overstory plot basal area (basal area of mature shortleaf pine) and with number of understory hardwood stems. The number of pine regeneration stems was also negatively correlated with site index. Poor sites appear more conducive to shortleaf pine regeneration. The number of hardwood understory stems per acre is negatively correlated with overstory basal area and positively correlated with site index.

A logistic model was developed to predict the probability of obtaining 300 or more shortleaf pine regeneration stems 10 years after thinning and hardwood control. The model indicates that the probability of successful pine regeneration increases as site index and overstory pine basal area retained after thinning decrease.

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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DISTURBANCE FROM THE INITIAL HARVEST IMPLEMENTING UNEVEN-AGED SILVICULTURE IN A PINE-HARDWOOD STAND IN SOUTHWESTERN MISSISSIPPI[1]

Michael G. Shelton and Paul A. Murphy[2]

Abstract-Logging disturbance is important in uneven-aged stands because harvests are frequent, merchantable trees are retained, and regeneration may be present. Logging disturbance was monitored during the establishment of a study testing the application of uneven-aged silviculture in an irregularly aged, pine-hardwood stand. Disturbances were: (1) seedbed conditions averaging 58, 16, 9, and 17 percent of the area in undisturbed litter, disturbed litter, mineral soil, and logging slash, respectively, (2) a 44 percent reduction in the number of submerchantable hardwood stems, and (3) mortality or severe damage of retained merchantable trees of 1.0 stem per acre for pines and 2.7 stems per acre for hardwoods. Pine regeneration 1 year after harvesting was significantly affected by the seedbed conditions existing after the harvest. Exposed mineral soil and disturbed litter increased the number of seedlings, while the effects of fine logging slash were negative.

INTRODUCTION

Most knowledge about the uneven-aged silviculture of loblolly (*Pinus taeda* L.) and shortleaf (P. *echinata* Mill.) pines was accumulated over a 50-year period at the Crossett Experimental Forest in southeastern Arkansas (Reynolds 1959, Reynolds and others 1984). Uneven-aged silviculture was used to rehabilitate understocked, cutover stands that already had somewhat of a reverse-J size-class distribution. Crossett guidelines call for aggressive competition control and periodic harvests to favor pine regeneration and provide acceptable growth and yield rates. Harvesting is one of the principal stand disturbances in uneven-aged stands, and it is the way that stocking of merchantable trees is regulated. Some of the impacts of harvesting benefit stand regeneration, such as creating favorable seedbed and environmental conditions and destroying some of the competing vegetation. However, other effects are harmful, such as damage to both regeneration and merchantable trees. To determine potential disturbance levels from logging uneven-aged stands, we monitored the conditions existing before and after the harvesting operation implementing a study testing uneven-aged silviculture in a pine-hardwood stand.

METHODS

Study Site

The study was installed in a mature, second-growth pine-hardwood stand in the Homochitto National Forest in Franklin County, Mississippi. Soils in the study area are mapped as the Lorman series (Vet-tic Hapludalfs), which has a silty loam surface horizon and a clayey subsurface. The site is in the Southern Pine Hill physiographic district. Elevations ranged from 200 to 260 ft above sea level. Plots were located on the side slopes in an area of undulating topography, and slopes ranged from 8 to 15 percent. The basal area of merchantable (d.b.h. ≥3.6 inches) pines averaged 81 ff per acre before harvest, with two-thirds consisting of shortleaf pine and one-third loblolly pine. Basal areas averaged 32 ft^2 per acre for merchantable hardwoods.

Study Design and Treatment Implementation

Eighteen square, 0.5-acre plots were installed and surrounded by a 58.2-ft isolation strip that received the same treatment. Treatments reduced merchantable basal area to two levels for pines (45 and 60 ft^2 per acre) and three levels for hardwoods (0, 15, and 30 ft^2 per acre). Treatments were assigned in a completely random design with three replications for each pine-hardwood combination.

The pine harvest was implemented using the basal-area maximum-diameter quotient technique of single-tree selection (Baker and others 1996). Guidelines were for a maximum diameter of 24 inches and a quotient of 1.2 for l-inch d.b.h. classes. Guidelines for maximum diameter and quotient were followed as closely as feasible because the stand lacked a balanced reverse-J structure. Hardwood retention favored the larger and higher quality red and white oaks.

The study area was harvested in dry weather during September and early October of 1990. Primary skidtrails were located along the crest of long, narrow ridges that extended through the study area, with secondary skidtrails extending downslope. Because plots were located on the side slopes, trees from one plot were not skidded through another, which isolated the harvesting impacts for individual plots. Loggers used two rubber-tired cable skidders with 120 horsepower engines. Logs were skidded tree-length with no special restrictions imposed. Harvested volume of merchantable pines averaged 998 ft^3 per acre and ranged from 0 to 2,400 ft^3 per acre for individual plots. Harvested pine sawtimber averaged 4,140 board ft Doyle per acre. This was a relatively high volume because it was the initial application of uneven-aged silviculture. Harvested volumes in uneven-aged stands on good sites will typically range from 1,200 to 4,000 board ft Doyle per acre depending on the cutting-cycle length (Baker and others 1996).

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

[2] Research Forester and Research Forester (deceased), USDA Forest Service, Southern Research Station, Monticello, AR 71656-3516, respectively.

Measurements and Data Analysis

Before harvesting (April 1990), tree saplings and shrubs (0.6 to 3.5 inches d.b.h.) were counted by l-inch d.b.h. classes on 36 temporary 0.01 -acre plots systematically located across the study area. After harvesting (October 1990), 10 permanent monitoring points were systematically located within each 0.5-acre plot. Points were at least 30 ft from the interior plot boundary and 68 ft from the exterior plot boundary. Seedbed conditions were evaluated at 12 points along a 24-ft line-transect centered around each permanent monitoring point. Visual estimation of seedbed coverage in a milacre plot around each permanent point provided values for comparison with regeneration inventories. Each evaluation used the same classification system for seedbed conditions: (1) undisturbed litter, (2) disturbed litter, (3) exposed mineral soil, (4) fine logging slash ≤0.5 inches in diameter (foliage and twigs), (5) medium logging slash from 0.6 to 4.0 inches in diameter (mainly branches), and (6) coarse logging slash ≥4.1 inches in diameter (chiefly stems).

Submerchantable trees ≥ 1 inch d.b.h. were inventoried after harvesting on O.Ol-acre plots at half of the permanent monitoring points. The purpose of this inventory was to determine the number of hardwood stems that were to be treated with herbicides. Any stem that would be treated during hardwood control was counted, even if it had been severely damaged. Retained merchantable trees in the 0.5-acre plot were inspected after logging for damage and defects. In September 1991, pine seedlings from the 1990 seed crop were counted on milacre plots centered around each of the 10 permanent monitoring points.

Mean values were calculated for measurements from the 10 permanent monitoring points within each 0.5-acre plot. Harvested volumes were calculated from the marking tally for each 0.5-acre plot, according to the procedure of Farrar and Murphy (1988) for pines, and Clark and others (1986) for hardwoods. Merchantability limits were: (1) trees ≥ 10 inches d.b.h. and to an 8-inch outside-bark top for pine sawtimber, (2) trees ≥5 inches d.b.h. and to a 4-inch outside-bark top for pine pulpwood, and (3) trees ≥6 inches d.b.h. and to a 4-inch outside-bark top for hardwood pulpwood.

Data were analyzed by nonlinear least squares regression using the SAS procedure MODEL (SAS Institute 1988). Coefficients of variables included in models significantly differed from zero at a probability level of ≤0.10.

RESULTS AND DISCUSSION

Seedbed Conditions

The most widespread seedbed condition was undisturbed litter, which accounted for 58 percent of the area (table 1). Most of the soil surface after harvesting was covered by some type of organic material, and only 9 percent of the area was exposed mineral soil. Although a mineral soil surface promotes pine seedling establishment, this relationship must be considered within the goal of securing acceptable regeneration. For example, acceptable pine regeneration will become established on litter seedbeds if the seed supply is sufficient (Cain 1991). In addition, Shelton (1995) pointed out that litter seedbeds are often beneficial because they reduce competing vegetation and prevent pine overstocking.

Because harvested volumes varied among 0.5-acre plots, the relationship between seedbed conditions and harvesting

Table I-Mean and range for seedbed conditions after the initial harvest implementing uneven-aged silviculture in a pine-hardwood stand

Seedbed condition	Mean	Minimum	Maximum
	- - *Coverage (percent of* area) - -		
Undisturbed litter	58	34	79
Disturbed litter	16	4	28
Logging slash	17	2	36
Mineral soil	9	2	14

intensity could be determined. Harvested volumes significantly affected all seedbed conditions except exposed mineral soil (table 2). Fit indices ranged from 0.27 to 0.61.

The area of undisturbed litter was negatively related to the harvested volumes of pines and hardwoods, which explained 60 percent of the variation in this relationship. The area in undisturbed litter was calculated from regression coefficients; values are plotted in figure 1. Undisturbed litter covered 66 percent of the ground surface when the pine harvest was 500 ft^3 per acre and no hardwoods were harvested. Undisturbed litter decreased to 36 percent when the harvested pine and hardwood volumes were 2,400 and 400 ft^3 per acre, respectively.

The area of disturbed litter increased with the volume of harvested pines, which explained 28 percent of the variation (table 2). Hardwood volume was not significant, which may reflect these species relatively low contribution to the total harvested volume (11 percent). The area of disturbed litter increased from 14 percent when 500 ft^3 per acre of merchantable pines were harvested, to 23 percent when 2,400 ft^3 per acre were harvested (fig. 1).

The area covered by logging slash increased with the volume of harvested hardwoods, explaining 61 percent of the variation (table 2). Coverage increased from a base level of 11 percent, which reflects the contribution of pines to logging debris (fig. 1). About 32 percent of the area was covered by logging slash when the volume of harvested hardwoods was 400 ft^3 per acre. The high contribution of hardwoods to logging slash undoubtedly reflects their large, deliquescent crowns when compared to the excurrent crowns of the pines. Hardwoods in this study had crown volumes that were about twice as large as pines of the same d.b.h. Most of the area covered by logging slash was attributable to fine slash (71 percent), while the remainder was medium (23 percent) and coarse slash (6 percent). The contribution of fine slash would have been much lower had the harvest been conducted during the dormant season. This seasonality can be used to reduce the visual impacts of the harvesting, especially when the hardwood volume is high.

Uneven-aged silviculture is characterized by frequent, low-intensity harvests. There has been little research concerning the levels of soil disturbance associated with the cycle cuts in uneven-aged stands. Harvested volumes in this study were at the upper end of the range for typical cycle

Table 2-Regression coefficients and associated statistics for the relationships between seedbed conditions after harvesting and the harvested volumes for the initial application of uneven-aged silviculture in a pine-hardwood stand

Seedbed condition	Regression coefficients[a] b_0	b_1	b_2	Root mean square error	Fit index
Undisturbed litter	*4.26*	*-0.133*	*-0.659*	*10.7*	*0.60*
Disturbed litter	*2.52*	.254	Ns[b]	*5.7*	.27
Logging slash	*2.43*	*Ns*	*2.557*	*7.5*	.61
Mineral soil	Ns	Ns	Ns	—	—

[a] The equation is: $SB = \exp(b_0 + b_1 PVOL + b_3 HVOL)$, where SB is the area covered by the specified seedbed condition in percentage, and P VOL and HVOL are the harvested pine and hardwood merchantable volumes, respectively, in 1,000 ft^3 per acre.
[b] Variables were dropped from regressions if their coefficients did not significantly (Ns) differ from zero at $P \leq 0.10$.

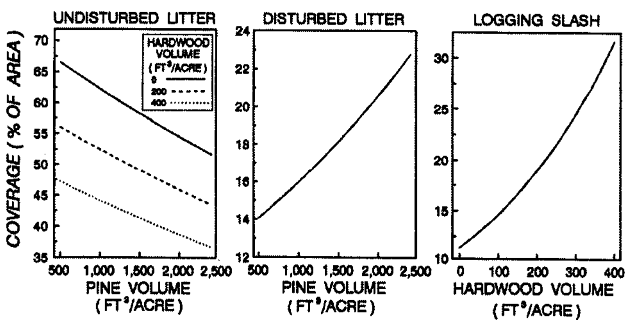

Figure l-Effects of harvested volumes on seedbed conditions after the initial harvest implementing uneven-aged silviculture in a pine-hardwood stand. Values calculated from regression coefficients in table 2.

cuts in uneven-aged stands, and the resulting disturbances probably also would be high. Kluender and others (1994) reported similar levels of disturbance for the initial harvest applying uneven-aged silviculture in pine-oak stands in the Ouachita Mountains; means were 42 percent of the area for undisturbed litter, 26 percent for disturbed litter, 12 percent for logging slash, and 10 percent for mineral soil. Soil disturbances from these initial harvests applying uneven-aged silviculture are considerably lower than those reported for even-aged reproductive cutting methods. For example, strip clearcutting a loblolly pine stand in the Coastal Plain of Virginia resulted in 34 percent of the area undisturbed, 49 percent disturbed, and 17 percent covered by slash (Pomeroy and Trousdell 1948). In loblolly-shortleaf pine stands of southern Arkansas, Grano (1971) observed that a seed-tree cut removing 5,600 board ft International per acre and 6 cords per acre of pulpwood exposed 25 percent of the surface to mineral soil.

Pine Seedling-Seedbed Relationships

The number of pine seedlings after the first growing season was significantly related to seedbed conditions existing after harvest as shown by the following equation:

$$N = \exp(3.29 + 0.0136MS + 0.00709DL \cdot 0.0184FLS) \quad (1)$$

In this equation, N is the number of seedlings per milacre; MS, *DL*, and *FLS* are the percentage of the milacre in exposed mineral soil, disturbed litter, and fine logging slash, respectively. Fit index for the equation was 0.16, root mean square error was 36.4, and there were 176 degrees of freedom. The effects of mineral soil and disturbed litter were both positive, while the effects of fine logging slash were negative. Coverage of fine logging slash was a better predictor than coarser size classes or total slash. This relationship reflects the well-known seedbed requirements for establishment of loblolly and shortleaf pine seedlings: mineral soil is the most favorable seedbed condition, while deep accumulations of organic materials are the least favorable (Shelton and Wittwer 1992). However, conditions are rarely so unfavorable that no establishment occurs, especially if seed production is high (Grano 1949).

The seedbed conditions existing when pine seeds are dispersed affect the percentage of seeds that germinate and become established. To show this relationship, equation (1) was solved for a reasonable range of seedbed conditions (fig. 2). The bumper seed crop of 1990 (1.5 million sound seeds per acre) resulted in 15 seedlings per milacre where seedbed conditions were poorest and 50 seedlings per milacre where conditions were most favorable. The seedling-to-seed ratio in the former was 1 .O percent and 3.3 percent in the latter. However, independent variables in equation (1) explained only 16 percent of the variation in seedling density. This finding demonstrates that seedbed conditions interact with many other factors to determine the successful establishment of pine regeneration.

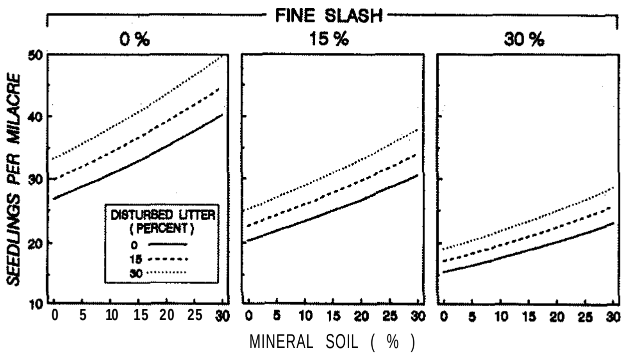

Figure P-The relationship between seedbed conditions after the initial harvest implementing uneven-aged silviculture in a pine-hardwood stand and the number of pine seedlings 1 year later. Values calculated from equation (1).

Vegetation Damage

Harvesting had a substantial effect on the number of submerchantable hardwoods (fig. 3). Before harvest, there were 730 stems per acre in the submerchantable classes (1 to 5 inches d.b.h.), which were reduced by 44 percent during harvest. In this evaluation, stems were counted if they required treatment with herbicides applied by frilling and cut-surface application; many stems were damaged but would still be treated. Losses varied substantially with stem size. Nearly 75 percent of stems in the l-inch d.b.h. class were lost, but almost no stems 23 inches d.b.h. were lost. Some submerchantable hardwoods were cut for access to merchantable trees; other stems were broken or uprooted during felling and skidding.

Harvesting provided a partial mechanical control of submerchantable hardwoods, which had both beneficial and harmful effects. It reduced the number of stems to be treated with stem-injected herbicide, but many of these stems were only top killed and would sprout. Because of the sprouting of top-killed hardwoods, Cain (1988) reported that stem-injected herbicides are more effectively applied before harvesting than after.

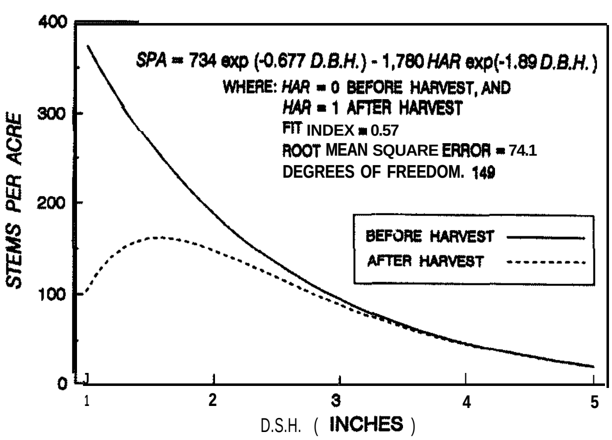

Figure 3-Effects of the initial harvest implementing uneven-aged silviculture in a pine-hardwood stand on the number of submerchantable hardwood stems (SPA).

Tree mortality or life-threatening damage during harvesting averaged 1 .O trees per acre for retained merchantable pines and 2.7 trees per acre for hardwoods. Most of these trees were in the smaller diameter classes, and their stems and/or tops were broken by felled sawlog trees. Skidding produced very little scarring to the boles of residual trees. Only 1.4 pines per acre and 1.3 hardwoods per acre were classified as having bole scarring as their major defect after harvest. However, these values may underestimate the actual amount of scarring if the tree was classified as having another, more limiting defect.

MANAGEMENT IMPLICATIONS AND CONCLUSIONS

Frequent harvesting is an important component of the successful management of loblolly and shortleaf pines in uneven-aged stands. The logging disturbance evaluated in this study had both beneficial and detrimental effects. Logging exposed mineral soil and disturbed the forest floor, which increased the number of pine seedlings. However, logging also created slash, which suppressed pine seedling establishment. Logging provided partial, mechanical control of submerchantable hardwoods. This reduced the number of hardwoods to be chemically treated during competition control, but it may also result in future problems from sprouting hardwoods. Only a few of the retained merchantable trees were damaged during harvesting.

Results of this study suggest a high potential damage to pine regeneration during periodic harvests in uneven-aged stands. Thus, particular care is needed in stands lacking good structure in merchantable size classes but with a cohort of developing regeneration, which is critical in developing a well-structured stand in the future. Less attention is needed in stands without regeneration or in stands with good structure in merchantable size classes. In many cases, regeneration may be excessive in uneven-aged pine stands, and logging provides a degree of precommercial thinning. Logging damage can be reduced by using careful planning, experienced loggers, directional felling, in-the-woods branch and top removal, shorter log lengths, mid-sized skidding equipment, and dry-weather skidding. Group selection may have some advantages over single-tree selection regarding potential logging damage to regeneration, because the distinctive openings are easily seen and avoided.

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Intensive Management of Pines

Moderator:

DEAN GJERSTAD
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SILVICULTURAL RESEARCH IN THE SOUTH DURING THE MIDDLE AGES - 1940 TO 1980 - PERSONAL RECOLLECTIONS'

Thaddeus A. Harrington[2]

Addressing the meeting's theme "Siivicuiturai Research-A Retrospective," the following invited paper is an opinion piece describing the early research career of its author.

Abstract-Following World War II, the USDA Forest Service (Forest Service) was the lead organization in developing and executing silvicultural research programs across the South. The author was intimately involved in all phases of this effort, from conducting personal research studies to organizing and directing large scale research programs. Personal experiences covered the South from Texas to Georgia and Tennessee to Florida. The paper looks at the changes that occurred as the research programs progressed from pauper projects to plush laboratories.

INTRODUCTION

it is a great pleasure for me to be back in the South, to see so many old friends and cohorts and to finally attend a Southern Silvicultural Research Conference. These biennial conferences were set up in 1980 to provide opportunities for fledgling researchers and seasoned pros to rub shoulders, discuss programs and present their research findings. It is very gratifying to see how they have developed, the quality and quantity of current offerings and the high level of support provided by industry, universities and government. I assisted in planning the virgin session but was transferred to Montana in 1980 and missed that occasion. It is apparent the conferences have well served the objectives for which they were established.

PERSONAL RECOLLECTIONS

When I came south 50 years ago the Forest Service was the lead organization in developing and executing forestry research programs. Actually their research programs began in the early 1900's with several specialized research centers scattered across the South. Then in the 1920's, Forest and Range Experiment Stations were established at New Orleans and Asheville, each with a Station Director and staff. As funding became available each station developed branch stations in carefully selected locations throughout the southern states. The bulk of the work conducted at these branches was silviculturai research. It is interesting to note that in 1949, when I was scratching my first chigger bites, the only Forest Service center in the entire South located in conjunction with a forestry school was our East Texas Branch on the campus of Stephen F. Austin State Teachers College, Nacogdoches, Texas. Another not so interesting point, a quick review of the Southern Research Station's new Directory of Research Scientists seems to indicate that we were doing more silvicultural research in 1949 than in 1999.

Those were exciting times fifty years ago, conducting field research. We had no laboratories as we know them today, and few greenhouses. The center headquarters were in locally rented offices or on the experimental forests. On the experimental forests the buildings, for the most part, had been erected by the CCC during the Depression. Our technicians and forest workers were often former CCC enrollees and were expert woodsmen and outstanding help. Most of the older foresters, that were running the show, were from the North or West and had transferred to Forest Service Research from the National Forests. Some had experience in the South prior to World War II, but most didn't. Ail personnel had endured the Depression of the 1930's and had served in the Armed Forces during the war. They could put up with anything and there were no "prima clonnas." Everyone was happy to have a job and worked hard to keep it. As I remember there were no Ph.D.'s at the field locations. At station headquarters there were one or two Ph.D.'s, usually entomologists or pathologists stationed with the Forest Service but actually working for the old Bureau of Entomology and Plant Quarantine or the Bureau of Plant Industry, Soils and Agricultural Engineering.

Very little of the information we based our early programs on came from statistically designed studies. Most of it was based on observations and judgement. There were some case studies, such as Farm Forests or species trials, that had been established across the South. Often our early studies were designed to prove information that we already felt was true. We researchers had excellent backgrounds in siiviculture and forest management that were obtained in our undergraduate education. Generally we had little or no schooling in writing scientific papers or in biometrics. The fact that we actually conducted sound research and effectively reported the results was due to a few very talented men. Editors Norb Sands, Southern Station, and Bud Merrick, Southeastern, taught us how to write. You seldom won an argument from either of them. Lew Grosenbaugh and Frank Freese at the Southern Station and Tom Evans and Jerry Clutter at Southeastern taught us how to design studies and analyze data.

Thinking back about my education, I believe we had the correct priorities for those times. At college we obtained a solid education in basic forestry, soils and botany. The fine details of biometrics and writing, and the humanities, i.e., getting along with people, we learned on the job. Getting along with others was easy to learn in those days; if you made someone angry you weren't sued. You were punched in the nose, a little interocular impact, and a great incentive for being polite, tactful and respectful of others.

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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We had no computers, of course, and very few calculators or adding machines. There were never enough electric calculators to go around. I had a small hand-powered Monroe -you turned the crank until the bell rang and then you flipped the carriage. It took a long time to run an analysis of variance but when you were done you knew what you had. At our Sewanee Research Center I had a fine Marchant calculator and an outstanding forest worker to assist me. I taught Vern how to do averages and summarize data and he never made mistakes. One day I left him in the office running averages while I went to the woods to scout out some new study areas. When I came back to the office later that afternoon and peeked in the door, there sat Vern, punching a number into the calculator, then erasing that number and entering another. I watched for several minutes and then asked him what he was doing. “Mr. Thadd,” he said, “I’ve been trying to think up numbers that weren’t in this machine but it has every number in it I can think of.” Now there is an inquiring mind.

There was very little money and nearly all that we had went for salaries. The theory then was to get some researchers working and then ask for more money based on actual needs rather than projected needs. The Research Center Leader was about the only one that went to meetings. He seldom did any research. He spent most of his time developing contacts with forest industry, land owners, university officials, and politically-connected individuals. He was establishing a base to go back to later for help in getting Congress to appropriate funds for his unit.

To show just how poor we were, in 1951 I was stationed on the Kaskaskia Experimental Forest in southern Illinois running a logging and sawmill operation for the Forest Service. We had talked Caterpillar into giving us a D-4 cat equipped with a logging arch. Allis Chalmers came through with an HD-7 tractor. Corley had given us a 54” portable circular sawmill. These items were donated to us for demonstration purposes, so prospective buyers could see the equipment in action. We had a contract with Sahara Coal Company to buy the mining ties, timbers and side lumber we cut. Leon Minckler, a dynamic young Research Forester at our Carbondale Center, had installed a number of silvicultural studies that needed logging. With non-government employees, paid by piecework, we logged the research areas and sawed the logs into products. Sahara Coal Company would deposit money in a local bank to cover the wood products we sold them. We would pay the laborers from this bank account.

It was such a neat setup that the Forest Service transferred me to Oxford, Mississippi to implement a similar operation on the Tallahatchie Experimental Forest. While I was surveying land lines in Mississippi all heck broke loose in Illinois. A Government Accounting Office team heard about our deal with Sahara Coal Company and investigated. It turned out the whole setup was grossly illegal. The GAO decided not to press any charges; our books were in excellent shape. They decided we were just a bunch of ignorant rednecks.

But there I was in Mississippi with no money to cover my salary, once the logging operation fell through. Luckily a researcher at our East Texas Branch wanted to go back to National Forest Administration and I was immediately moved into his slot at Nacogdoches. About a week after I got to Nacogdoches the Center Leader at Oxford called me on the phone. He wondered if I had inadvertently carried off their only diameter tape when I moved. That’s being poor.

Things were tough but interesting. Right after the war our vehicles were mostly those that had been confiscated from moonshiners. One black Pontiac sedan that I occasionally got to drive was really hot. You had to keep a very light pressure on the accelerator or you’d snap your neck. But the pick-up trucks were the best. If the inside two passengers didn’t chew tobacco you could get four men in the front seat and fifteen in the bed.

We worked long days. Time started when you got to the plots to be measured, and you stayed in the woods until five p.m. Travel to and from the woods was on your own time. Ten and twelve hour days were not unusual. A good bit of the time we didn’t have enough technician help. Often you installed and measured your own studies, but collecting your own data is actually quite desirable. You know what’s going on in your studies and you learn a great deal by observation. When you analyze the data the results are usually biologically feasible. Every silviculturist should spend at least a quarter of his or her time in the woods. If you’re not an observant woodsman you are not a silviculturist.

While I was at Nacogdoches my wife frequently tallied data for me. Since she couldn’t ride in a government vehicle we had to use our personal car to drive to and from the experimental forest, with no compensation for mileage.

We were transferred fairly often because of small budgets and the need to utilize the special talents of an employee at more than one center. When you left a center your research studies were assigned to another researcher. That never seemed quite right to me. But when you have five kids you don’t argue with your bosses very often. While at Oxford, Nacogdoches, and Sewanee, a period of seven years, I originated and installed thirty studies. Everyone of these was published on by some subsequent scientist. Only two men, John Stransky at Nacogdoches and Glen Smalley at Sewanee, ever gave me credit in their publications.

As mentioned earlier, most of our researchers were ex-G.I.'s, and could they ever scrounge. We had to set strict limits on what could be obtained from the surplus property lists. Some of the items proved to be very costly. The office declaring the surplus would charge the office ordering the items for packing and shipping. We needed some drainage tile for a swampy spot around the office. On one surplus list we found just the tile we needed and the location was only a couple hundred miles away. Shipping couldn’t be too expensive. What we didn’t know was the tile was in the ground and they charged us for digging it up.

Another time I heard that one of our wood utilization researchers, must have been at the Forest Products Laboratory, needed a wood press for preparing plywood samples. He called the originating agency advertising a sample press to verify the capability of the machine. The outfit assured him that it would do all he wanted. The order was placed and a month later the railroad freight office called to notify him that a very large plywood press was on a flat car on the local siding waiting to be off-loaded. That was the last surplus he ever ordered.

Timberland owners, farmers, consulting foresters, state foresters, industrial foresters and even the general public had a great deal of interest in our research programs. Several times a year we had very well-attended field days at our experimental forests. At most centers we had a farm forestry demonstration that included good and poor practices. Small private landowners, in particular, followed these results religiously until we finally shelved most farm forests in the late 1960's.

Our staff was in constant demand to give local talks at churches, women's clubs, Chambers of Commerce, etc. These provided excellent opportunities for young researchers to develop skills in organizing and delivering speeches.

As our research programs matured we needed to beef-up our staffs with scientists with advanced degrees and training in all the fancy and exotic equipment that was becoming available for more basic soil and silviculture research. In the 1960's, the Government Employees Training Act, GETA, was passed and we could send deserving scientists to graduate school at government expense. At government expense meant the project to which the lucky scholar was assigned paid the bill.

We selected highly productive young scientists who had already earned the Masters Degree, for the first go around. But later, age was not important and we financed many Master's programs as well. The scientist selected for the training signed an agreement that he would return and work for the Forest Service for a period three times the length of time spent in training. If he dropped out or left the Forest Service he had to return the money. Very often the scientist would take the data from studies in the project for use as thesis material. GETA was a wonderful law. It was to our more mature research programs in the 1960's what the G.I. Bill had been to the programs following World War II. Prior to GETA it was difficult to recruit Ph.D.'s. Very few Ph.D.'s were graduating and few Ph.D.'s were looking for jobs. We didn't have much money for salaries and personnel slots were seldom available. Through GETA we could develop our own experts from people we knew were producers. We obtained some outstanding scientists. We also lost some of our best scientists to the forestry schools. They'd offer faculty positions at salaries we couldn't always meet. In such cases we seldom asked for our money back. In those days the Forest Service was such an outstanding research outfit that we could depend on our ex-employee-turned-professor to help us recruit the very best of the school's graduate students.

In no time the Ph.D. diploma was the main requirement for joining the research fraternity. One problem with having such highly educated people on your staff was they sometimes became "prima donnas" and didn't like to do heavy duty fieldwork anymore. I got around that by conducting an intensive dumbing-up program. Over a period of several months I could usually convince the new Ph.D. that he really wasn't a better scientist. He just had learned more big words.

During the 1950's and 1960's the southern forestry schools were rapidly expanding in curricula, student numbers and research programs. We worked closely with the schools, and they with us, on all sorts of cooperative efforts. Most schools had cooperative research studies with us and we generally had an open relationship, sharing our thoughts about current and future programs. However, each research unit had a brief list of professors with whom only published or "accepted for publication" material was discussed. Even government employees don't like to be scooped on their precious ideas.

With the advent of more complex research programs came the need for modem research facilities. The Forest Service built their first modern laboratory at Olustee, Florida in 1959. I was transferred there as Timber Management Project Leader in 1960, just as the building was being completed. In those days the Forest Service didn't permit an employee of my grade the nicety of visiting a new assignment ahead of time to find lodging for one's family. I drove down from Sewanee, Tennessee with the whole family, in our old Rambler station wagon. Nobody had told me there was a new laboratory building at Olustee, just that my work station was 13 miles east of Lake City on Highway 90. When we hit Lake City it was still early so we decided to drive to Olustee to see where I'd be working. About 13 miles east of Lake City they were building a funny looking motel-like structure, but no sign of the log lab buildings I expected. We drove by this structure three or four times, knowing it couldn't be a Forest Service building. Finally, I drove into the area and asked a worker what that was being built. It was the Naval Stores and Timber Production Laboratory, my new office. I drove through Olustee the other day; that building is now a ranger station and still the ugliest laboratory we ever built.

Soon we were building new labs at all of our research locations. Eventually we did get smart and moved most of the research centers to university cities. The labs were built adjacent to or on the campuses of our southern forestry schools, providing a much improved research environment for our highly educated scientists.

CLOSING COMMENTS

In closing I must recognize all of the outstanding cooperation the Forest Service received in the early days of our research program in the South. I know we still receive this cooperation today, but in the early days with very little money and young dynamic personnel, we couldn't have existed and grown without this support. I have worked across the United States and in no other area has the working relationships with universities, forest industry, forest associations, agricultural and chemical industries, state forestry and Extension services and local businesses been so excellent. The 1940's, 1950's, and 1960's were great days to be working as a research forester in the South. People understood the need for wood, and for forest management activities. Occasionally we would get little ditties stuck on our trees, such as:

"You've got the money, we've got the time
You kill the hardwoods, we'll burn the pine."

But overall the importance of forestry to the local economy was recognized. Local radio stations and newspapers were always happy to get our stories.

The 1970's were probably the high point in the Forest Service research organization. We had excellent facilities staffed with intelligent, experienced and highly motivated personnel. Southern people still had a rural attitude and appreciated that a sound scientific basis was needed to provide a productive and environmentally healthy forest economy. Now that the Southern population is more urban than rural the people are not as receptive to natural resource based industries. It is more **difficult** to receive funding for federal forestry research programs and reduced funding has closed many laboratories. But the Forest Service has also contributed greatly to the demise of our research organization. Over the past fifteen years a highly incompetent and unqualified Washington Office staff, with some help from inexperienced field administrators, has diluted the greatest forest research organization in the world by losing critical mass in the core disciplines of forest science-silviculture, pathology, entomology, genetics, and mensuration.

My advice to scientists presently employed by the Forest Service is to work hard, maintain high personal standards of integrity and productivity, and work within the system to bring back the stature of this once prestigious organization. To research managers, my advice is to hire the very best talent available and support these people with the resources they need.

CHARACTERIZATION OF OPTIMUM PHYSIOLOGICAL RESPONSES OF FIELD-GROWN LOBLOLLY PINE[1]

Zhenmin Tang, Jim L. Chambers, and James P. Barnett[2]

Abstract-Photosynthetic photon flux density (PPFD), air temperature (Ta), needle net photosynthesis (Pn), vapor pressure difference (VPD), stomatal conductance (gw), transpiration (E), and predawn and daytime xylem pressure potentials (XPP) were measured in a loblolly pine (*Pinus taeda* L.) plantation in 1995 and 1996. Boundary-line analyses were conducted to determine optimum physiological responses and critical levels of Ta, PPFD, VPD, and XPP that restricted gas exchange. Our results showed that under field conditions, the maximum Pn, gw and E were 6.0 μmol m^{-2} s^{-1}, 180 mmol m^{-2} s^{-1} and 3.5 mmol m^{-2} s^{-1}, respectively. Irradiance less than 1100 μmol m^{-2} s^{-1} was the most significant variable limiting Pn. Threshold values of Ta, VPD and XPP that resulted in a decrease in Pn and gw were 33 °C, 1.3 KPa and -1.3 MPa, respectively. Our findings suggest that the boundary-line technique is an alternative for assessing and predicting responsive physiology of trees without artificial constraints on the environment.

INTRODUCTION

It is predicted that global climate is changing, with a rise in ambient CO, concentration, an increase in annual mean temperature, and more fluctuation in seasonal precipitation (Cooter 1998, Hansen and others 1988). Global climate change may increase the variability of stand resource availability and cause stresses that will impact the growth and productivity of southern pine forests (Peters 1990). Long-term studies of trees larger than seedlings are needed to understand how foliage physiology, crown development and tree growth respond to microclimate variation in forest stands. Such studies also will provide data to develop process models for predicting the effects of global climate change on leaf gas exchange, root growth, tree size and stand productivity.

Recent ecophysiological research suggests that foliage production, needle physiology and shoot growth are closely correlated with variation in stand environment (Gravatt and others 1997, Leverenz and Hinckley 1990, Sword and others 1996, Tang and others 1999b, Teskey and others 1994). These studies also indicate that there is great variability in canopy and soil factors, which makes it difficult to assess stand responses to environmental changes. Interpretation of the impacts of silvicultural treatments and global climate change on tree growth and stand productivity hinge on our ability to correctly determine and model the tree physiological responses under field conditions. Often, forest scientists, working in the field, impose artificial constraints on the tree environment to reduce variability and thus increase the resolution of statistical significance. An alternative known as boundary-line analysis can be use to study relationships between plant and environmental variables without artificial restrictions on the tree environment (Chambers and others 1985, Webb 1972). Researchers have used this technique to model and predict physiological responses of forest species in the field and found reasonable agreement between prediction models and field data (Chambers and others 1985, Reed and others 1976). The objectives of this paper are to: (1) characterize optimum responses of physiological variables of field-grown loblolly pine associated with independent environmental and plant variables, and (2) examine these dependent physiological variables in response to critical or threshold levels of the independent variables.

MATERIALS AND METHODS

Study Site

The study was conducted in a plantation located in Rapides Parish, Louisiana. The soil at the site is a well-drained Beauregard silt loam (fine-silty, siliceous, thermic, plinthaquic paleudult). In May 1981, 14-week-old containerized loblolly pine seedlings were planted at a 1.8 x 1.8-m spacing. Survival was 97 percent seven years after planting (Haywood 1994). Twelve plots (0.057 ha and 13 x 13 trees each plot) were established in the fall of 1988. Two levels of fertilization (fertilized and non-fertilized) and thinning (thinned and non-thinned) were randomly assigned to these plots in a 2 x 2 factorial design with three replications. Thinning was done by removing every other row of trees and every other tree in the remaining rows, leaving 721 trees ha-'. Non-thinned plots had 2990 trees ha^{-1}. Fertilization was completed by broadcast application with diammonium phosphate (134 kg N ha^{-1} and 150 kg P ha-'). Understory vegetation was minimized by herbicide application as needed. Post-treatment tree growth and stand yield during 1989-l 992 was reported by Haywood (1994). Thinning and fertilization were conducted again in March 1995. After re-treatments, thinned plots had 512 trees ha-' (15.6 m^2 ha") left, whereas non-thinned plots maintained the density of 2863 trees ha^{-1} (42 m^2 ha-'). Urea (200 kg N ha^{-1}), monocalcium phosphate (50 kg P ha^{-1}) and potash (50 kg K ha") were applied in fertilized plots. Steel towers and wooden walkways were built in two replications (eight plots) in 1991-1992 to access the upper and lower portion of the live crowns.

Physiological Measurements

Net photosynthesis (Pn), stomatal conductance to water vapor (gw), transpiration rate (E), and vapor pressure difference (VPD) from the intercellular space of needles to air were measured in situ on the branches within the upper and lower crown, with a LI-6200 photosynthesis system and a 250-ml leaf chamber (Li-Cor, Inc., Lincoln, NE). Photosynthetic photon flux density (PPFD) and air temperature (Ta) within the upper and lower crown were

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recorded with a LI-190S quantum sensor and a thermocouple mounted on the leaf chamber. During each measurement, the middle section of two fascicles was enclosed in the leaf chamber and recorded for changes in CO, concentration in the leaf chamber in their natural orientation on the branch. The fascicles were then detached from the branch and their xylem pressure potentials (XPP) were measured with a pressure chamber (PMS Instrument Co., Corvallis, OR). Predawn XPP was taken between 0400 and 0500 h. Total needle volume and surface area per fascicle were determined by water displacement (Johnson 1984). We expressed Pn, gw, and E on a leaf surface area basis.

Two kinds of physiological and environmental data were collected for boundary-line analyses. They were: (1) monthly diurnal measurements in one replication and (2) semi-monthly measurements in two replications. Diurnal measurements were taken on dominant or codominant trees accessible from the walkways during June through November 1995. On each sampling day, three south-facing branches in the upper crown and other three in the lower crown were randomly chosen in each plot. Same set of the selected branches was used throughout the growing season. Previous- and current-year fascicles on terminal or nearby lateral shoots were measured separately seven times between 0800 and 1700 h at a 1.5-hour interval on partly or fully sunny days. A total of 84 measurements per plot were completed on each sampling day. Additional diurnal measurements were taken on a different set of branches during June and July 1996.

Twice each month during June through October 1995, gas exchange measurements were conducted between 0930 and 1130 h, on three south-facing branches in the upper and lower crown of dominant or codominant trees. Trees and branches were randomly selected at the start of each measurement. On one day, four plots of the first replication were measured and four plots of the second replication were taken on the next day. Similar measurements were performed between 0930 and 1130 h and between 1300 and 1500 h during April through December 1996. A total of 3326 observations were collected during 1995 and 1996.

Boundary-line Analysis

Boundary-line analysis is a tool for determining and predicting a relationship between a dependent variable and an independent variable (Chambers and others 1985, Webb 1972). When Pn (dependent variable) is plotted against PPFD (independent variable), for example, a scatter diagram is produced (fig. 1). If data are sufficient to enclose a broad range of variation in the dependent variable response, the upper extreme of the data points (excluding outliers) can be drawn with a boundary line as in Figure 1. The boundary line represents the maximum response of Pn to a given level of PPFD, when all other important variables are optimum for Pn, or when a variable overriding PPFD reduces the level of the Pn response. Data points below the response line include: (1) measurement errors, (2) responses when the independent variable is non-optimum, and (3) variation caused by other overriding or interacting variables that limit the dependent variable response (Chambers and others 1985, Webb 1972).

Several two-variable scatter diagrams were constructed with the physiological and environmental data (a total of 3326 observations) collected in 1995 and 1996. In order to reduce potential overestimation of physiological responses due to possible measurement errors (Chambers and others 1985), and to assist in developing boundary lines, we chose the upper limit 5 percent of the data points for each dependent variable to draw a boundary-line curve for each diagram, Least-square regression was developed with SAS statistical software (SAS Institute, Inc. Cary, NC) and used to draw the resulting boundary line for each two-variable response. Each line represented an average response of the uppermost 5 percent of the dependent variable points. It was utilized to show the potential optimum response of the physiological variable to a single environmental or plant variable. Data points above the boundary-line curve were assumed to be outliers and measurement errors, whereas those below the curve were considered as non-optimum responses. This interpretation provides a slightly conservative estimate of the maximum dependent-variable response for the range of the independent variable shown, but represents the shape of the response patterns and should adequately reflect critical or threshold values of the independent variables.

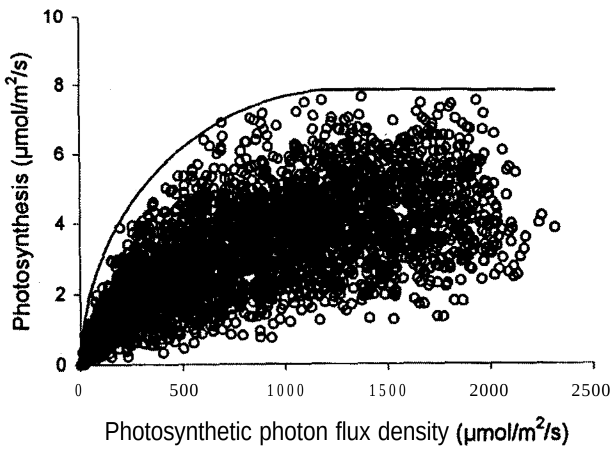

Figure i-Scatter diagram of data and the boundary line drawn for needle net photosynthesis in response to photosynthetic photon flux density.

RESULTS AND DISCUSSION

Our data covered an extensive range of within-crown environmental conditions (table 1). Photosynthetic photon flux density varied from 2 to 2316 $\mu mol\ m^{-2}\ s^{-1}$, Ta was between 4 and 43 ^0C, and VPD changed from 0.14 to 5.0 KPa during the measurement periods. Because of frequent precipitation, needle predawn XPP fluctuated from -0.44 to - 0.81 MPa, with the most negative values recorded in November 1995 and December 1996 (fig. 2A and 2B). These predawn values (higher than -1 .O MPa) showed that soil moisture supply was sufficient for gas exchange of foliage during the growing season (Gravatt and others 1997, Tang and others 1999a). The broad coverage of within-crown environmental variation assures the reliability of using the boundary-line technique for assessing gas exchange responses of field-grown trees (Chambers and others 1985, Dougherty and Hinckley 1981).

Large variation in the physiological variables was found in the field (table 1). We used a regression curve as the boundary line to closely represent the optimum response of

Table I--Statistical summary of the physiological and environmental variables measured in a 15- to 16-year-old loblolly pine plantation

Variable[a]	n	Mean	Minimum	Maximum	Standard deviation
PPFD (μmol m^{-2} s^{-1})	*3326*	a67	*2.0*	*2316*	*542*
Ta (^0C)	*3326*	28.8	*4.0*	*43.0*	6.8
VPD (KPa)	*3326*	1.78	.14	*5.00*	.91
Pn (μmol m^{-2} s")	*3326*	*3.19*	*.oo*	8.12	1.51
gw (mmol m^{-2} s^{-1})	*3326*	88.4	*4.51*	*247*	38.7
E (mmol m^{-2} s^{-1})	*3326*	*1.46*	.04	*5.42*	.a3
XPP (-MPa)	*3326*	*1.31*	.49	*2.74*	.35

[a] PPFD = within-crown photosynthetic photon flux density, Ta = within-crown air temperature, VPD = vapor pressure difference, Pn = net photosynthesis, gw = stomatal conductance, E = transpiration, and XPP = daytime xylem pressure potential.

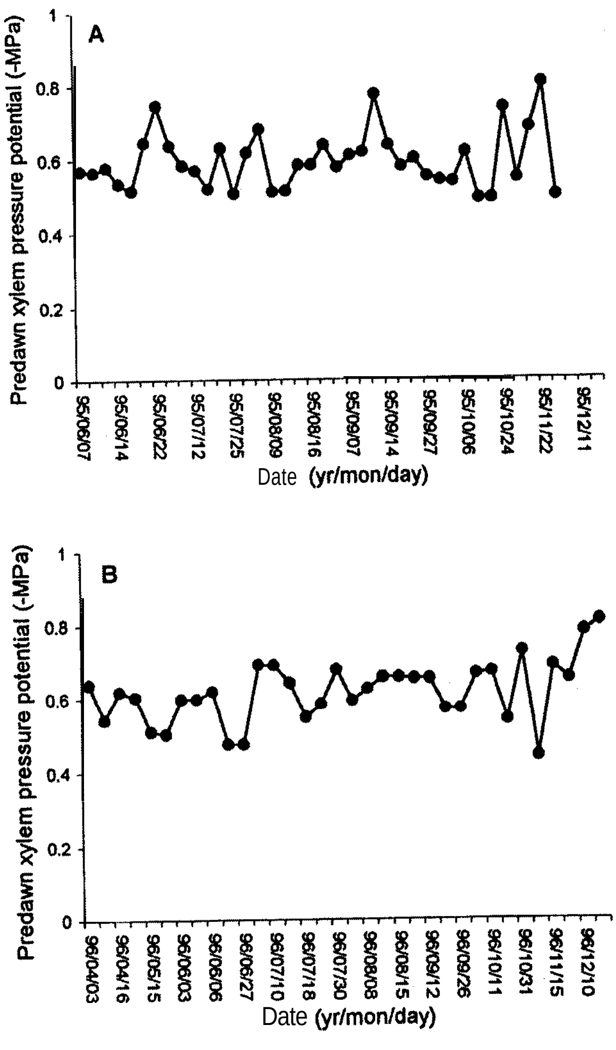

Figure 2-Seasonal pattern of predawn xylem pressure potential in (A) 1995 and (B) 1996.

each dependent physiological variable to an independent environmental or plant variable (fig. 3A-3D). The boundary-line Pn response to changing PPFD was in agreement with the findings by Teskey and others (1966) for loblolly pine, and Teskey and others (1994) for slash pine (*Pinus elliottii* Engelm. var. *elliottii*). Initially, Pn increased rapidly with rising PPFD, and it became light saturated as PPFD approached 1100 μmol m^{-2} s^{-1} (fig. 3A). Maximum Pn was approximately 6.0 μmol m^{-2} s^{-1}, consistent with the light-saturated Pn point reported for this species (Fites and Teskey 1966). In addition, Pn rose quickly with small increases in Ta and reached the peak rates between 23 and 33 ^0C (fig. 3B). A similar relationship between Pn and Ta was observed by Teskey and others (1994) in 23-year-old slash pine trees. However, they did not have data to show how Pn of that species responded to Ta values above 35 ^0C. Field observations from the present study indicate that in loblolly pine, a rapid decline in Pn occurred as Ta exceeded 33 ^0C. It has been recognized that light availability is the most critical variable for Pn, although high Ta may limit the process (Leverenz and Hinckley 1990, Tang and others 1999a, Teskey and others 1994). Our boundary-line responses illustrate that Pn was significantly restricted by PPFDs lower than 1100 μmol m^{-2} s^{-1} (R^2 = 0.75) and by Tas outside a range from 23 to 33 ^0C (R^2 = 0.67). These results support the above conclusion.

We observed a threshold Pn response to both VPD and XPP (fig. 3C and 3D). Net photosynthetic rate remained at the highest level and showed little response to low VPD and high XPP (less negative). Threshold values of VPD and XPP for a Pn reduction were near 1.3 KPa and -1.3 MPa, respectively. Needle Pn decreased nearly 40 percent, as VPD increased to 3.5 KPa. A similar reduction occurred as XPP decreased to -2.3 MPa. Eventually, Pn approached zero as VPDs reached near 5.0 KPa and XPPs decreased below -3.0 MPa, respectively. These findings indicate that although PPFD was not limiting, either VPDs above 1.3 KPa or XPPs below -1.3 MPa reduced the maximum Pn level, implying that other variables may override or interact with the independent variable to control the Pn response. Teskey and others (1994) reported that in mature slash pine, Pn started to decline at a VPD of 1.5 KPa. A similar threshold

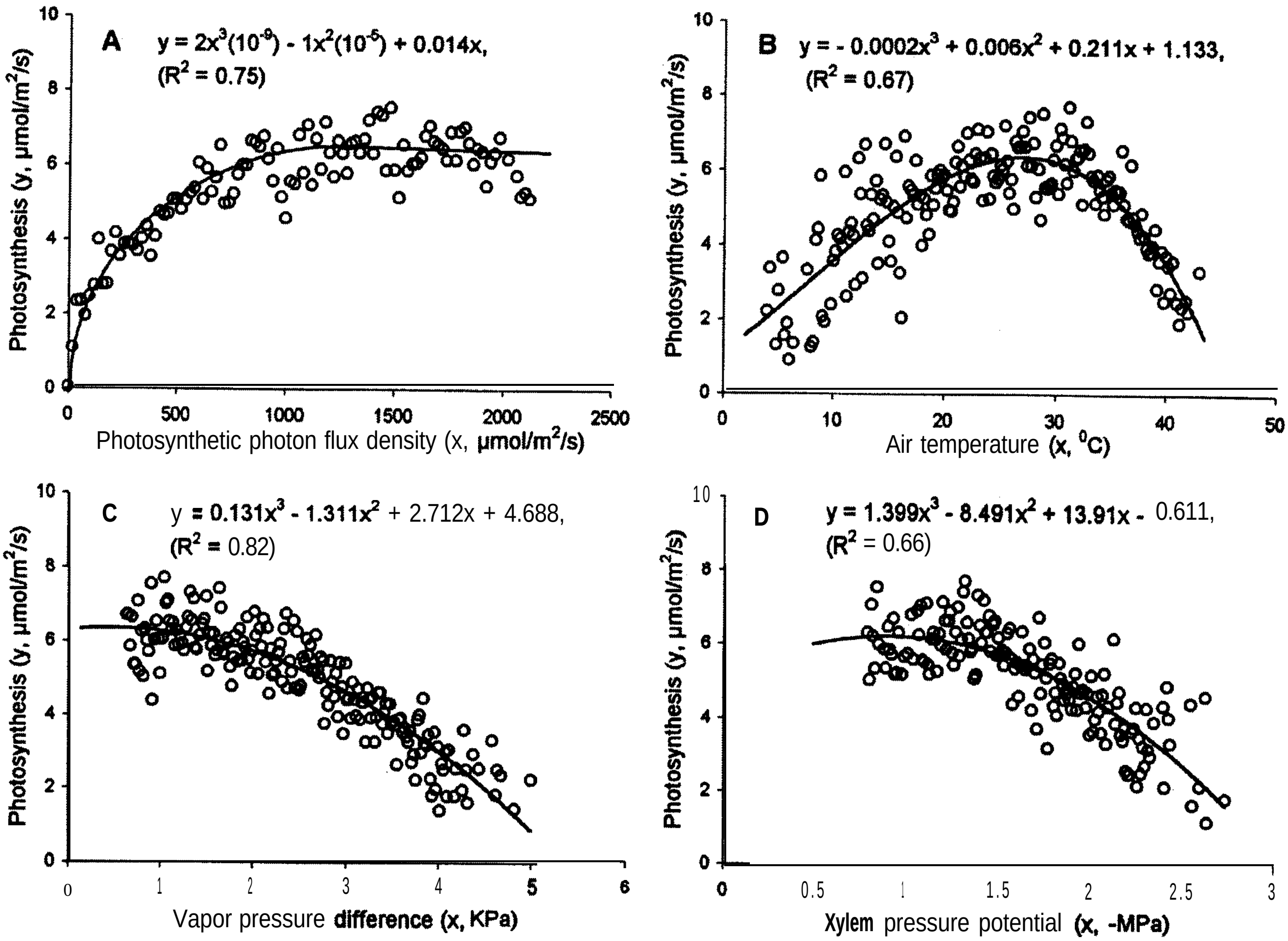

Figure 3—Boundary-line response of net photosynthesis to (A) photosynthetic photon flux density, (B) air temperature, (C) vapor pressure difference, and (D) daytime xylem pressure potential. Data represent the upper 5 percent of dependent variable responses to the entire range over the independent variable values.

Pn response to changing XPP was documented by Dang and others (1997) for jack pine (*Pinus banksiana* Lamb., -1.2 MPa), Sheriff and Whitehead (1984) for radiata pine (*Pinus radiata* D. Don, -1.8 MPa), and Jarvis (1980) for Scots pine (*Pinus sylvestris* L., -2.0 MPa). The threshold XPP for Pn from our study means that maximum carbon uptake of loblolly pine is more sensitive to water stress than that of radiata and Scots pine.

Boundary-line responses of gw to independent environmental and plant variables corresponded to the Pn response (fig. 4A-4D). The correspondence between gw and Pn responses was expected, because the physiological variables are closely correlated (R^2 = 0.70) (Teskey and others 1988). Initially, gw rose sharply with increasing PPFD and Ta (fig. 4A and 4B). As PPFD reached approximately 550 µmol m^{-2} s^{-1}, stomata appeared to become light saturated and gw attained a maximum level of 180 mmol m^{-2} s^{-1}. Stomatal conductance decreased quickly after Ta exceeded 33 °C. Additionally, no response of gw was found at low VPD and high XPP levels. However, gw showed a threshold response to a VPD of 1.3 KPa and a XPP of -1.3 Mpa (fig. 4C and 4D), suggesting that plant water stress may develop to reduce the level of the gw response. Stomata were partly closed as gw declined about 50 percent at a VPD of 3.5 KPa. Stomatal conductance also decreased about 50 percent as XPP approached near -2.3 MPa. This provides an explanation for a 40-percent reduction in Pn at that time. Complete stomatal closure occurred when VPD increased to 5.0 KPa and XPP decreased to -3.0 MPa. Teskey and others (1986) studied the effects of daytime XPP on Pn and gw in loblolly pine seedlings. They found that the most negative XPP causing a decrease in gw was about -1 .O MPa, and complete stomatal closure took place at -2.0 MPa. Critical XPP values for a gw decline and full stomatal closure from our large trees are 0.3 MPa and 1 .O MPa, respectively, lower than those of seedlings. This apparently shows distinct physiological differences between seedlings and trees of the same species, and demonstrates that seedling physiological performance may not accurately represent tree physiological responses to environmental variation.

Strong correlations were found between E and Ta and VPD (R^2 = 0.90 and 0.83, respectively). Initial increases in Ta enhanced E significantly (fig. 5A). Maximum E was about 3.5 mmol m^{-2} s^{-1} at a Ta near 40 °C. When gw was high at low VPD (fig. 4C), E remained low (fig. 5B), reflecting a low

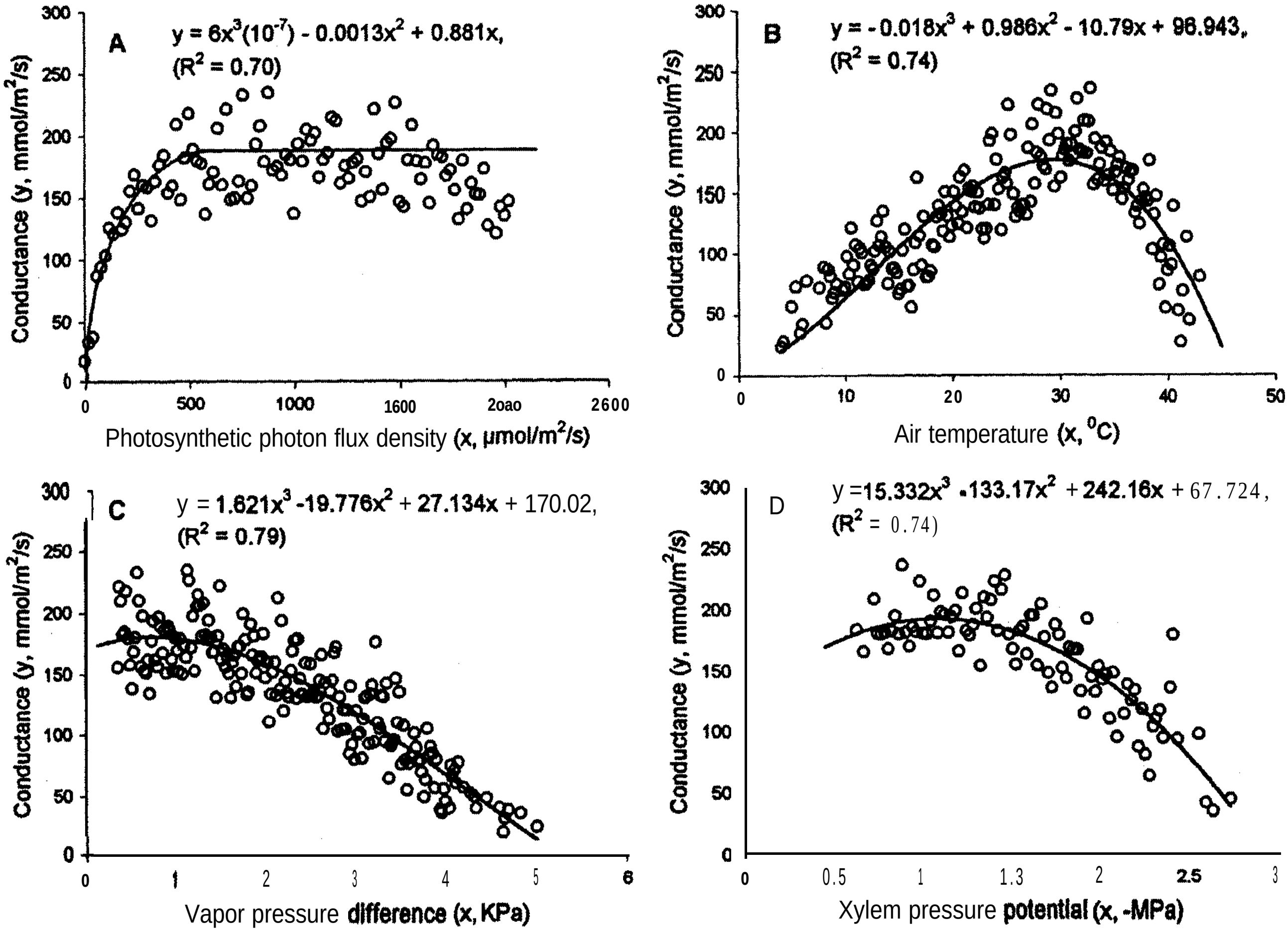

Figure 4-Boundary-line response of stomatal conductance to (A) photosynthetic photon flux density, (B) air temperature, © vapor pressure difference, and (D) daytine xylem pressure potential. Data represent the upper 5 percent of dependent variable responses to the entire range over the independent variable values.

evaporative demand. As VPD increased, E increased correspondingly. However, E began to decline with VPDs exceeding 3.5 KPa, because gw decreased nearly 50 percent and stomata became partially closed at that time. Our boundary-line responses of E and gw agreed with the results reported by Cregg and others (1990) who examined the water relations of a 1 O-year-old loblolly pine plantation in southeastern Oklahoma.

Microclimate variables in forest stands control the growth of trees through their effects on tree physiological processes (Teskey and others 1987). These variables will be influenced by global climate change. One of the predicted climate change scenarios is global warming (Hansen and others 1988). Current general circulation models of the global climate have projected that seasonal Ta and VPD will rise 2-4 °C and 0.2 KPa, respectively, in the southern United States (Cooter 1998). Predictions suggest that there will be more days with Ta above 33 °C and VPD above 3.5 KPa in the summer (Cooter 1998). Our boundary-line response equations indicate that increases in Ta and VPD may impact the gas exchange performance of southern pine forests. If current irradiance and precipitation remain unchanged, and if foliage of southern pine trees cannot acclimate to elevated Ta and VPD, the maximum gw, Pn and E will be decreased significantly with global climate change. Extremely high Ta (higher than 40 °C) and VPD (greater than 3.5 KPa) during the summer will cause leaf stomatal closure. Consequently, Pn and E will be reduced substantially.

Annual precipitation is predicted to decrease and the frequency and severity of drought are predicted to increase with global warming (Hansen and others 1988). During a drought, soil moisture supply and water potential of trees decrease, causing water stress that reduces leaf expansion, root growth, and aboveground productivity (Albaugh and others 1998, Linder and others 1987, Sword and others 1998, Teskey and others 1987). Boundary-line relationships between XPP and Pn and gw (R^2 = 0.88 and 0.74, respectively) found in our study predict that drought will restrict foliage gas exchange considerably by the effect of low XPPs (lower than -2.3 MPa) on gw and Pn. Other studies have suggested that low XPPs will impact plant carbon fixation directly by reducing the maximum catalytic capacity of Rubisco (Wong and others 1985). High VPDs associated with a drought may also limit gw, Pn, and E significantly.

In summary, boundary-line analysis is an effective technique for examining physiological responses of large trees under field conditions. When PPFD, Ta, and VPD were optimum, loblolly pine achieved a maximum Pn of 8.0 $\mu mol\ m^{-2}\ s^{-1}$, gw

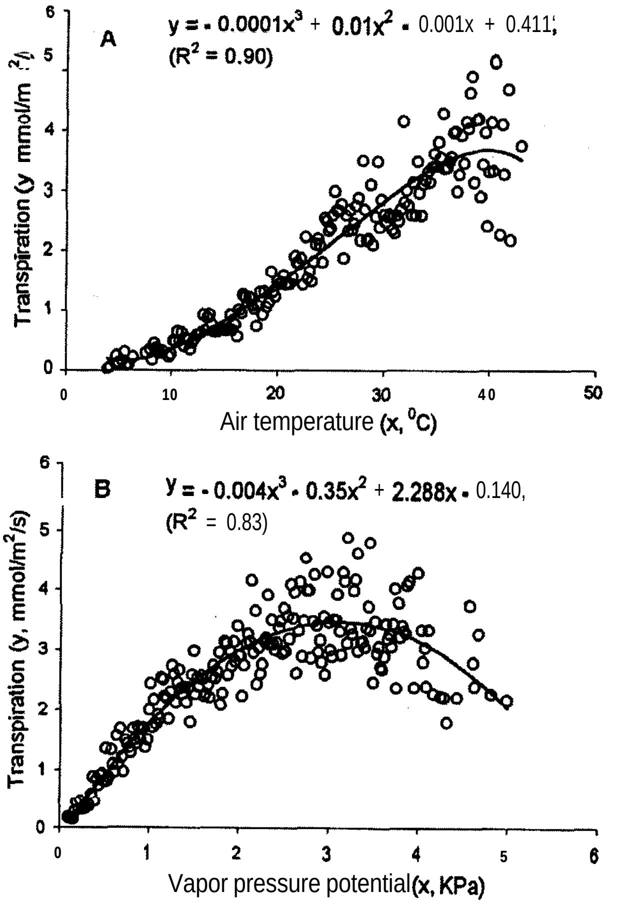

Figure 5—Boundary-line response of transpiration to (A) air temperature and (B) vapor pressure difference. Data represent the upper 5 percent of dependent variable responses to the entire range over the independent variable values.

of 180 mmol m^{-2} s^{-1}, and E of 3.5 mmol m^{-2} s^{-1}. Threshold values of the independent environmental variables and corresponding physiological responses may be useful in modeling the negative impacts of global climate change on carbon gain and tree growth in southern pine ecosystems. Our boundary-line responses demonstrate that elevated Ta and VPD will lead to significant decreases in photosynthetic production, stomatal activity, and water relations of trees. Further research must be conducted to determine the ameliorative role of cultural treatments in managing the detrimental effects of increasing Ta and VPD, and decreasing XPP on the responsive physiology, tree growth, and stand productivity of southern pine forests.

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RESPONSE OF DOMINANT HEIGHT, BASAL AREA AND SURVIVAL TO FIRST AND SECOND THINNINGS IN LOBLOLLY PINE PLANTATIONS[1]

Ralph L. Amateis[2]

Abstract -Permanent plot data from a loblolly pine (*Pinus taeda* L.) plantation thinning study were used to evaluate the response of dominant height, basal area and survival following first and second thinnings. When compared to the unthinned control, results showed a significant negative impact on basal area and survival following first thinning. Following a second thinning there were positive significant differences in dominant height and survival between the thinned and control plots. Following the second thinning total basal area production (amount removed plus standing) was not different from the control plots. An analysis of the 3-year growth period following first and second thinnings showed significant differences in dominant height and basal area growth and mortality. The findings from this study suggest that growth and yield models for thinned stands could be improved by differentiating between first and second thinnings.

INTRODUCTION

Thinning is a widely practiced midrotation silvicultural treatment in loblolly pine plantations. A typical thinning operation removes slow-growing smaller trees and damaged or diseased trees and is timed so that merchantable pulpwood volume can be harvested (Amateis, and others, 1996). This provides an intermediate cash flow and shifts future growth of the stand to the larger, better-quality residual trees. In some cases a single thinning will be applied. In other cases subsequent thinning(s) may be appropriate. The decision of how many thinnings to apply will depend on a number of factors including the cost of thinning operations, particular product objectives, the price differentials for those products, and anticipated rotation lengths.

In order to evaluate the effects of thinning, managers need quantitative models which adequately express the response of important stand characteristics to thinning. To be useful for a range of thinning scenarios such models should be appropriate for single as well as multiple thinning regimes.

The purpose of this study was to examine the effect of first and second thinnings on dominant height, basal area and survival in loblolly pine plantations. There were two objectives: (1) to determine how thinning impacts these stand variables as compared to an unthinned control, and, (2) determine the difference, if any, in growth following first and second thinnings.

DATA

Data from forty-five locations of the Loblolly Pine Growth and Yield Research Cooperative's region-wide thinning study were available for evaluating first versus second thinnings. These locations were established in loblolly pine plantations on cutover, site-prepared areas during the dormant seasons of 1980-1982 throughout the Piedmont and Coastal Plain regions in the Southeast (Burkhart and others 1985). At each location three plots were established: (1) an unthinned control plot, (2) a lightly-thinned plot, and (3) a heavily-thinned plot. Rigorous guidelines were established for selecting stands suitable for the study. Site index, basal area and trees per acre of plots within a stand were required to be similar in order to minimize the plot-to-plot variation of these stand characteristics at time of treatment. In general, the three plots within a stand did not vary by more than five feet in dominant height, 20 square feet per acre in basal area and 100 stems per acre at establishment. The result was that at time of plot establishment the differences in stand conditions between plots at a location were minimal. For the 45 locations the average stand age at time of establishment was 14 years, ranging from 8 to 24 years. The average site index was 59 feet and ranged from 42 to 73 feet.

Thinning treatments were applied at plot establishment: control (no thinning), lightly-thinned (approximately 30 percent of the basal area removed), and heavily-thinned (approximately 50 percent of the basal area removed). Second thinnings were applied 12 years later to the lightly- and heavily-thinned plots. The focus of the second thinning was to leave the largest, best quality trees expected to produce sawtimber at final harvest. In general, this often meant thinning the lightly-thinned plots to 70-85 square feet per acre and the heavily-thinned plots to 50-65 square feet per acre. The specific thinning intensity for each plot was determined by overall stand vigor (age, site index, current stocking) and the number of years remaining to rotation. Both first and second thinnings on these plots were primarily from below with some removals of larger trees due to poor form, damage, disease or spacing considerations. Plots were remeasured three years after each thinning. Site index at each installation was determined by applying the height-age pair closest to index age (25 years) from the control plot using the site index equation from Burkhart and others (1987). Tables 1 and 2 provide summaries for important stand characteristics at time of each thinning and three years after each thinning.

ANALYSES

One approach that can be used to evaluate the response of the first thinning compared to the response at a second thinning is to compare each to a baseline. This approach to analyses is well suited to the available data because at each location the two treatment plots have an accompanying untreated control plot. Therefore, for each treatment plot two response variables were defined for dominant height, two for basal area and two for survival:

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HT_{31} - HC,, BT_{31}- BC,, NT_{31} - NC_{31}

HT_{32} - HC_{32} BT_{32}- BC_{32} NT_{32} - NC_{32}

where HT_{31} and HT,, are the dominant height of the thinned plot three years after the first thinning and second thinning, respectively, HC,, and HC, are the dominant height of the unthinned control three years after the first thinning and the second thinning, respectively, BT,, and BT, are the cumulative basal area (removed plus standing) of the thinned plot three years after the first thinning and second thinning, respectively, BC,, and BC, are the basal area of the unthinned control three years after the first thinning and the second thinning, respectively, NT_{31} and NT, are the cumulative number of trees (removed plus surviving) of the thinned plot three years after the first thinning and second thinning, respectively, and NC,, and NC,, are the number of trees of the unthinned control three years after the first thinning and the second thinning, respectively. Thus, the six response variables above represent the difference between a treated plot and the baseline at a particular site and corresponding to either the first or second thinning at that site.

The null hypotheses to be tested were:
there is no difference in dominant height three years after treatment between the first and second thinning and the control,

or : H,,: (HT_{31} - HC,,) = 0
H,: (HT_{32} - HC,) = 0.

There is no difference in total basal area production three years after treatment between the first and second thinning and the control,

or : H_{03}: (BT,, - BC,,) = 0
H_{04}: (BT, - BC,,) = 0.

There is no difference in total number of trees three years after treatment between the first and second thinning and the control,

or : H,,: (NT,, - NC,,) = 0
H,,: (NT, - NC,,) = 0.

A paired t-test was conducted on. the 90 pairs of first and second thinning responses for dominant height, basal area and number of trees. Table 3 presents the mean difference between the treated and control plots for each variable and the results of the t-test. Three years after the first thinning the thinning treatment has shorter dominant trees, reduced basal area production and fewer total trees (removed plus surviving) as compared to the control. For basal area and number of trees these differences are significant. By three years after the second thinning, on the average the thinned plots had taller dominant and codominant trees, had produced as much basal area and had accumulated more harvestable trees than the corresponding unthinned plots.

A second approach to evaluating the effects of first versus second thinnings is to compare the mean rates of change (growth for dominant height and basal area, and mortality for number of trees) following each thinning. This can be

Table l-Before and after thinning statistics at time of first thinning (plot establishment) and at time of second thinning (12 years after establishment) for 90 twice-thinned plots

	Mean	Std. dev.	Minimum	Maximum
		Establishment		
Dominant height before thinning (ft)	35.9	9.3	15.7	55.7
Dominant height after thinning (ft)	36.3	9.4	15.9	57.0
Trees/acre before thinning	531	109	271	637
Trees/acre after thinning	294	67	142	454
Trees/acre removed in thinning	237	78	63	442
Basal area before thinning (ft^2/ac)	90.2	34.6	21.0	180.8
Basal area after thinning (ft^2/ac)	58.4	21.7	12.9	117.6
Basal area removed in thinning (ft^2/ac)	31.8	17.1	7.0	85.9
		Second thinning		
Dominant height before thinning (ft)	59.8	7.5	41.2	75.7
Dominant height after thinning (ft)	60.6	7.7	41.5	75.9
Trees/acre before thinning	280	63	142	444
Trees/acre after thinning	155	38	89	240
Trees/acre removed in thinning	125	44	40	250
Basal area before thinning (ft^2/ac)	120.7	23.9	53.4	176.2
Basal area after thinning (ft^2/ac)	68.1	25.0	12.9	155.5
Basal area removed in thinning (ft^2/ac)	36.5	19.0	6.2	106.1

Table 2—Mean dominant height, basal area and survival statistics by treatment at time of establishment, 3 years after establishment, after second thin and 3 years later (Year 15) for 90 twice-thinned plots (standard deviation in parentheses)

	Establishment	Year 3	Second thinning	Year 15
		Unthinned control		
Dominant height (ft)	36.2(8.8)	42.6(7.6)	59.5(6.8)	64.6(6.8)
Basal area (ft^2/ac)	94.9(33.0)	115.4(29.0)	151.5(32.3)	157.9(33.1)
Trees/acre	562(132)	544(124)	451(109)	414(104)
		Light thinning		
Dominant height after thinning (ft)	36.0(9.5)	41.8(8.5)	60.1(7.7)	65.1(7.5)
Basal area after thinning (ft^2/ac)	64.0(23.3)	82.0(20.3)	85.8(14.6)	95.3(15.5)
Survival after thinning (trees/acre)	331(63)	327(62)	182(31)	178(31)
		Heavy thinning		
Dominant height after thinning (ft)	36.6(9.4)	42.2(8.3)	61.1(7.7)	66.0(7.4)
Basal area after thinning (ft^2/ac)	52.9(18.6)	69.6(17.5)	69.3(13.4)	78.0(15.1)
Survival after thinning (trees/acre)	256(49)	253(48)	128(22)	125(22)

Table 3-Mean difference (thinned - unthinned) between thinned and unthinned control plots for three stand variables 3 years after a first thinning, prior to a second thinning and 3 years after a second thinning (test statistic for a paired t-test is given in parentheses)

	3 years after first thinning	Prior to second thinning	3 years after second thinning
Dominant height (ft)	-0.58 (1.95)	0.25 (0.73)	0.87 (2.22)[a]
Basal area (Square ft/acre)	-7.78 (5.66)[a]	0.95 (0.39)	3.73 (1.38)
Number of trees per acre	-18.89 (2.03)[a]	88.80 (7.07)[a]	99.80 (9.50)'

[a] Significant at the a = 0.05 level.

accomplished by considering thinning (whether first or second) as a class variable and using analysis of covariance methods. A number of covariates were examined including age of thinning and various measures of thinning intensity. Only age of thinning proved to be a significant covariate for these data. The results showed a significant relationship between adjusted dominant height and basal area growth and mortality between the two thinning treatments. The test statistic comparing dominant height growth following thinning was 34.20; for basal area growth the test statistic was 14.24 and for mortality following thinning it was 8.80. Ail were significant at the a = 0.05 level. Thus, the conclusion was that given the age of thinning, neither a single dominant height and basal area growth equation nor a single mortality equation could be used for both first and second thinnings.

DISCUSSION AND CONCLUSIONS

The analyses presented here indicate that for three primary stand characteristics affected by thinning the response to thinning three years after treatment varies. First thinning response is characterized by a reduction in dominant height, total (removed and standing) basal area production and total (harvested and standing) number of trees as compared to the unthinned control. This thinning "shock" (Harrington and Reukema, 1983) is most significant for basal area and less so for number of trees and dominant height.

Twelve years after thinning the thinned plot total basal area production has achieved that of the unthinned controls; total number of trees (harvested and standing) is greater than those in the controls and dominant stand height is not different between the control and thinned plots. Three years after a second thinning a similar comparison shows that the dominant height, total basal area and total number of trees has surpassed the unthinned control. For dominant height and number of trees the difference is significant. Thus it appears that there is little, if any "shock" associated with the second thinning. The significant difference in dominant height three years after the second thinning is due in part to the selection effects of two low thinnings which removed some of the smaller codominant trees. That plus the faster growth from larger, better quality residual trees has produced a statistically significant, but rather small (about one foot) increase in average dominant height on these twice-thinned plots.

The analysis of covariance evaluation of three-year growth following first and second thinnings shows a significant difference in dominant height and basal area increment as well as mortality. For dominant height and basal area, these differences imply that the negative impact of post-thinning "shock"on growth was significantly greater for the first thinning than for the second. There was significantly less mortality for the three-year period following the second thinning than following the first.

When assessing the results of this study, it should be remembered that:

1. Only the response in the first three year period following thinning could be evaluated. It is not clear how longer elapsed time since treatment might affect a comparison between first and second thinnings.

2. Data were only available for two thinnings spaced twelve years apart. It is not apparent what effect additional thinnings or thinnings that occur closer together or farther apart in time might have on the analyses.

The results found in this study should be helpful to modelers who are developing equations for predicting response to thinning treatments. When modeling growth following thinning, it should be possible to develop more precise models by differentiating first from second (and subsequent) thinnings.

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SEASONAL FINE-ROOT CARBOHYDRATE AND GROWTH RELATIONS OF PLANTATION LOBLOLLY PINE AFTER THINNING AND FERTILIZATION[1]

Eric A. Kuehler, Mary Anne Sword, and C. Dan Andries[2]

Abstract-In 1989, two levels each of stand density and fertilization were established in an a-year-old loblolly pine (*Pinus taeda* L.) plantation. In March 1995, treatments were reapplied, and root elongation and carbohydrate concentrations were monitored for 2 years. Our objective was to evaluate relationships between seasonal root growth and carbohydrate concentration in response to thinning and fertilization. Peak root elongation occurred between May and July. Root elongation was greater in response to thinning throughout 1995 and, although not always significant, was consistently greater in thinned plots in 1996. Root growth was reduced in the fertilized plots throughout 1996. Positive effects of thinning on fine-root starch concentrations were observed. Starch levels were consistently lower in response to fertilization for most of 1995 but were greater in fertilized plots during winter 1996. Glucose levels tended to be greater in response to thinning both years and less in response to fertilization in 1995. We conclude that fine-root carbohydrate concentration and net root elongation are characterized by distinct seasonal patterns, and that the magnitude of seasonal root elongation and carbohydrate concentrations is influenced by silvicultural treatments.

INTRODUCTION

Loblolly pine (*Pinus taeda* L.) is of significant economic importance in the southern United States (Schultz 1997). Many abiotic factors, such as moisture, fertility, and light, limit the growth of this species (Allen and others 1990, Teskey and others 1994a). Roots supply the essential water and mineral nutrients needed for growth. Thus, the ability of tree root systems to supply these resources affects stand productivity (Cropper and Gholz 1994, Eissenstat and Van Rees 1994).

The production of new roots in forest stands may increase or decrease in response to silvicultural treatments such as thinning and fertilization (Sword and others 1998a, 1998b, Albaugh and others 1998). Root-growth responses to silvicultural treatments have been linked to changes in leaf area, carbon fixation, and photosynthate allocation to the root system (Albaugh and others 1998, Gower and others 1992). Since new root growth is regulated, in part, by carbohydrate availability in the root system (Kozlowski and Keller 1966, Noland and others 1997), knowledge of how silvicultural treatments affect root carbohydrate relations is needed to understand how root growth is manipulated by these treatments.

Our objective was to evaluate relationships between seasonal root growth and carbohydrate relations of plantation loblolly pine in response to thinning and fertilization. We hypothesized that: (1) seasonal patterns of fine-root starch and glucose concentrations are closely related to new root growth, and (2) manipulation of stand density and soil fertility affects the relationship between fine-root starch and glucose concentrations and root growth.

MATERIALS AND METHODS

This study was conducted in a 14-year-old loblolly pine plantation on the Palustris Experimental Forest in Rapides Parish, LA. The soil is a Beauregard silt loam that is low in available phosphorus (Kerr and others 1980). Genetically unimproved, container-grown loblolly pine seedlings were planted in 1981 at 1.8- x 1.8-m spacing. In 1988, 12 treatment plots, 13 rows of 13 trees each (0.06 ha), were established. Two levels of fertilization (none; 744 kg ha" diammonium phosphate) in April 1989 and two levels of thinning (none: 2990 trees ha“; row thinned: 731 trees ha^{-1}) in November 1988 were randomly applied in a two-by-two factorial design with three replications. In March 1995, fertilization (none; 444 kg urea + 248 kg triple super phosphate + 100 kg potash ha-‘) and thinning (none: 42 m^2 ha^{-1}; 15.6 m^2 ha^{-1}) were reapplied.

Two of the three replications were blocked by topography. Precipitation was quantified electronically in a clearing approximately 25 m from the study. Volumetric soil water content of the 15-cm depth was measured biweekly at three locations per plot of each replication using time domain reflectometry.

Using previously described methods, net root elongation (mm dm^{-2}) in five Plexiglas rhizotrons per plot of two replications was quantified on a biweekly basis between April 1995 and March 1997 (Sword and others 1996, Sword and others 1998b). Root elongation from April 1995 through February 1996 is also reported elsewhere (Sword and others 1998b).

At 2- to 4-week intervals, 10 soil cores (6.5 cm x 15 cm) were extracted from random locations in the periphery of each plot of two replications using a metal coring device (Ruark 1985). Branched fine-roots (≤ 1 .O-mm diameter) were elutriated from soil cores (Smucker and others 1982). Roots from each plot were pooled, washed, frozen (-80 “C), lyophilized, and ground (40-mesh). Fine-root starch and glucose concentrations were determined using a modification of the procedure described by Jones and others (1977). Starch and soluble sugars were extracted from 25 mg ground root tissue and enzymatically converted to glucose. Glucose was quantified by the glycolytic production of reduced nicotinamide adenine dinucleotide phosphate (NADPH). Spectrophotometricaily, NADPH was measured at 320 nm. Carbohydrate concentrations are expressed as mg g^{-1} ash-free dry weight.

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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New root elongation and root carbohydrate data at each measurement interval were transformed (log[Y+1]) as needed to establish normality and subjected to an analysis of variance using a randomized complete block design with two replications. Main and interaction effects were considered statistically significant at probabilities (Pr) $\leq$ 0.05.

RESULTS

From January through June 1996, precipitation was 76 percent less than during the same period in 1995 (fig. 1). During the growing season (May-November)and period of maximum root elongation (May-July), reductions in precipitation of 22 and 30 percent, respectively, were observed in 1996 when compared to 1995. For the periods extending both from May through July and May through November, the mean soil water content at 15 *cm* was 20 percent less in 1996 than in 1995.

During the 1995 growing season (May-November), 70.0 percent of the root elongation occurred from May through July, and 26.5 percent occurred from August through November (fig. 2). In **1996, 42.2** and 46.3 percent of root elongation occurred from May through July and August through November, respectively.

As reported by Sword and others **(1998b),** root elongation was positively and significantly affected by thinning throughout 1995. This trend was consistent during the 1996 growing season, although only significant in May (fig.2). Root elongation was not affected by fertilization in 1995 (Sword and others 1998b) but was significantly reduced by fertilization during most of 1996.

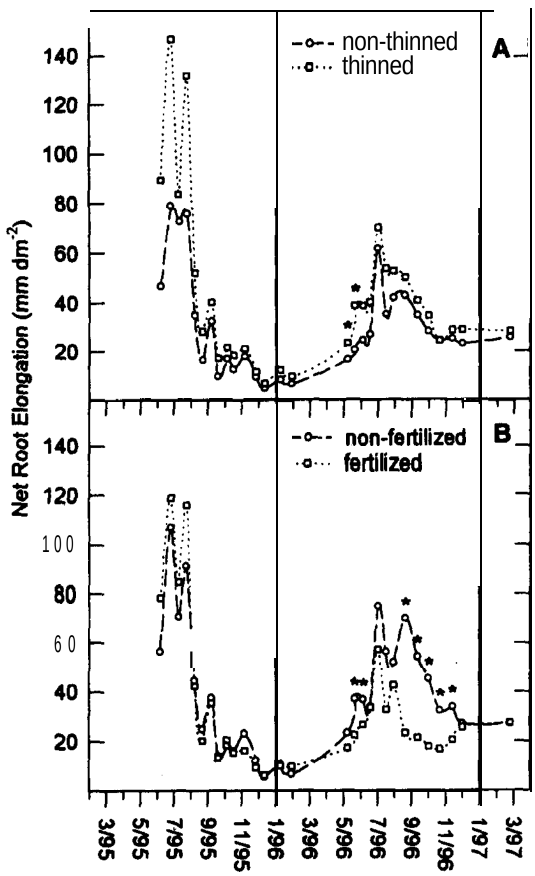

Figure 2-Net root elongation of **loblolly** pine (mm **dm^{-2})** by thinning (A) and fertilization (B) treatments in 1995 and 1996. As reported by Sword and others **(1998b),** root elongation was positively and **significantly** affected by thinning throughout 1996-96. An asterisk **(*)** indicates statistical significance at Pr $\leq$ 0.05 on measurement dates In 1996-97.

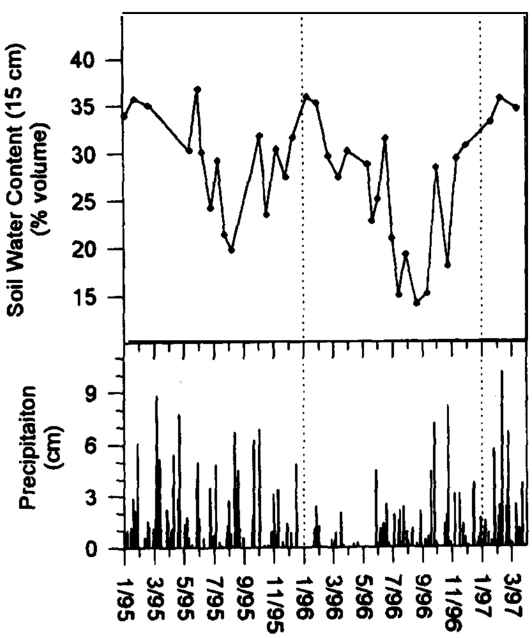

Figure l-Percent volumetric soil water content at 15 cm (A) and daily precipitation (cm) (B) in 1995 and 1996.

The seasonal pattern and magnitude of fine-root starch concentration were similar in 1995 and 1996 (figs. 3 and 4). In both years maximum concentrations of fine-root starch were observed in March and April, and minimum concentrations from July through November. The seasonal pattern of fine-root glucose concentration was similar in 1995 and 1996; minimum concentrations occurred from January through May and progressively increased during June and July. Maximum fine-root glucose concentration in 1995 and 1996 was observed in August through October and August through December, respectively.

During the period of maximum fine-root glucose concentration in 1995 and 1996, the magnitude of concentration differed. From August through October 1996, the fine-root glucose concentration was 16 percent greater than from August through October 1995.

Fine-root starch concentration was generally greater in response to thinning between March 1995 and February 1997 (fig. 3a); however, statistical significance was sporadic

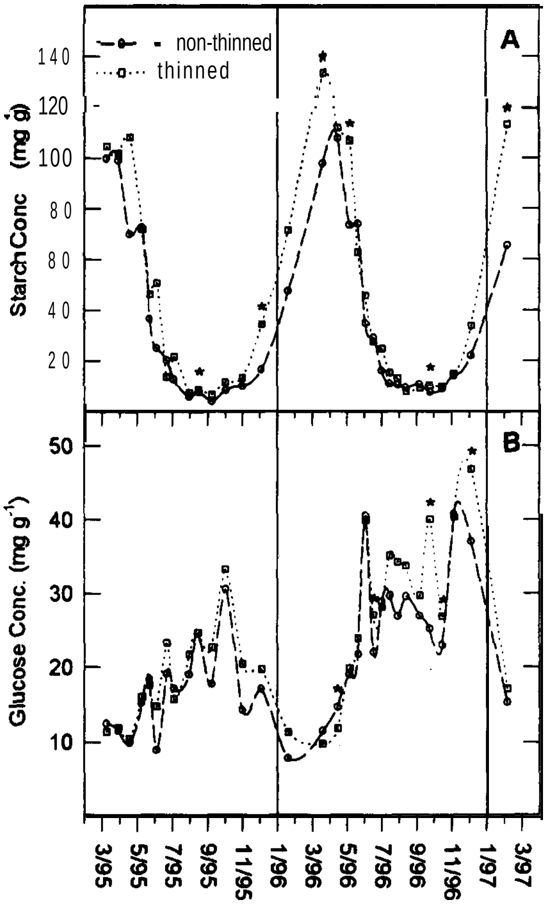

Figure 3-Fine-root starch (A) and glucose (B) concentration (mg g^{-1} ash-free dry tissue) by thinning treatment in 1995 and 1998. Thinning was a statistically significant effect (Pr $\leq$ 0.05) on measurement dates noted with an asterisk (*).

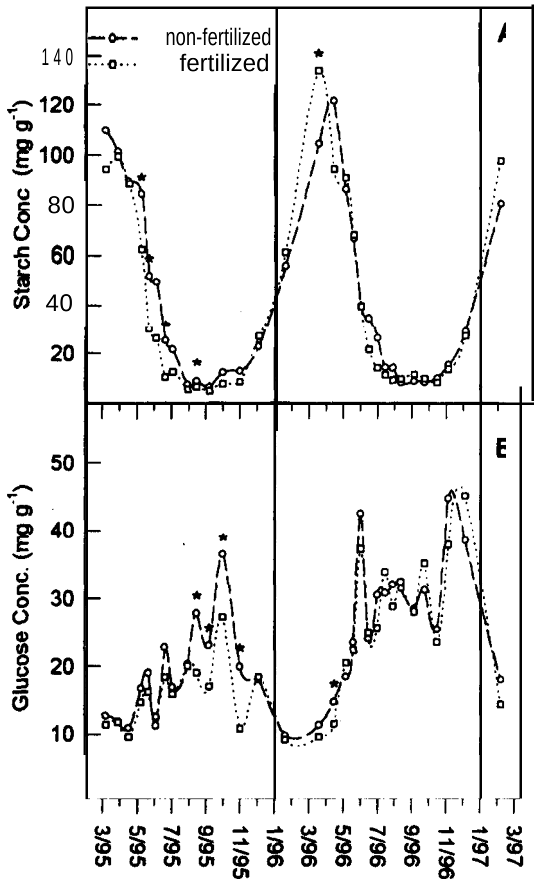

Figure 4—Fine-root starch (A) and glucose (B) concentration (mg g^{-1} ash-free dry tissue) by fertilization treatment in 1995 and 1998. Fertilization was a statistically significant effect (Pr $\leq$ 0.05) on measurement dates noted with an asterisk (*).

(table 1). Fine-root glucose concentration was not significantly affected by thinning in 1995 (fig. 3b). In mid-April 1996, however, the concentration of glucose in fine-roots was significantly lower, and in mid-June and three times in the fall of 1996, was significantly greater in response to thinning (table 2).

In 1995, before starch accumulation began in November, fine-root starch concentration was consistently lower in response to fertilization with intermittent significance (table 1, fig. 4a). This response was reversed in March 1996. Fine-root glucose concentration was significantly lower in response to fertilization from August through November 1995 and April 1996 (table 2, fig. 4b). After April 1996, fine-root starch and glucose concentrations were not significantly affected by fertilization.

DISCUSSION

Fine-root starch concentration was modal with periods of accumulation from December through March and depletion from April through July. Minimum starch concentration was maintained from August through November. These results are consistent with other observations of southern pine species (Adams and others 1986, Gholz and Cropper 1991). Teskey and others (1994a) suggested that substantial photosynthesis continues throughout winter in warm climates. Our results indicate that, during winter root, starch is a sink for photosynthate in plantation loblolly pine.

Based on the results of seedling experiments, newly transloceted photosynthate is considered the primary source of energy for conifer root growth rather than stored starch (Ritchie and Dunlap 1980, van den Driessche 1987). If the availability of current photosynthate is limited, however, a greater portion of stored starch may be used as an energy source for root growth (Noland and others 1997, Philipson 1988). In both 1995 and 1996, fine-root starch concentration decreased between March and June, while net root elongation increased between May and July. Although fine-root starch concentration was near its lowest level, fine-root glucose concentration was relatively high in July. This suggests that starch and current photosynthate provided the

Table l-Probability of a greater F-value associated with significant effects on the fine-root starch concentration (mg g") of 16-year-old loblolly pine from March 1995 through February 1997 in response to two levels each of thinning and fertilization

Variable	df	Probability > F-value						
		Measurement dates						
		1995						
		5-11	5-23	6-22	8-17	9-8	11-3	12-11
Block (B)	1	0.8297	0.2327	0.2196	0.0232	0.5252	0.7893	0.8011
Thinning (T)	1	.6373	.3291	.0854	.0190	.0866	.2430	.0056
Fertilization (F)	1	.0009	.0508	.0082	.0044	.3030	.0595	.8763
T x F	1	.8867	.3977	.0183	.0041	.8593	.7425	.8398
		1996						1997
		1-25	3-20	5-7	8-13	9-24	IO-16	2-6
Block (B)	1	.2863	.1100	.7001	.0181	.6289	.5612	.5440
Thinning (T)	1	.0841	.0126	.0031	.1011	.0194	.2629	.0093
Fertilization (F)	1	.7659	.0222	.5471	.0650	.1298	.0781	.1207
T x F	1	.1980	.3592	.0200	.1645	.8650	.8115	.0497

Table 2-Probability of a greater F-value associated with significant effects on the fine-root glucose concentration (mg g") of Is-year-old loblolly pine from March 1995 through February 1997 in response to two levels each of thinning and fertilization

Variable	df	Probability > F-value					
		Measurement dates					
		1996					
		7-6	8-17	9-8	9-25	11-3	
Block (B)	1	0.1912	0.8104	0.1758	0.0100	0.3764	
Thinning (T)	1	.0817	.1530	.0734	.2230	.1823	
Fertilization (F)	1	.1666	.0362	.0364	.0125	.0102	
T x F	1	.0086	.0410	.5477	.0201	.1467	
		1996					
		4-16	6-17	7-30	9-24	IO-16	12-5
Block (B)	1	.0227	.7550	.1861	.6035	.0459	0.1136
Thinning (T)	1	.0328	.0486	.0706	.0303	.0106	.0337
Fertilization (F)	1	.0176	.6060	.3226	.7008	.1667	.0894
T x F	1	.0873	.1713	.3328	.3485	.0450	.0867

glucose for root elongation through June. In July, however, after starch reserves were depleted, root elongation proceeded, primarily with glucose supplied by current photosynthate. Sword and others [in press] reported that fine-root sucrose concentrations remained relatively constant from March 1995 through January 1996. It is believed that both starch and current photosynthate are sources of energy for loblolly pine root metabolism during the period of maximum root elongation. However, the relative contributions of starch and current photosynthate to root metabolism during this period cannot be determined by this study.

Past research has shown a positive relationship between light availability to the shoot and root carbohydrate concentration in pine (Noland and others 1997, Shiroya and others 1966). With a reduction in stand density, greater light availability in the forest canopy may have resulted in more photosynthate production (Peterson and others 1997), and carbohydrate allocation to root growth (Sword and others 1998b). In 1995, elevated root carbohydrate concentrations corresponded to a distinct increase in root elongation in response to thinning. Similar root-growth responses to thinning were observed in 1993 and 1994 (Sword and others 1998a, 1998b). Positive stand-productivity responses to thinning have been attributed to increases in light availability and carbon fixation in the canopy, and carbon allocation to diameter growth (Kozlowski and others 1991). On sites where tree growth is limited by the availability of water or mineral nutrients, thinning may also enhance stand productivity by increasing carbon allocation to root growth and, therefore, soil resource uptake.

Fertilization had a negative effect on root elongation in 1996, but no effect in 1995. Absence of an effect in 1995 was not unexpected, because the effect of fertilizer application in 1989 on root elongation was negligible by 1993 and absent by 1994 (Sword and others 1998a, 1998b). Also, starch and current photosynthate availabilities for root metabolism and growth in 1995 were defined by leaf-area attributes established before fertilizer was reapplied. Specifically, foliage produced in 1994 was the source of starch that accumulated in fine-roots from December 1994 through March 1995. Also, carbon gains after fertilization are attributed, in part, to an increase in leaf area (Teskey and others 1994b, Vose and Allen, 1988). Because the fascicle density of the first flush is determined during terminal bud development in the previous year (Stenberg and others 1994), leaf area and, therefore, the amount of photosynthate produced on the fertilized plots in 1995, could not have been strongly affected by the reapplication of fertilizer in March 1995.

Past research has shown that nitrogen fertilization causes a shift in the proportion of photosynthate allocated to aboveground and root-system growth (Albaugh and others 1998, Gower and others 1992). Albaugh and others (1998) found that for 9- to 12-year-old loblolly pines, average annual biomass allocation was 14 percent greater to aboveground tissues and 63 percent lower to fine-roots in response to fertilization. Our results demonstrate a similar response to fertilization. In July 1995, after starch was depleted from fine-roots and current photosynthate became the primary energy source for root growth, fertilization resulted in a lower concentration of fine-root glucose but did not affect root elongation. In 1996, a similar fine-root glucose response to fertilization was not observed, but fertilization resulted in less root elongation. We hypothesize that less photosynthate was allocated to the root system on fertilized plots than to the root system on non-fertilized plots, resulting in a reduced concentration of fine-root glucose in 1995 and reduced root elongation in 1996.

These results indicate that during the growing season, fertilization reduced photosynthate allocation to the root system; although during the dormant season (December through March), photosynthate allocation to roots appeared to respond differently. Termination of branch growth and continued photosynthesis in winter, together with an increase in leaf area per tree in response to fertilization, may have led to the observed increase in fine-root starch concentration in March. Thus, the presumed negative effect of fertilization on carbon allocation to the root system may not apply during the accumulation of starch in the dormant season.

Past research has shown that root elongation in loblolly pine is sensitive to water availability (Ludovici and Morris 1996). Sword and others (1998a, 1998b) observed that the seasonal reduction in root elongation during July 1993 and 1994 coincided with reduced soil water content. In this study, the magnitude of root elongation was less in 1996 than in 1995. This reduction was associated with an unusually dry winter and spring. Limited soil water availability from May through July 1996 may have inhibited root elongation. The seasonal pattern of root elongation in 1996 was also different from what was reported between 1993 and 1995 (Sword and others 1998a, 1998b). More root elongation occurred from August through November in 1996 than during the same period in previous years. After an extensive period of reduced water availability from January through August 1996, sufficient precipitation resumed in September. Expansion of the loblolly pine root system network by root elongation is generally restricted to May through July (Sword and others 1998a, 1998b). The seasonal pattern of root elongation observed in 1996 suggests that if root elongation is inhibited from May through July, a portion of the forfeited root system expansion can potentially be recovered between August and November.

Reduced water availability may have prompted the 54 percent increase in fine-root glucose concentration between 1995 and 1996. Because maintenance of a high solute concentration in root cells increases their hydration by osmosis (Kramer 1983), storage of glucose rather than starch may have been a physiological mechanism of drought tolerance. Storage of root carbohydrates as glucose rather than starch may also have been an energy conservation strategy by which glucose was a readily available source of energy for rapid root growth in the event of precipitation.

SUMMARY

Root-starch reserves in plantation loblolly pine appear to be a carbohydrate sink during the dormant season. These reserves may be a source of energy for loblolly pine root metabolism early, when maximum root elongation is occurring. Thinning was beneficial to starch accumulation and the growth of fine roots. On sites where tree growth is limited by the availability of water or mineral nutrients, thinning may enhance stand productivity by increasing carbon allocation to root growth and, therefore, soil resource uptake. Generally, nitrogen fertilization had a negative effect on carbon allocation to loblolly pine roots except during the dormant season, when starch accumulation increased in response to fertilization. Limited soil water availability from May through July 1996 appeared to inhibit root elongation. However, root elongation resumed later in the growing season, as water became available.

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FOUR-YEAR GROWTH RESULTS FROM 16-YEAR-OLD INTENSIVELY MANAGED LOW DENSITY LOBLOLLY PINE PLANTATIONS'

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Abstract-In 1994 eighty four permanent research plots were established in two twelve year-old loblolly pine (*Pinus taeda*) plantations in East Texas. Plots differed in relation to: soil-site type, density of trees per acre, fertilization treatments, and competing vegetation control. Three levels of thinning treatments reduced the basal areas to 36, 60, and 84 square feet of basal area (approximately 100,200, and 300 stems, respectively) per acre. All residual trees were pruned to a height of 25 feet. Plots were re-measured in 1995, 1996, and 1998. Significant differences in diameter and height growth rates were detected in 1996 and 1998. Average diameter growth rates from 1995 to 1998 ranged from 0.64 to 0.31 inches per year depending on density class and treatment type.

INTRODUCTION

In 1994, Stephen F. Austin State University in cooperation with Temple-Inland Forest Products Corp., established 84 monumented experimental plots in two typical loblolly (*Pinus taeda*) pine plantations in East Texas. This study was designed to evaluate the effects of heavy thinning, pruning, fertilization, and competition control, the goal being to produce large clear sawtimber on short rotations. This project was based on studies reported by Burton (1982) and Wiley and Zeida (1992). The style of management on these studies are sometimes referred to as "Sudden Sawlog". Both studies used very intensive management practices such as multiple thinnings, bush-hoggings, and prunings, the later study also included three prescribed burnings. While these studies utilized silvicultural practices to maximize sawtimber production, there was no consideration given to the costs associated with this management. The main goal of our study is to grow the largest amount of high quality, knot free, wood while being able to recapture the management costs and still be a profitable investment. The objectives of this study were to report on the growth results four years after thinning treatments were applied.

STUDY SITES

The two study sites differ in relation to soil drainage type. Site one is located in the southern comer of Angelina County and is considered a moderately drained site with a Moswell complex (Dolezel 1988). Site two is located in south-eastern Anderson County and is considered a well drained site with a Fuquay series (Coffee 1975). Both study areas were on non-old-field sites that were previously forested with loblolly pine. Both stands were planted in 1982 with a local variety seed source. Site one was more densely planted with approximately 800 stems per acre while site two was planted with approximately 800 trees per acre. The understory in site one was almost non-existent, while site two contained a heavy mix of woody shrubs and hardwood saplings.

METHODS

The study was implemented during the summer of 1994, while the stands were in their twelfth growing season. Three treatments were installed in a completely randomized without replacement factorial design with three replications for each treatment. Treatments included in the study were three levels of residual densities (35, 60 and 84 square feet of basal area per acre), two levels of fertilization (fertilized and non-fertilized), and two levels of competition control (herbicide and non-herbicide). For each level of thinning, one plot would receive no fertilization and no competition control; one plot would receive fertilization only; one plot would receive competition control only and one plot would receive both fertilization and competition control. Six control plots per site were also established which would receive a standard row thin and no other silvicultural treatment. Plots were positioned within the two stands in a strip-wise pattern as closely together as possible while maintaining uniformity and avoidance of windrows, skid roads, drainages, trails and other anomalies. Each plot consisted of a square one-quarter-acre inner plot surrounded by a 33 foot wide buffer. Plot buffers would receive the same treatment as the plot they surrounded, but would not be used in data collection.

Each tree in a plot was measured for diameter in inches at 4.5 feet above ground level (dbh), total height in feet, height to first live branch, and crown width. Presence of fusiform rust (*Cronatium quercuum* f. sp. *fusiforme*), crooks, forks or other defects were also tallied.

After plot boundaries were established and tree data were recorded, each plot was revisited for residual crop trees selection. Residual trees were selected in the following five criteria, in order of decreasing importance: (1) Larger dbh, (2) stem form, (3) taller trees, (4) spatial distribution, and (5) crown quality. Residual densities were achieved using a modified form of Reineke's stand density index (SDI) (Zeide 1985). Selected densities can then be calculated using the following equation:

$$SDI = N\left(\frac{D}{10}\right)^{1.7} \quad (1)$$

Where:
N = Number of stems per acre
D = Quadratic mean diameter

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Table 1 shows residual density relationships. Thinning treatments were conducted in the fall of 1994 and all harvested trees were hauled to area mills. All residual trees in treatment plots were subsequently pruned during the winter of 1994-l 995 to a height of 25 feet. The following summer (1995) each tree was numbered and remeasured. That fall, plots to receive competition control were treated by hand spraying of herbicides. Herbicide application consisted of approximately 16 ounces of Arsenol AC, 24 ounces of Garlon 4, and 32 ounces of Red River 90 per acre. Mixture totaled approximately 30 gallons per acre for application. Hardwood trees and shrubs greater than two inches in diameter were also “hacked and squirted”. In the spring of 1996, fertilization plots were treated with a combination of Urea and Diamonium Phosphate (DAP) giving a blended analysis of 29.21-16.79-O. Fertilizer was applied with shoulder mount hand crank spreaders at a rate of 563 pounds per acre. Plots were remeasured again during the summers of 1996 and 1996.

RESULTS

Stand attributes before thinning are given in Table 2. Dominant heights at site one were in the mid to upper sixties and in the mid to upper **fifties** on site two. For both sites this is out of the range of most site quality curves. Maximum diameters for both sites were in the 11 inch class. Stand attributes after thinning are shown in Table 3. For both sites the average diameter increased with decreasing density.

Table l-Density attributes after thinning for the two study sites

Site	Density class	Density level	Stand density index	Basa area/acre	Stems per acre
				Ft²	
1	Low	1	***70***	***35.6***	***103.7***
1	Med	***2***	***120***	***60.1***	***196.3***
1	High	***3***	***170***	***63.7***	***300.0***
2	Low	1	***70***	***35.6***	***105.3***
2	Med	***2***	***120***	***60.6***	***190.3***
2	High	***3***	***170***	***64.2***	***290.0***

This is due to the selection method in which the biggest and best trees were selected for the lowest density plots. While the higher density plots contained the same kind of trees as their lower density counterparts they also contained “less than the best” trees as well. The same relationship holds true for the average total tree heights.

Diameter Growth

Tree tagging accomplished in 1995 allowed tracking of individual tree growth through 1996. If treatments besides thinning are disregarded, significant differences in diameter growth (alpha = 0.05) were detected between each of the thinning levels. At both sites, diameter growth was greatest for the lowest density level and decreased with increasing density. Growth rates ranged from 0.27 inches per year for density class three on site one to 0.64 inches per year for density class one on site two (table 4).

When all treatments were added back into the model, no interactions were detected between the three factors. For each density level with the exception of density class one on site two, diameter growth was significantly greater with fertilization treatments. Even at the exception, plots with the fertilization treatment had a greater, although not statistically significant growth rate. There were no significant differences detected due to the competition control treatments (table 5).

Height Growth

When looking only at thinning treatments no significant differences in height growth where detected for site one. Site two however showed density one had significantly slower height growth than the group of density class two and three. As shown in Table 6, height growth ranged from one foot per year for site one density two to 2.3 feet per year for density level three on site two. Additionally, although the trees where taller on site one, site two had significantly greater height growth. Site two had an overall average yearly height growth of 2.0 feet, while site one’s growth was 1 **.1** feet per year.

No interactions were found between fertilization and competition control treatments. Significant differences between fertilization treatments were found on density levels one and two for site one. For those two treatment levels fertilization increased height growth. For the competition control treatment, density level one and two on site one showed significantly different height growth. No competition control for density level one on site one yielded greater height growth, while on density level two on site one growth was higher for the competition control treatment. For the remaining density and site levels no recognizable trends were present (table 7).

Table P-Initial stand attributes (before thinning) for the two study areas

Site	Stems per acre	Basal area per acre	Average diameter	Average total height	Average volume per acre
		Ft²	*Inches*	*Feet*	*Ft³*
1					
2	710.5 550.9	166.6 132.4	6.3 6.4	46.1 43.6	**3,899.5** 2,767.0

Table 3—After thinning stand attributes for the two study areas

Site	Density level	Average diameter	Average total height	Average volume per acre
		Inches	*Ft*	Ft^3
1	1	7.81	52.8	889.2
1	2	7.33	51.9	1,436.4
1	3	8.98	51.3	1,988.0
2	1	7.83	45.1	885.1
2	2	7.54	44.8	1,468.1
2	3	7.20	44.5	1,951.7

Table 4—Average diameters and diameter growth by site and density level between 1995 and 1998

Site	Density level	Average diameter 1995	1998	Growth per year
		- - - - - - - - - Inches[a] - - - - - - - - -		
1	1	8.07	9.75	0.56 A
1	2	7.55	8.77	.40 B
1	3	7.28	8.03	.27 C
2	1	8.12	10.04	.64 A
2	2	7.78	9.08	.43 B
2	3	7.40	8.33	.31 c

[a] Like letters within the same site show no significant difference using Duncan's multiple range test at the alpha = 0.05 level.

Table 5—Average yearly diameter growth between 1995 and 1998 by site, density level, fertilization, and competition control treatments

Site	Density level	Treatments: Fertilization	No fertilization	Competition	No competition
1	1	0.60 A	0.53 B	0.57 A	0.56 A
1	2	.45 A	.36 B	.42 A	.38 A
1	3	.29 A	.25 B	.28 A	.26 A
2					
2	11	.68 .49	.39 AB	.45 A	.42 A
2	3	.33 A	.29 B	.32 A	.30 A

Like letters within the same site, density, and treatment type show no significant difference using Duncan's multiple range test at the alpha = .05 level.

DISCUSSION

Diameter Growth

When thinning treatments are looked at independent of the other treatments, heavier thinning or less residual densities resulted in greater diameter growth. This could be attributable to two causes. First, the objective of thinning is to re-distribute growth to the fewer residual trees. Therefore, the lower the residual density the more growth can be allocated to each remaining tree. Second, increased growth could be due to the residual selection method, where on the lowest density plots the absolute best trees were selected as the crop trees. The medium density class would then contain the best trees as well as the next to the best trees. Finally, the highest density plots would contain the best of the best, the next to the best, and then other less desirable stems to maintain spacing and density requirements.

When looking at diameter growth in relation to density and the fertilization treatment, higher growth rates resulted from trees being fertilized. Although one exception was noted, probably due to some unknown variation, the trend was the same.

Competition control treatments made no significant difference in relation to diameter growth. There was, however, a trend favoring competition control. Although

Table 6—Average heights and height growth between 1995 and 1998

Site	Density level	Average height 1995	Average height 1998	Growth per year
		Feet[a]		
1	1	56.6	59.5	1.0 A
1	2	55.7	59.2	1.2 A
1	3	55.1	58.5	1.1 A
2	1	48.8	53.6	1.6 B
2	2	48.2	54.5	2.1 A
2	3	47.9	54.8	2.3 A

[a] Like letters within the same site show no significant difference using Duncan's multiple range test at the alpha = 0.05 level.

Table 7-Average yearly height growth between 1995 and 1998 by site, density level, fertilization, and competition control treatments

Site	Density level	Treatments: Fertilization[a]	No fertilization	Competition	No competition
1	1	1.7 A	0.7 B	0.5 A	1.4 B
1	2	1.5 A	.a B	1.5 A	.a B
1	3	1.3 A	1.0 A	1.1 A	1.1 A
2	1	1.4 A	1.8 A	1.6 A	1.6 A
2	2	2.1 A	2.1 A	2.0 A	2.2 A
2	3	2.4 A	2.2 A	2.3 A	2.3 A

[a] Like letters within the same site, density, and treatment type show no significant difference using Duncan's multiple range test at the alpha = 0.05 level.

the average difference only amounted to 0.026 inches per year, the trend was consistent.

Height Growth

No significant differences in height growth were detected in site one and only density class one was significantly lower than either class two and three on site two. The trend in lower height growth on lower densities that occurred in site two would seem logical in that on lower density conditions there would be less competition for light. However, site one did not display the same relationship.

When looking at the effects of fertilization and competition control combined with density levels, a small percentage of statistically significant differences were detected. However, it would seem there was no logical pattern that arose and therefore it was concluded there was no practical significance and differences may be attributed to happenstance and/or measurement anomalies.

In summary, a surprising preliminary result was that site two started out with virtually the same average diameter as site one: Site one had trees averaging over seven feet taller:

and site two has out performed site one both in diameter and height growth. Although site one was considered to be much better than site two at the beginning of the study, growth rates could be better at site two for three reasons. First, site two initially had much more competing vegetation than site one. Therefore, by reducing the non-planted vegetation as well as the competing pines, by means of thinning, the residual crop trees could be responding at a greater rate. Second, it is possible that site two could have received more rain during the two severe droughts that East Texas had experienced since the study plots were established. The third possibility may also be that lands of lower site quality respond more favorably to intensive low density management.

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FINANCIAL ANALYSIS OF PRUNING COMBINED WITH LOW DENSITY MANAGEMENT OF SOUTHERN YELLOW PINE IN EAST TEXAS: AN ASSESSMENT'

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Abstract-Time study was conducted on pruning of research plots in a 12-year-old loblolly pine (*Pinus taeda*) plantation thinned to 58 square feet basal area (190 trees) per acre. Pruning times with labor and equipment costs were used to determine per acre and per tree pruning costs. Pruning costs were used to find values necessary to break-even on a pruning investment. Soil expectation value (SEV) calculations were used to compare profitability of management utilizing heavy thinning with pruning to traditional management regimes. Calculations were performed using a current hourly wage of $8.00, stumpage price of $400.00, per thousand board feet (MBF) and real interest rates of 0.13, 2.78, 7.00, and 10.00 percent. Per acre combined labor and equipment cost was $116.07. Cost per tree to prune to a height of 25 feet was $0.61. Break-even values were found to range from $118.82 to $645.34 per acre depending on interest rate. Profit increase by utilizing low density management combined with pruning was found to range from $491.43 to $88,093.04 per acre over traditional management for a perpetual series of full rotations.

INTRODUCTION

The practice of pruning in pine plantations is nothing new to Australia, New Zealand and Sweden. The procedure has been studied in the United States, but has not been commonly implemented into widespread practice. Until recently, it was virtually unheard-of in East Texas. Temple-Inland Forest Products Corporation has initiated research to grow pine trees at a low stand density on short rotation. The aim is to produce large trees within that short rotation and, by pruning, yield crops of high-quality logs for high-grade products.

Based on studies conducted in Arkansas, the Temple study will determine the feasibility of the practice in East Texas pine plantations. Young pine plantations have been heavily thinned and boles of the selected residual trees were pruned to a height of 25 feet. After a recovery period of several years, the stands may undergo a second thinning. Residuals from this second entry are the crop trees which will remain until the end of the rotation. The study will evaluate various treatment levels of thinning, fertilization and competition control to determine optimum treatment combinations.

The attractiveness of this approach to management is the high-quality wood volume produced. The quality of such a product is the result of intensive, high-cost management. In theory, the product will more than pay for such extensive management. This study is directed toward assessment of whether or not pruning combined with low density management is a wise investment for landowners.

OBJECTIVES

Objectives of this study were to: 1) determine per tree and per acre pruning costs; 2) determine break even values of a pruning investment; and 3) compare profitability of low density management with pruning to traditional management.

METHODS

Background

Data for this study were collected from a 12-year-old loblolly pine plantation in eastern Anderson County, Texas. Planted in 1982, the stand lies primarily on Fuquay series loamy fine sand (Loamy, silicious, thermic, Arenic Plinthic Paleudults), with some small areas on Kirvin-Sacul association fine sandy loam (Clayey, mixed, thermic, Typic and Aquic Hapludults) (Coffee 1975). The research area consists of 42 two-thirds-acre permanent research plots. These plots were established as part of a long-term study initiated by Temple-Inland Incorporated to determine the optimum management regime for short rotation pine plantations in East Texas. The research is based on previous studies conducted in Arkansas (Burton and Shoulders 1974, Wiley and Zeide 1994).

After an initial inventory, crop trees for the residual stand were selected and the stand was thinned, then pruned to a height of 25 feet. Time measurements were collected as workers pruned the stand. Findings presented here focus on portions of the stand thinned to 58 square feet basal area per acre (BA). Mean dbh was 7.5 inches, with 190 trees per acre.

Time Study

Pruning time per tree was measured to the nearest second. Three different measurements were utilized in determination of pruning time per tree: 1) time elapsed while pruning a tree (start to finish); 2) time elapsed moving between trees (finish to start); and 3) time elapsed in pruning and moving between trees (start to start).

For the purposes of this study, pruning was considered to start when the sawblade made contact with the first limb of a tree being pruned. Pruning was considered finished at the moment a worker's behavior began to suggest progression

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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towards pruning another tree. This involved observation of very subtle visual signals. There was a perceptible breaking point when a worker would give a tree a final visual inspection, and through facial expression or body motion indicate the completion of pruning on a tree.

Pruning was conducted using pole saws. Pruning to 25 feet required pruners to work in pairs, with one worker (top worker) pruning the top portion of each tree and the other (bottom worker) pruning the lower portion. A pair of workers was selected for observation, and one of the three time measurements was conducted on one worker in the pair. The process was performed for five repetitions then conducted on the other worker in the pair. Timing alternated in this fashion until each worker had been observed on five repetitions of the three time measurement categories. Another pair of workers was then selected for observation and the procedure continued.

Pruning Times
A mean of 51 individual time measurements was taken per worker per measurement category. Including both workers, start to finish times ranged from 25 seconds to 5 minutes and 51 seconds. Between tree times ranged from 1 second to 3 minutes and 8 seconds. Start to start times ranged from 25 seconds to 6 minutes and 1 second. Mean pruning times are presented in Table 1.

Table l--Mean times observed in minutes and seconds for workers pruning one tree to 25 feet In a 12-year-old loblolly pine plantation at 58 BA

Time measurement	Bottom worker	Top worker
Start to finish[a]	1:42	1:14
Finish to start[b]	0:14	0:10
Start to start[c]	2:10	1:09

[a] Start to finish was the time consumed strictly by the pruning activity alone on one tree.
[b] Flnish to start was the time between completion of pruning one tree and the commencement of pruning the next tree.
[c] Start to start times were separate, individual measurements of the time between commencement of pruning one tree and the commencement of pruning the next tree.

Because workers functioned as pairs, the slower worker set the pace of the pair. To avoid under representing net time per tree, mean trees pruned per day was calculated using times of the slower worker. In this study, it was the bottom worker mean start to start time of 2 minutes and 10 seconds. Times for both workers were not added together because faster workers yielded the same net productivity as slower workers. Faster workers simply took more breaks during a workday. These per tree times were used to calculate a mean value of 194 trees pruned per day per worker pair. Mean trees pruned per day (179.5) was also calculated from workers' daily tallies in other stands of various densities as a check for comparison to values resulting from time data collected on individual tree prunings.

Trees pruned per day by one pair of workers was calculated by dividing 7 hours by the minutes and seconds value used to represent pruning one tree and moving to the next. For example, a worker can prune at a rate of 2 minutes and 10 seconds per tree. Over a 7 hour (420 minute) period, the worker will complete his portion (one half) of the pruning on 194 trees. A figure of 7 hours was used to calculate trees pruned per day because an 8 hour workday does not contain 8 actual hours physically pruning. The extra hour allowed time for walk-in, walk-out, and equipment assembly, disassembly, and maintenance.

Net trees pruned per hour was found by dividing trees pruned per day by 8 hours. For example, a pair of workers pruned 194 trees in one day. Dividing 194 trees over an 8 hour day showed a 24.25 trees per nour production rate for the worker pair. Since it took a pair of workers to complete a tree, the figure was divided by 2, yielding a net trees pruned per worker per hour of 12.125. A net value of 97 trees per worker per day was found by dividing the pairs 194 trees per day production by the two workers in the pair. In other words, a worker pair's trees per day total must be divided by 16 man-hours to find net hourly worker productivity.

Labor Costs
Wage paid to pruners was assigned at $6.00 per hour. Social Security and benefits paid were assigned at a rate of 19.95 percent (Nathan 1987). Hourly and per acre labor costs were found by combining trees per hour and trees per acre information.

Equipment Costs
Pruning was conducted using pole saws. A saw in this context was considered to be a pole saw head attachment and three 6-foot aluminum pole sections. In practice the bottom worker would use two poles and the top worker would use four poles, for a three poles per worker average. Retail prices were used in determining equipment costs as presented in (table 2). Cant Saw files, needed for sharpening blades, retail for $7.53 (Simonds Industries Inc. Inter-vale Road, Fitchburg, MA, 01420).

Per Acre Pruning Costs
Cost of pruning to 25 feet per acre was found by multiplying man-hours by wages and adding per tree equipment cost for the appropriate number of trees per acre (table 3). Pruning cost per tree per man was found by dividing hourly cost by trees pruned per hour (table 4).

Per Tree Pruning Costs
Per tree equipment costs were calculated based on an average of 97 trees per worker per day and an assumed 250

Table P-Pruning tool costs in dollars from Forestry Suppliers, Incorporated (1998 Catalog 49)

Item	Price	Shipping	Total
	---------- Dollars ----------		
Saw head	48.00	4.20	52.20
6' aluminum pole	26.50	4.20	30.70
Replacement blade	23.95	4.20	28.15

Table 3-Per acre labor and equipment cost, by hourly wage and stand density index, to prune a 12-year-old loblolly pine plantation to 25 feet

Hourly wage	Soc. Sec. & bene.[a]	Man-hours	Equip-ment cost	Total cost
----- *Dollars* ----			------ *Dollars* -----	
6.00	1.20	15.67	3.25	116.07

[a] Social Security and benefits paid.

Table 4-Cost per tree to keep one worker pruning loblolly pine plantations to 25 feet

Hourly wage	Soc Sec & bene.[a]	Equipment cost/hour	Trees/ hour	Total cost per tree
---------- *Dollars* ---------				Dollars
6.00	$1.20	0.21	12.12	0.61

[a] Social Security and benefits paid.

day work-year. Saws were expected to last 3 years, blades were expected to be replaced every 20 days, and files were expected to be replaced after 4 months. Total dollar value of equipment was divided equally by the calculated number of trees it would prune over its useful life. Equipment cost per tree ($0.017105292) was multiplied by trees per acre to establish equipment cost per acre, and trees per hour rates to determine equipment cost per hour.

Break Even Values

To determine break-even values, labor plus equipment costs was expressed on a per acre basis and compounded to rotation age using a range of interest rates. Real rates of interest used were 0.13, 2.78, 7.00, and 10.00 percent. Use of real rates means that the interest rates used in these analyses take inflation into account, as opposed to current rates which do not. The 0.13 percent rate is the 1939-l 997 **average** real rate of return on investing in 3 month Treasury bills and is analogous to a current rate of 4.34 percent (Economic Report of the President 1998). The average real rate of return from investing in Baa corporate bonds during the same time period was 2.78 percent, and is analogous to a current rate of 7.09 percent (Economic Report of the President 1998). Baa corporate bonds are those rated by Moody's Investors Service as being of medium quality considering risk (Moody's Investors Service 1996). A real rate of 7.00 percent was chosen **as** an intermediate between returns on Baa corporate bonds and the 10.00 percent real rate selected to represent the real return available from investments like well-chosen mutual funds (Kronrad 1996a). The 7.00 and 10.00 percent real rates are analogous to current rates of 11.59 and 14.72 percent respectively.

SEV Calculations

Soil expectation value (SEV) calculations were used to compare the low density management with pruning (referred to hereafter simply as low density management) to traditional management over the range of interest rates. Soil expectation value is a measure of the net present worth (NPW) of a perpetual series of forest rotations and is defined in this study by the following formula.

$$SEV = NPW\left[\frac{1}{(1+i)^n - 1} + 1\right] \quad (1)$$

where
NPW = net present worth of a single rotation
i = interest rate
n = length in years of a single rotation

Net present worth is a measure of value in today's dollars of an investment minus expenses for a single, finite time frame (Gittinger 1982). This SEV formula is a derivation of Faustmann's original formula from 1849. More detailed discussions on the formula's development are presented by Gaffney (1960), Davis (1966), Samuelson (1976), Hyde, (1980) and Gregory (1987). Analyses were conducted using SEV rather than NPW due to the 5 year difference in rotation length between traditional and low density management. Because an investment in traditional management takes place over a 35 year time frame and investment in low density management takes place over a 30 year time frame, it was necessary to look at both investments on an infinite basis for a meaningful comparison of value.

Future stumpage values were projected by compounding current stumpage price for the appropriate number of years at a real 40 year mean annual price increase of 2.0 percent (Kronrad 1996a). Current stumpage price used was $400.00 per thousand board feet. This was well within the range of prices observed in Texas Timber Price Trends for the year 1997. Wood volume projections were based on growth data from stands in Arkansas under similar management (Kronrad 1994). To present a range of possible outcomes, SEV's were calculated at real interest rates of 0.13, 2.78, 7.00, and 10.00 percent. Values used in analyses are presented in Tables 5 - 7.

Table 5—Stumpage price per thousand board feet (MBF) of pine sawtimber compounded at a real price increase of 2.0 percent

Project year	Price per MBF Doyle $400
	Dollars
0	400.00
8	468.66
12	507.30
15	538.35
17	560.10
18	571.30
20	594.38
23	630.76
27	682.75
30	724.54
35	799.96

Table 6—Projected per acre future volumes of loblolly pine plantations thinned at age 12 to 58 BA

	Cords age 12		MBF Doyle		
Age 12 density	Cut	Keep	Age 20 cut	Age 20 keep	Age 30 total
58 BA	16.04	18.12	3.520	2.560	12.880

Table 7-Range of wood prices and labor costs used in financial analyses presented in year zero dollars

Item	Value
	Dollars
Hourly wage	6.00
Timber harvest marking and administration cost[a]	10.00
Pulpwood price[b]	25.00
Sawtimber price[c]	400.00

[a] Percent commission from harvest revenue.
[b] Dollars per standard cord.
[c] Dollars per MBF Doyle.

SEV Comparisons

Comparison was made using with and without analysis. With and without analysis is comparison of investment value exercising a specific option to the same investment not exercising the option (Gittinger 1982). In this case, comparison was between management of East Texas southern yellow pine plantations with a low density treatment regime and traditional management of East Texas southern yellow pine plantations without the low density treatment regime.

Primary analyses to determine break even values considered the project as it was actually observed walking into the stands at year 12. In the case that landowners are considering implementation of low density management on a tract of bare land, SEV's were calculated at a range of interest rates and used in with and without analyses of full rotations using an assumed planting cost of $125 per acre (Kronrad 1996b). The planting cost was assumed to be $125 per acre in analyses of both traditional and low density management in order to compare more uniform scenarios and avoid confounding evaluation of low density management by using a lower planting cost in comparison to traditional management.

RESULTS

Per Acre Labor and Equipment Costs

Per acre labor and equipment cost was calculated by multiplying hourly wage and the Social Security and benefit percentage by number of man-hours per acre, then adding the product of equipment cost per tree multiplied by trees per acre. Man-hours per acre were calculated by dividing number of trees per acre by number of trees pruned per worker per hour. For example, at 58 BA, a single worker pruned at a net rate of 12.125 trees per hour. With a mean of 190 trees per acre, pruning the acre would take 15.67 hours. At the $6.00 minimum hourly wage, 15.67 hours of labor costs $94.02 Social Security and benefits paid at the U.S. Department of Labor calculated rate of 19.95 percent on wages brings the total up to $112.82. Equipment use on 190 trees at a cost of $0.0171 per tree raises the total cost by $3.25 to $116.07 per acre (table 3).

Cost Per Tree

Cost per worker to prune a tree to 25 feet can be found by dividing total per acre pruning cost by trees per acre. To show separate components of total cost, the value was calculated by dividing the sum of hourly wage, Social Security and benefits, and hourly equipment cost by trees pruned per hour. Because hourly equipment cost was found by multiplying per tree equipment cost of $0.0171 by trees pruned per hour, the result was the same as dividing the sum of hourly wage and Social Security and benefits by trees pruned per hour and adding the per tree equipment cost. Hourly equipment cost is presented here as a point of interest. For example, at 58 BA, a single worker incurs a total cost of $7.41 including labor, benefits, and equipment use. Dividing the cost by the 12.125 trees the worker prunes in that hour shows a net cost of $0.61 per tree (table 4).

Break Even Values

Tables 3 and 4 present pruning costs in today's dollars. To find the future value of the costs carried to the end of the rotation, these values were compounded using a range of interest rates (table 8). Values in Table 8 represent the per acre dollar value increase at time of final harvest needed to break-even on a pruning investment. This means that the per acre dollar value of the final harvest must be increased by amounts shown in the table ($118.82 to $645.34) over that of like stands as a direct result of pruning. This dollar value increase may rise from production of additional merchantable board footage (from decreased "topwood") or from a premium paid for pruned stumpage.

Financial Analyses

In the case that landowners may consider implementation of low density management on a tract of bare ground today, soil expectation values for full rotations under both treatment options were calculated using a range of interest rates

Table O-Total cost per acre of pruning a 12-year-old loblolly pine plantation to 25 feet compounded 18 years using various Interest rates

	Interest rate (percent)			
Hourly wage	0.13	2.78	7.00	10.00
	-------------------Dollars-------------------			
6.00	118.82	190.14	392.31	645.34

Table 9—Per acre soil expectation values using medium stumpage prices and medium labor costs for full rotation length by management regime and interest rate

Stand treatment	Interest rate (percent) 0.13	2.78	7.00	10.00
	Dollars			
58 BA	259,893.68	8,652.23	1,839.32	775.96
Traditional management	171,800.64	5,242.07	897.50	284.53

(tables 8 and 9). Over the full rotation length low density management was more profitable than traditional management in all cases.

With and Without Analyses

With and without analyses yield a dollar value showing how profitable it is to implement a particular management option versus not implementing the option. Outcome of evaluating East Texas pine plantation management with low density treatments, versus a traditional management treatment (without low density management) is shown in Table 10.

Depending on interest rate, the profitability increase from low density management over traditional management ranged from $491.43 to $88,093.04 per acre on a perpetual series of full rotations. For example, landowners who could invest elsewhere at a real interest rate of 7.00 percent, but choose today to begin low density management on a tract of bare land, can expect to earn an additional $941.82 per acre over investment in traditional management for a series of perpetual rotations. As a moderate scenario, this figure is relative to current prices of $400.00 per MBF for sawtimber, $25.00 per cord for pulpwood, $6.00 per hour for labor, and 10.00 percent commission paid for marking and administration of a thinning or harvest operation.

DISCUSSION AND CONCLUSIONS

This study presents information at a range of interest rates in attempt to provide broadly applicable outcomes for a range of financial scenarios. The assumption should not be made that results of this study would be applicable to any species, pruned at any age, on any site in any region. To assess the potential profitability of low density management under those varied conditions, further research is necessary. Presently, no premium is offered to landowners selling pruned logs. Because of this, and in the interest of providing conservative figures, this study assumed no premium price allowance for pruned stumpage. It is reasonable to think that if low density management were to come into widespread common practice, industry would be willing to compensate landowners for the higher value of their wood. Although a reasonable expectation, landowners should be quite reluctant to engage in low density management without some guarantee of compensation. This study has considered values necessary to break even, but has not considered methods by which landowners may assure compensation for a pruning investment. Future research may investigate some type of certification system whereby landowners and industry were both guaranteed that logs from specified stands were pruned at a recorded size and age.

Ultimately, the profitability of low density management comes from the additional wood volume produced as a result of the reduced stems per acre. It must be noted, however, that fewer stems per acre alone cannot be used to produce merchantable wood volume since open grown pines are excessively knotty, making pruning a necessity. Therefore, these two management techniques must be practiced together to be effective. By these analyses, low density management was more profitable than traditional management in all cases.

Table 10—With and without analysis showing added profitability per acre of east Texas pine plantation management with low density management treatments and without low density management treatments under traditional management on perpetual rotation

Stand treatment	Interest rate (percent) 0.13	2.78	7.00	10.00
	Dollars			
58 BA	88,093.04	3,410.22	941.82	491.43
Traditional management	0.00	0.00	0.00	0.00

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EFFECTIVENESS OF IMAZAPYR AND METSULFURON IN CONTROLLING HARDWOODS IN A MIDROTATION LOBLOLLY PINE STAND[1]

Bruce R. Zutter[2]

Abstract-h the Piedmont of Alabama, a fall aerial application of imazapyr (0.50 lb ae ac^{-1}) and metsulfuron (0.60 oz ai ac^{-1}) in a IO-year-old loblolly pine (*Pinus taeda* L.) stand reduced hardwood stem density, stand basal area, and stand volume to 25, 22, and 16 percent of that without treatment two growing seasons after treatment. Efficacy was not influenced by fertilization (200 lb ac^{-1} N + 50 lb ac^{-1} P) in early spring after spraying. Mortality and percent reduction in height of tagged stems averaged 54 and 75 percent, respectively. Percent reduction in height of black cherry (*Prunus serotina* Ehrh.), dogwood (*Cornus* spp.), persimmon (*Diospyros virginiana* L.), and sweetgum (*Liquidambar styraciflua* L.) exceeded 85 percent. Height reduction of water oak (*Quercus nigra* L.) and southern red oak (*Quercus falcata* Michx.) averaged 49 and 62 percent, respectively, with no reduction for either eastern redcedar (*Juniperus virginiana* L.) or Florida maple (*Acer barbatum* Michx.). There was a slight tendency for mortality and reduction in height to increase with increasing hardwood height.

INTRODUCTION

Complete control of woody vegetation in midrotation southern pine stands has been shown to result in a significant gain in growth (Oppenheimer and others 1989, Pienaar and others 1983, Shiver 1994). Gains in merchantable volumes of 0.50 cd $ac^{-1}yr^{-1}$ and 0.33 cd $ac^{-1}yr^{-1}$ for eight or more years have been reported following complete control of woody vegetation in midrotation loblolly and slash (*Pinus elliottii* Engelm.) pine stands, respectively (Fortson and others 1998). The magnitude of such responses have resulted in the operational application of herbicides to control hardwoods and/or shrubs on thousands of acres of midrotation southern pine stands annually. Pine response has been shown to be inversely related to hardwood levels following release of two- to three-year-old pines (Quicke and others 1996, Zutter and others 1988) and stands past midrotation (Bower and Ferguson 1968, D'Anieri and others 1986). Thus, it is important to understand the level of control obtained with operational midrotation treatments in order to obtain some idea how yields might differ from values from studies using complete control treatments.

In 1995 members of the Auburn University Silvicultural Herbicide Cooperative (AUSHC) and the North Carolina State Forest Nutrition Cooperative (NCSFNC) initiated a region-wide study to examine the response of midrotation southern pine stands to operational vegetation control and fertilization. Through 1998 a total of 11 study locations have been established in loblolly or slash pine plantations. This paper summarizes the effectiveness of an operational application of imazapyr and metsulfuron in controlling hardwoods at the initial study location. Specific questions addressed include: 1) influence of fertilization on treatment effectiveness, 2) differences in susceptibility by hardwood species, and 3) differences in susceptibility by hardwood size (height).

METHODS

Site Description and Past History

The study site is located in Tallapoosa County, Alabama in the Piedmont physiographic region. Soils on the site are of an eroded phase of the Pacolet series. Following the harvest of a natural mixed pine-hardwood stand, the area was prepared for planting by drum-chopping and burning. Bareroot 1-O loblolly pine seedlings were hand-planted in 1986. The stand was completing its tenth growing season at the initiation of the study.

Study Design and Treatments

Treatments consisted of a factorial combination of two levels of operational vegetation control (none, treated) and two levels of operational fertilization (none, treated). Treatments were arranged in a randomized complete block design (RCBD) with three blocks. The vegetation control treatment consisted of 0.50 lb ae ac^{-1} of imazapyr (Arsenal AC, 16 oz product ac^{-1}) plus 0.60 oz ai ac^{-1} metsulfuron (Escort, 1 oz product ac^{-1}) in a water carrier. A spray volume of 15 gpa was applied by helicopter on September 19, 1995. Herbicide treated areas were a minimum of 150 ft wide (three swath widths) and 600 ft long. The fertilization treatment consisted of an application of 200 lb ac^{-1} of elemental N and 50 lb ac^{-1} of elemental P applied as diammonium phosphate (250 lb ac^{-1}) and urea (337 lb ac^{-1}). Fertilizer was applied by hand March 31 through April 1-4, 1996 to treatment areas of approximately 0.25 ac.

Hardwood Assessment and Analysis

Assessment of treatment effectiveness occurred on a single 0.1 ac measurement plot located within each treatment plot. All hardwood rootstocks taller than 4.5 ft in height were recorded by species, and d.b.h. (O.l-inch class and 0.5-inch classes thereafter) and height (1 -ft classes) noted for each stem > 4.5 ft in height. All stems within rootstocks $ 12 ft in height were tagged. In addition, hardwood rootstocks < 12 ft in height were tagged, recorded by species and stems tallied by d.b.h. and height class on six 7-ft radius subplots within each 0.1 ac measurement plot. Additional black cherry, sweetgum, southern red oak and water oak rootstocks < 12 ft in height were located throughout each measurement plot and each stem tagged and measured. Measurements were made prior to treatment and at the end of two growing seasons after treatment (two GSAT).

Analysis of data at the stand level consisted of computing a volume index (VI) for each sampled stem using the following

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formula: VI = **(d.b.h.*d.b.h./144 · height)/3.** Analysis of variance **(ANOVA)** appropriate for a two-factor RCBD was conducted on stem density, mean height (living stems), stand basal area, and stand volume index for stems > 4.5 ft in height at the initial and two GSAT measurements.

Analysis of data at the stem and species level (tagged hardwoods) consisted of first determining mortality and percent change in height ([height two growing seasons after treatment - initial **height]/initial** height * 100) on each plot. This was determined: 1) across all species and height classes, 2) by species across all height classes, 3) across all species by height class, and 4) by major species (black cherry, sweetgum, southern red oak, water oak) and height class. Height classes were: # 9 ft, 10 to 17 ft, and $ 18 ft, representing approximately less than one-third, one-third to two-thirds, and greater than two-thirds of average pine height at the time of treatment. **ANOVA** for a two-factor RCBD was conducted of response variables considered across all height classes and a split-plot **ANOVA** used for analyses considering height class as a factor (height class = subplot).

RESULTS AND DISCUSSION

Stand Level Response

Sweetgum, water oak, southern red oak, and black cherry comprised 73 percent of stand basal area and 68 percent of stem density at the initial assessment (table 1). Initial hardwood stem densities, stem height, stand basal area, and stand volume did not differ between levels of vegetation control or fertilization (table 2). Two growing seasons after treatment (two GSAT) there was also no effect of fertilization nor was the interaction between vegetation control and fertilization significant.

Effects of vegetation control two GSAT were highly significant (table 2). Values two GSAT for stem density, stand basal area, and stand volume index with vegetation control (VC only, VC + Fert) were only 25 percent, 22 percent, and 16 percent of that without vegetation control

Table l-Initial hardwood species composition

Species	Stand basal area		Stem density	
	$Ft^2\ ac^{-1}$	%	No. ac^{-1}	%
Sweetgum	5.7	*42*	*1,102*	*35*
Water oak	2.3	*16*	*601*	*19*
So. red oak	1.3	*9*	*304*	*10*
Black cherry	.8	*6*	*128*	*4*
Red maple	.4	*3*	*142*	*4*
Florida maple	.3	*2*	*136*	*4*
Dogwood	.3	*2*	*64*	*2*
Eastern redcedar	.3	*2*	*39*	*1*
Persimmon	.2	*2*	*35*	*1*
Others	*2.0*	*16*	*618*	*20*
Total	*13.6*	*100*	*3,169*	*100*

(Check, Fert only), respectively. An alternative means of expression is in terms of percent control with respect to the check- 75 percent, 78 percent, and 84 percent control for stem density, stand basal area, and stand volume index, respectively. Stems surviving the vegetation control treatment averaged nearly 4 ft less in height (table 2).

Stand volume index is perhaps the meaningful measure of effects of vegetation control as it incorporates the effects of mortality and reduction in height and/or diameter growth of surviving hardwoods. It is likely that volume index is more highly correlated with resource use than density or basal area. Stem density, stem height, stand basal area, and stand volume increased without vegetation control, suggesting an increasing demand for resources by hardwoods with increasing stand age.

Stem/Species Level Response

For all analyses at the stem/species level (tagged hardwoods) there was no interaction of vegetation control and fertilization and no effect of fertilization ($p < 0.10$). Thus, all summaries of results will be presented in terms of the main effect of vegetation control (i.e. averaged over levels of fertilization).

Mortality across all species two GSAT was significantly lower with vegetation control than without vegetation control, 54 percent versus four percent, respectively. However, effects of vegetation control treatment differed greatly by species (table 3). Mortality of black cherry and persimmon each exceeded 90 percent and dogwood and **sweetgum** each exceeded 70 percent two GSAT. Mortality of oaks was low, but statistically significant, averaging only 17 and 31 percent for water oak and southern red oak respectively. No mortality was noted for either eastern **redcedar** or Florida maple.

Effects of vegetation control expressed in terms of percent change in height were of greater magnitude than that for mortality (table 3), a decline of 75 percent with vegetation control and an increase of 13 percent without vegetation control across all species two GSAT. Mean height of tagged black cherry, dogwood, persimmon, and **sweetgum** all declined by 85 percent or more two GSAT. Water oak and southern red oak mean heights declined by 49 and 62 percent, respectively. Eastern **redcedar** and Florida maple increased in mean height with vegetation control.

Mean height of surviving stems two GSAT was significantly lower with vegetation control for each species except eastern **redcedar** and Florida maple. Differences in height two GSAT due to treatment ranged from about 5 ft for less susceptible species such as the oaks to seven or more feet for the more susceptible species such as black cherry, dogwood, sweetgum, and persimmon. In the absence of vegetation control, mean height increased an average of 2.2 ft, ranging 0.9 to 3.9 ft depending upon the species.

Influence of Hardwood Size (Height) on Response

Effects of fertilization and interactions of fertilization with either vegetation control or hardwood height were not significant ($p < 0.10$) in the analysis of the effects of hardwood height on herbicide effectiveness. The effect of vegetation control on mortality and percent change in height was dependent upon the initial height (size) of the hardwoods. The interaction between the level of vegetation

Table 2-Mean hardwood stem density, stem height, stand basal area, and stand volume index pre-treatment (initial) and two growing seasons after treatment (2 GSAT); and tests of the effects of vegetation control (VC), fertilization (Fert), and the interaction (VC x Fert)

	Stem density		Stem height		Stand basal area		Stand volume index	
Treatments	initial	2 GSAT	initial	2 GSAT	initial	2 GSAT	initial	2 GSAT
	Stems ac^{-1}		*Feet*		*$Ft^2\ ac^{-1}$*		*$Ft^3\ ac^{-1}$*	
Check	3,239	3,308	11.3	12.6	13.6	18.5	123	186
VC only	2,263	767	12.5	8.8	11.0	3.5	98	24
Fert only	2,514	2,751	11.3	12.9	10.8	16.4	94	162
VC + Fert	2,539	746	12.1	9.1	12.1	4.2	109	32
Main effects and interaction	*Probability > F-value*							
VC	0.419	<0.001	0.190	<0.001	0.984	<0.001	0.843	<0.001
Fert	.525	.154	.865	.606	.682	.508	.832	.782
VC x Fert	.408	.376	.381	.399	.416	.596	.333	.625

control and hardwood height was significant for percent change in height (p = 0.003) and nearly significant for mortality (p = 0.115) when considering effects on ail species together (tables 4 and 5). As hardwood height increased, mortality tended to decline in the absence of vegetation control and increase with vegetation control (table 4). Greater mortality of hardwoods in the lowest height class in the absence of herbicide treatment is likely to have been strongly influenced by lower light availability due to their position well below the main canopy of pine and large hardwoods. The very high mortality of black cherry (26 percent), a shade intolerant species, would seem to support the importance of light. Mortality of both southern red and water oak following vegetation control tended to increase with increasing height class, a range of about ten percentage points, but the trend was not statistically significant.

Percent change in height became more positive (i.e. growth increased) without vegetation control and more negative with vegetation control as hardwood height increased (table 4). As hardwood height increases, an increasing proportion of the crown is in the mid- to upper part of the canopy which should increase interception of light as well as interception of herbicide applied above the pine canopy.

The effect of vegetation control on mean stem height two GSAT was dependent upon hardwood height (p < 0.001 for VC x height, table 5). Mean height across ail species was lower with vegetation control in each height class, but the magnitude of the decrease was greater with increasing height class: 3.0 ft, 8.0 ft, and 13.4 ft from the lowest to highest height class (table 4). Similar patterns were noted for each of the major species. With vegetation control, mean height of surviving oaks two GSAT tended to be greater than that for sweetgum or black cherry across ail height classes (table 4). in the absence of vegetation control, height growth over the two GSAT increased with increasing height class. Height growth of black cherry and sweetgum was 2 to 3 ft greater than that for either oak species in the upper two height classes (1 O-l 7 ft, $18 ft) and comparable in the lowest height class (# 9 ft) (table 4).

Table 3—Mean hardwood stem mortality (Mort), percent change in stem height two growing seasons after treatment (2 GSAT), and Initial and 2 GSAT stem height by level of vegetation control (VC)

Species	Treatment	Mort	Change in height[b]	Stem height* Initial	Stem height* 2 GSAT
		------- Percent -------		---------- Feet ----------	
All	No VC	4''	+ 13*	12.7	14.9*
	VC	54	- 75	13.3	7.1
Black cherry	No VC	2*	+ 24*	14.6	18.5*
	VC	90	- 94	14.5	7.6
Dogwood	No VC	0*	+ 12*	12.6	14.4*
	VC	77	- 86	11.1	7.2
Eastern redcedar	No VC	0	+ o	0.0	10.0
	VC	0	+ 18	9.3	11.0
Florida maple	No VC	0	+ 19	12.3	14.7
	VC	0	+ 10	12.9	14.1
Persimmon	No VC	11*	+ 7*	11.7	14.3*
	VC	93	- 96	13.6	8.0
So. red oak	No VC	4	+ 5*	9.9	10.9*
	VC	31	- 62	10.8	6.1
Sweetgum	No VC	2*	+ 19*	13.3	16.1*
	VC	71	- 89	13.7	5.0
Water oak	No VC	3*	+ 4*	11.8	12.7'
	VC	17	-49	12.6	7.7

[a] Includes only living stems.
[b] Includes all tagged stems two GSAT, living and dead.
[c] An asterisk denotes a significant difference ($p < 0.05$) in means for no vegetation control (No VC) and vegetation control (VC) for a given species and response variable.

SUMMARY AND CONCLUSIONS

The fall operational application of imazapyr and metsulfuron reduced hardwood abundance by 75 to 85 percent depending upon the measure of abundance. In the absence of data on long-term response of loblolly pine to operational midrotation vegetation control, forest managers may wish to multiply the loblolly pine responses from complete vegetation control reported by Fortson and others (1996) by 0.75 to 0.85 to estimate potential growth response on sites with similar hardwood competition. Poorer control of oaks compared to sweetgum, black cherry, dogwood, and persimmon suggests that pine responses to the imazapyr-metsulfuron combination will be less on sites with a higher component of oaks in the stand than the approximate 25 percent observed in this study.

Table 4-Mean hardwood stem mortality (Mot-t), percent change in stem height two growing seasons after treatment (2 GSAT), and initial and 2 GSAT stem helght by level of vegetation control (VC) and initial height class

Treatment	Initial height class	Mort	Change In height[b]	Stem height[a] Initial	Stem height[a] 2 GSAT	Mort	Change In height	Stem height Initial	Stem height 2 GSAT
		---Percent---		---Feet---		----Percent----		----Feet----	
				All species					
No VC	≤ 9	11	+ 3	5.5	8.4				
	I0-17	2	+ 11	13.4	15.4				
	$18	0	+ 18	20.4	24.3				
VC	≤ 9	53	- 71	5.5	3.4				
	I0-17	50	- 73	13.6	7.4				
	$18	60	- 79	20.9	10.9				
				Black cherry				So. red oak	
No VC	≤ 9	26	+ 15	4.4	4.9	5	+ 5	5.9	6.6
	I0-17	0	+ 25	14.1	17.8	4	+ 2	12.5	13.4
	$18	0	+ 23	20.9	25.7	0	+ 13	19.5	21.9
VC	≤ 9	94	- 97	5.8	2.0	27	- 68	5.7	2.6
	I0-17	94	- 97	13.6	6.1	35	- 68	13.2	5.9
	$18	73	- 82	20.6	9.3	38	- 64	19.6	9.1
				Sweetgum				Water oak	
No VC	≤ 9	6	+ 18	5.0	6.2	7	+ 1	6.4	7.0
	I0-17	1	+ 17	13.5	16.0	1	+ 4	13.0	13.7
	$18	0	+ 20	20.7	25.1	0	+ 4	20.0	21.7
VC	≤ 9	72	- 86	5.5	2.5	19	- 49	5.9	3.7
	I0-17	70	- 88	13.7	5.1	16	- 47	13.2	8.1
	$18	72	- 91	20.9	7.1	29	- 55	19.9	12.7

[a] Includes only living stems.
[b] Includes all tagged stems two GSAT, living and dead.

Table 5—Results of statistical tests of main effects of vegetation control (VC), initial hardwood height class (Height) and the interaction (VC x Height) for mean hardwood stem mortality (Mort), percent change in stem height two growing seasons after treatment (2 GSAT), and initial and 2 GSAT stem height

Treatment	Initial height class	Mort	Change In height[b]	Stem height[a] Initial	Stem height[a] 2 GSAT	Mort	Change In height	Stem height Initial	Stem height 2 GSAT
	- Probability > F-value	*- -*							
		All species							
VC	~0.001	<0.001	0.226	<0.001					
Height	.420	.442	< .001	< .001					
VC x height	.115	.003	.513	< .001					
		Black cherry					So. red oak		
VC	< .001	< .001	.585	< .001		0.067	~0.001	0.244	~0.001
Height	.120	.817	< .001	< .001		.821	.787	< .001	.001
VC x height	.430	.273	.388	< .001		.814	.787	.510	.146
		Sweetgum					Water oak		
VC	< .001	< ,001	.461	< .001		.020	< .001	.862	< .001
Height	.555	.816	< .001	< .001		.426	.585	< .001	< .001
VC x height	.656	.530	.917	< .001		.190	.528	.428	.001

[a] Includes only living stems,
[b] Includes all tagged stems two GSAT, living and dead.

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INFLUENCE OF INTENSIVE CULTURE ON WATER RELATIONS OF LOBLOLLY PINE[1]

Price C. McLemore III, Lisa J. Samuelson, Tom A. Stokes, and Tom Cooksey[2]

Abstract-The influence of irrigation and liquid fertilization (fertigation) on predawn and midday leaf water potential, and leaf osmotic potential at the turgor loss point and at full saturation was examined in four-year-old loblolly pine (*Pinus taeda* L.) grown under intensive culture for four years. Our objective was to determine if intensive culture would increase drought resistance of young plantation grown loblolly pine. Results indicated that neither fertigation nor irrigation significantly enhanced osmotic adjustment over control treatments.

INTRODUCTION

Most research concerning intensive culture and physiological function has been done on seedlings in greenhouse studies. Forest stand experiments with irrigation and fertilization are usually done to measure increased biomass production. Since irrigation and fertigation are potentially realistic forms of stand management in the future, more knowledge about the physiology of these systems is needed.

Our objective was to examine tree water relations in response to intensive culture in a four-year-old loblolly pine plantation. Because increased photosynthesis may increase photosynthate accumulation, we hypothesized that fertigation would enhance osmotic adjustment. Increased photosynthesis in response to resource manipulation has been reported for pine species. For example, Linder (1987) reported a 20 percent increase in the rate of light saturated net photosynthesis using fertigation on *Pinus sylvestris* L. in Sweden. Murthy and others (1998) also reported significantly higher rates of photosynthesis for certain months in loblolly pine due to irrigation and fertigation. Samuelson (1998) reported increased rates of photosynthesis for 1-year-old loblolly pine in response to irrigation and fertigation. Regimes promoting high nutrient and light availability may promote high carbon assimilation rates and may promote the acquisition of osmotica (Abrams 1988).

STUDY SITE

The study is maintained by International Paper Company and located in the Upper Coastal Plain 22 km west of Bainbridge, Georgia. The study was arranged using a randomized complete block design with three blocks. Treatment plots (0.20 ha) were hand-planted in January 1995 with one-year-old bareroot loblolly pine seedlings using a 2.4 m x 3.7 m spacing. All trees measured were improved, second generation, half sibs from 1 family. This is the same site as described by Samuelson (1998).

METHODS

Complete weed control was the only treatment applied in control plots. Irrigation plots were maintained with complete weed control and drip irrigation on a yearly basis, in 1998: 24 l day^{-1} tree^{-1}. Fertigation plots were maintained with complete weed control and drip irrigation with a fertilizer solution of NH_4NO_3 and urea, H_3PO_4, and K_2O applied seasonally. In 1998 N, P, and K were supplied at rates of 135, 33, and 130 kg ha^{-1} yr^{-1}, respectively. A detailed description of cultural treatments was presented by Samuelson (1998).

Shoots from the mid canopy were removed from two randomly selected trees per treatment per block. Each shoot was clipped from a tree, cut again underwater, and left in a container in the dark to rehydrate. Excision dates were August 18, August 26, and September 16, 1998. Pressure volume curves were developed using passive dehydration and a pressure chamber on August 17 and 18, August 27 and 28, and September 17 and 18. Due to the large number of samples, two different dates were used making rehydration times vary between 18 to 42 hours. Measurements were conducted by block so that rehydration times were similar across treatments. Osmotic potential at full turgor (OPIOO), osmotic potential at zero turgor (OPO) and relative water content at zero turgor (RWCO) were calculated. Predawn water potential (WPpd) and midday water potential (WPmd) were measured using needles from the mid to upper canopy. WPpd measurements were recorded on July 6, August 16, August 26, and September 16, 1998 on 2 to 6 trees per treatment plot. WPmd measurements were recorded on July 6, August 16, and August 26, 1998 on 2 to 6 trees per treatment plot. Data were analyzed by date using a randomized complete block design.

RESULTS AND DISCUSSION

No significant ($P<0.05$) differences in RWCO, OPO, OPIOO were observed on any measurement date (fig. 1-3). Across all treatments, OPIOO ranged from -1.11 to -1.43 MPa and OPO ranged from -1.9 to -2.5 MPa. An average OPIOO of -1.64 MPa and OPO of -2.59 MPa was previously reported for foliage collected from a loblolly pine tree in January and February (Neufeld and Teskey 1986).

In July, WPmd was lowest in the control treatment and in August WPmd was lower in the irrigated than in the fertigated treatment (fig. 4). Across the growing season, WPpd was lower in the control versus irrigated treatments (fig. 5). Higher RWCO in September may be a function of reduced water stress in all treatments. Across all treatments, trees were operating within 0.1 to 0.7 MPa of the turgor loss point. In August 28, the control treatment had the largest difference between WPmd (-1.8 MPa) and OPO (-2.5 MPa). Irrigation increased WPpd, but irrigation and fertigation had no influence on osmotic adjustment.

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18. 1999.

[2] Graduate Research Assistant, Associate Professor, and Research Specialist, Auburn University, AL 36849; and Research Forester, International Paper, Bainbridge, GA 31717, respectively.

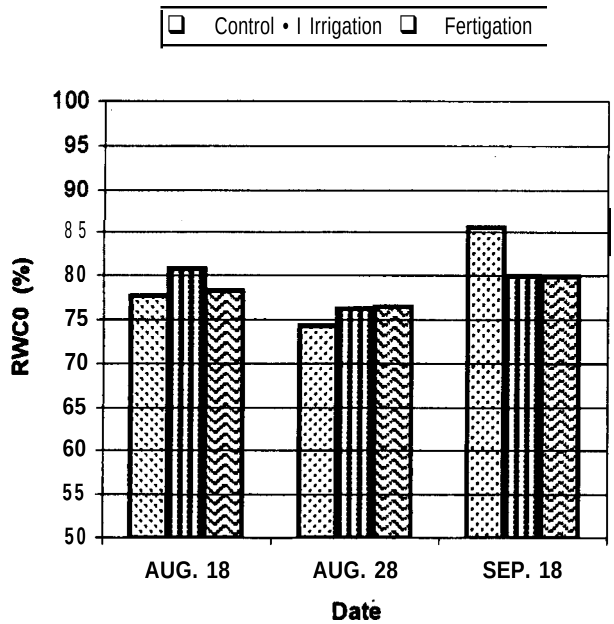

Figure l-Influence of intensive culture on relative water content at the turgor loss point (RWCO) of **4-year-old** loblolly pine during the 1998 growing season.

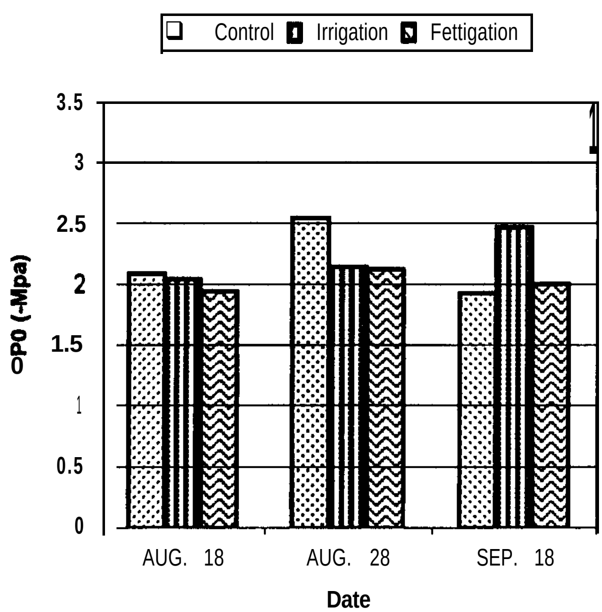

Figure 2-Influence of intensive culture on osmotic potential at the turgor loss point (OPO) of **4-year-old** loblolly pine during the 1998 growing season.

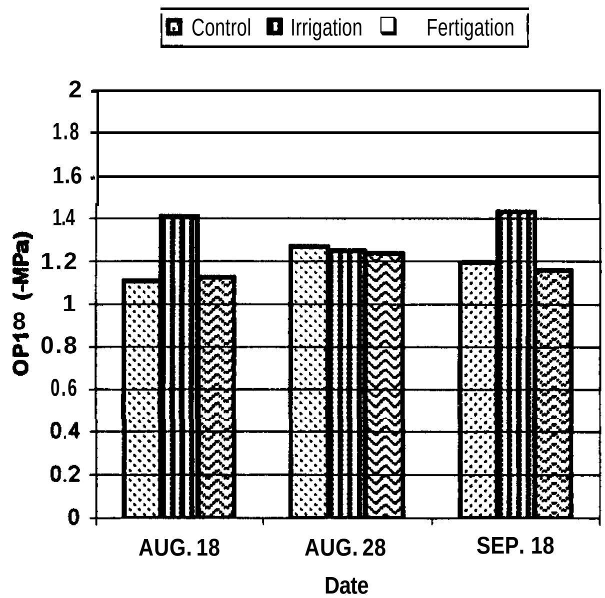

Figure **3—Influence** of intensive culture on osmotic potential at full saturation **(OP100)** of **4-year-old** loblolly pine during the 1998 growing season.

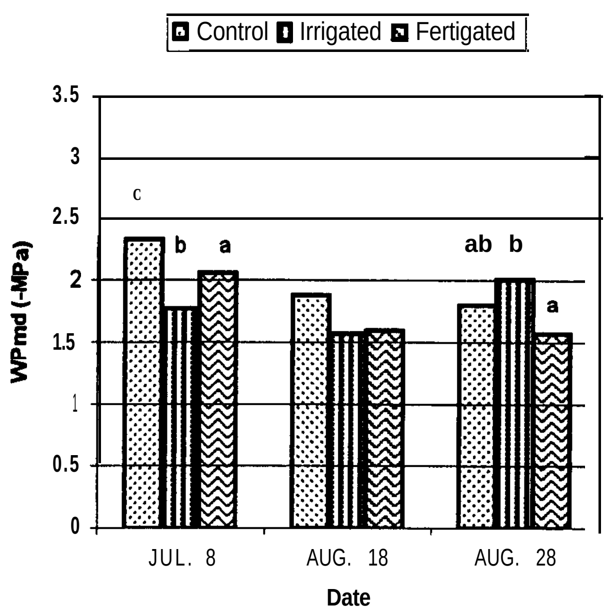

Figure **4—Influence** of intensive culture on midday osmotic potential **(WPmd)** of **4-year-old** loblolly pine during the 1998 growing season.

Dosskey and others (1993) tested irrigated Douglas-fir seedlings under differing regimes of phosphorous fertilization for increased growth and drought resistance. Irrigation and irrigation with differing amounts of phosphorous fertilization did not significantly enhance osmotic adjustment. Stewart and Lieffers (1993) examined the influence of drought, irrigation, and fertilization on drought resistance in lodgepole pine **(*Pinus contorta*** Dougl. ex Loud.) seedlings. No treatment effects on osmotic adjustment were detected. Kleiner and others (1992) conducted a greenhouse study on red oak *(Quercus* ***rubra*** L.) and chestnut oak *(Quercus* ***prinus*** L.). They determined that drought tolerance was not improved by increased nutrient availability. Values for **OP100,** OPO, **WPpd,** and **WPmd** reported for these two oak species were similar to our loblolly pine values, though RWCO values of red oak and chestnut oak were marginally higher.

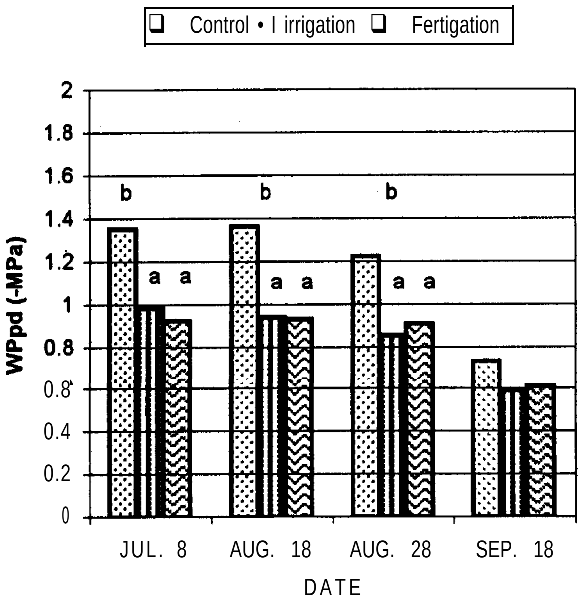

Figure 5—Influence of intensive culture on predawn osmotic potential (WPpd) of 4-year-old loblolly pine during the 1998 growing season.

In conclusion, irrigation and fertigation did not significantly increase osmotic adjustment in four-year-old plantation grown loblolly pine perhaps because leaf net photosynthesis was not increased by fertigation the fourth growing season. However, leaf area accumulation was approximately doubled in response to fertigation after four growing seasons. Alternatively, despite greater leaf area and lack of drought conditioning in fertigated trees, osmotic potential at the turgor loss point was similar between control and fertigated treatments. Thus, control trees that were exposed to drought throughout the growing season were not more drought tolerant. These results indicate that intensive culture does not affect drought tolerance through osmotic adjustment in loblolly pine.

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RESPONSE OF A MIDROTATION SLASH PINE STAND TO HEXAZINONE[1]

Bruce R. Zutte?

Abstract-h 1980, a study was established in a 12-year-old slash pine (*Pinus elliottii* Engelm.) stand on an excessively drained site in Chesterfield County, South Carolina to examine the effectiveness of hexazinone in reducing woody competition and subsequent pine growth response to decreased woody competition. Treatments included three pelleted formulations of hexazinone (2 cc, 1 cc, and ½ cc pellets (Velpar® Gridball')) each applied at a rate of 1.4 ai ac^{-1} and an untreated check. No significant differences were noted among hexazinone formulations in effects in reducing woody competition or effects on pine response. Hardwood density and basal area were 35 percent and 20 percent lower, respectively, with hexazinone treatment four growing seasons after treatment (four GSAT). Hexazinone treatment had no significant effect on height growth over four GSAT. However, hexazinone treatment increased growth in d.b.h., stand basal area, and stand volume over the four GSAT. The increase in merchantable volume growth averaged approximately 1/3 cord $ac^{-1} yr^{-1}$.

INTRODUCTION

Although most of the midrotation release of southern pines in the Southeast is done using imazapyr, hexazinone is another herbicide that may give effective results on some sites. With proper prescription based on surface soil texture, soil organic matter content and stand age, hexazinone has been shown to provide effective control of hardwoods in young slash and loblolly pine (*Pinus taeda* L.) plantations without significant pine mortality (Glover and others 1991, Haywood 1995a, Long and Flinchum 1992, Minogue and others 1988, Quicke and others 1996, Zutter and others 1988).

This paper examines hardwood control and pine response from an operational rate of three formulations of hexazinone in a midrotation slash pine stand on an upland site. Four years of data were gathered following treatment and prior to a wildfire which destroyed the stand.

METHODS

Site Description and Past History

The study site is located in Chesterfield County, South Carolina in the Sandhills physiographic region. Surface soils are of a loamy sand texture. Following the harvest of a natural longleaf pine-hardwood stand, the area was prepared for planting by drum-chopping and burning. Bareroot 1-O slash pine seedlings were machine-planted in 1969. The stand was beginning its twelfth growing season at the initiation of the study.

Study Design and Treatments

Treatments consisted of three solid formulations of hexazinone (2 cc, 1 cc and ½ cc pellets (Velpar® Gridball")) applied at a rate of 1.4 lb ai ac^{-1}, and an untreated check. Treatments were applied to 0.15 ac plots and arranged in a randomized complete block design with four blocks.

Vegetation Assessment and Analysis

Pines were assessed on 0.1 measurement plots centered within each treatment plot. Height and d.b.h. were measured on each pine at treatment and four growing seasons after treatment. Initial assessment of competing woody vegetation was done on four 6.6-ft radius subplots in each 0.1 ac pine measurement plot. Rootstocks of hardwoods and shrubs ≥ 1 ft tall were recorded by species (or species group) and height (1-ft classes), and groundline diameter (0.5inch classes) noted for each stem. At the end of the first growing season an ocular estimate of the percent of the crown without foliage, or crown reduction, was made on each rootstock. At the end of the fourth growing season after treatment hardwoods and shrubs were measured on the entire 0.1 ac pine measurement plot. Species, d.b.h. class (l-inch), height class (IO-ft classes) were noted for each hardwood stem. Shrubs were recorded by rootstock and species and height class (IO-ft classes) noted for each rootstock.

Competing vegetation data were analyzed using ANOVA appropriate for a randomized complete block design. Pine response four growing seasons after treatment (four GSAT) was analyzed using analysis of covariance with initial values used as a covariate. Contrasts were developed to examine: 1) mean of hexazinone treatments to the untreated check, and 2) effect of hexazinone pellet size.

RESULTS AND DISCUSSION

Competing Vegetation

Competing hardwood and shrub vegetation was simple, being comprised of turkey oak and *Vaccinium* spp. Initial abundance of turkey oak and *Vaccinium* spp. did not differ among treatments. Turkey oak was more dominant as a competitor than *Vaccinium* spp. based on its greater height and abundance (table 1).

For turkey oak, crown reduction one GSAT was significantly greater, and stem density and stand basal area four GSAT were significantly lower with hexazinone treatment (table 2). Stem density and basal area of turkey oak with the hexazinone treatment averaged 35 percent and 20 percent, respectively, of the untreated check four GSAT. No differences were noted in effects on turkey among pellet sizes. Hexazinone had no significant effects on crown reduction or abundance of *Vaccinium* spp. These results are consistent with results from other studies (Haywood 1995b, Boyd and others 1995, Zutter and others 1988).

Pine Response

Mortality of slash pine averaged less than three percent over the four GSAT and did not differ between the hexazinone treatment and the untreated check or among pellet sizes.

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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Table I-Initial stand attributes

Attribute	Slash pine	Turkey oak	*Vaccinium* spp.
Height (ft)	25	10	4
D.b.h. (in.)	3.7	—[a]	—
Basal area[b] (ft^2 ac^{-1})	43	40	1
Stocking (stems ac^{-1})	504	2,031	380
Volume (ft^3 ac^{-1})	540	—	—

[a] No data.
[b] Basal area at groundline for turkey oak and *Vaccinium* spp.

Mean height growth averaged 0.7 ft greater with hexazinone treatment compared to the check, however the difference was not statistically significant (table 3). There was also no effect of pellet size on height growth. D.b.h., stand basal area, and stand volume were each significantly greater with hexazinone treatment and did not differ among pellet sizes. Application of hexazinone resulted in average increase in pine basal area of 6 ft^2 ac^{-1} and a decrease in turkey oak basal area of 7 ft^2 ac^{-1}, a "trade off" of approximately 1 :1. The increase in stand volume with hexazinone averaged 40 ft^3 ac^{-1} yr^{-1} total volume outside bark or about 1/3 cord ac^{-1} yr^{-1} in merchantable volume, a response similar to that noted by Shiver (1994) over 14 years following treatment.

SUMMARY AND CONCLUSIONS

Application of a proper rate of hexazinone pellets on an excessively drained site reduced hardwood stand basal area four growing seasons after treatment to only 20 percent of that without treatment. This reduction yielded a merchantable volume response of approximately 1/3 cord ac^{-1} yr^{-1}. Based on four-year results of Pienaar and others (1983) and fourteen-year results of Shiver (1994) on the Pienaar and others(1983) study, this response might have continued for an additional ten years if a wildfire had not destroyed the stand four growing seasons after treatment. It is extremely important that hexazinone rate is prescribed accurately based on soil factors such as surface texture and organic matter content. Thus, rate may need to vary across a site if there is a significant change in those soil factors and a forest manager wishes to obtain good hardwood control without pine mortality as noted by Minogue and others (1988) and Glover and others (1991). Although the pelleted formulations used in this experiment are no longer available, liquid (Velpar L®) and soil formulations (Velpar ULW® and others) are currently available for use.

Table 2-Mean first-year crown reduction, and stand basal area and density four growing seasons after treatment for hardwoods and shrubs by treatment; and results of contrasts comparing mean hexazinone response to untreated check and effect of hexazinone pellet size (overall, linear, quadratic)

	Turkey oak			*Vaccinium* spp	
Treatments	Crown reduction	Basal area	Stem density	Crown reduction	Rootstock density
	Percent	*Ff ac⁻¹*	*No. ac⁻¹*	*Percent*	*No. ac⁻¹*
2 cc pellet	89	1.5	159	0	25
1 cc pellet	96	1.0	255	0	135
½ cc pellet	90	2.9	321	2	75
Check	1	9.3	695	0	160
Contrast	*Probability of > F-value*				
Hex vs check	< .001	< .001	.001	.881	.154
Pellet size	.432	.403	.474	.795	.750
- Linear	.734	.458	.594	.940	.647
- Quad	.222	.265	.281	.765	.588

Table 3—Slash pine height, d.b.h., basal area, and volume growth over four growing seasons by treatment; and results of contrasts comparing mean hexazinone response to untreated check and effect of hexazinone pellet size (overall, linear, quadratic)

Treatment	Height	D.b.h.	Basal area	Total volume OB
	Feet	*inches*	*Ft² ac⁻¹*	*Ft³ ac⁻¹*
2 cc pellet	4.8	0.98	*23.3*	*577*
1 cc pellet	3.7	.94	*21.7*	*498*
½ cc pellet	4.2	.94	*21.1*	*479*
Check	*3.5*	.73	*18.8*	*381*
Contrast	- - - - - - - - *Probability of > F-value* - - - - - - -			
Hex vs check	.170	< .001	.006	.006
Pellet size	.298	.830	.577	.284
- Linear	.296	.561	.316	.128
- Quad	.245	.896	.912	.769

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Pine Fertilization

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HERBICIDE AND FERTILIZER COMBINATIONS FOR NEWLY PLANTED LOBLOLLY PINE SEEDLINGS ON A FLATWOODS SITE IN SOUTHEASTERN ARKANSAS: YEAR THREE RESULTS[1]

Jimmie L. Yeiser[2]

Abstract-Herbicide and fertilizer combinations were tested for enhanced loblolly pine (*Pinus taeda* L.) seedling performance on a chemically prepared, flatwoods site in southeastern AR. Fertilizer treatments were selected combinations of 40, 50, and 50 pounds per acre of elemental N, P, or K, respectively. Arsenal+Oust (4 ounces+2 ounces per treated acre) was applied for herbaceous weed control (HWC). One treatment of herbicide or herbicide+ fertilizer was applied per year; the same rate was used for years one (1996) and two (1997). After three growing seasons, the greatest seedling volume resulted from two treatments of HWC+NPK fertilizer. Two treatments of HWC alone provided 80 percent and one treatment of HWC achieved 67 percent of the best volume. Of plots receiving year one treatments only, HWC produced the greatest year-three seedling volume. Post-treatment herbaceous biomass was greatest on untreated checks and plots receiving NPK fertilizer.

INTRODUCTION

Public land management continues to emphasize non-timber values, shifting a greater proportion of society's demand for fiber to private lands. In response, managers seek refinement of old and development of new technologies to increase the productivity of timberlands. Vegetation management and fertilization are two technologies that potentially increase yields.

OBJECTIVE

The objective of this study was to control herbaceous weeds and fertilize newly planted loblolly pine (*Pinus taeda* L.) seedlings for one or two growing seasons after planting and record resultant growth of seedlings and returning herbs.

METHODS

A flatwoods site in southeastern AR (Bradley County) near Vick was selected for testing. The site was clearcut during the summer of 1995 and followed in August with a helicopter application' of Accord+Arsenal (2 quarts + 12 ounces) per acre. The site was burned approximately eight weeks after treatment and in February 1996 hand planted with bare-root loblolly pine seedlings on an 8-feet X IO-feet spacing. Analysis at study Initiation indicated the Myatt-Kalmia complex, a mound phase silty clay loam soil (Larance 1961), had a pH of 5.3 with 10 pounds and 50 pounds per acre of P and K, respectively.

Test treatments are as follows.

1. Check-no herbaceous weed control (HWC) or fertilizer.
2. HWC in year one. No fertilizer.
3. HWC in years one and two. No fertilizer.
4. HWC and 50 pounds per acre of elemental P-fertilizer in year one.
5. HWC and 50 pounds per acre of elemental P-fertilizer in years one and two.
6. HWC and 40 pounds and 50 pounds per acre of elemental - and P-fertilizer, respectively, in year one.
7. HWC and 40 and 50 pounds per acre of elemental - and P-fertilizer, respectively, in years one and two.
8. HWC and 40 pounds, 50 pounds, and 50 pounds per acre of elemental N-, P-, and K-fertilizer, respectively, in year one.
9. HWC and 40 pounds, 50 pounds, and'50 pounds per acre of elemental N-, P-, and K, fertilizer, respectively, in years one and two.

A herbicide mixture of Arsenal + Oust (4 ounces + 2 ounces per treated acre) was applied annually durlng year one (May 2, 1996) or years one and two (May 9, 1997) for control of herbaceous competitors. Herbicide was applied as an early post-emergent (< 2 Inches tall) treatment using a CO_2 backpack sprayer and hand-held ``T" boom with four, 8002 nozzles. Herbicide was mixed with water until the total application volume was 10 GPA. Volunteer pines were cut from all plots and hardwood sprouts treated with a cut-surface application of concentrated Garlon 4.

Commercial fertilizer was manually applied annually during year one (May 8, 1996) or years one and two (May 13, 1997). Fertilizer was applied at 40, 50 and 50 pounds per acre of elemental N, P, and K, respectively. First-year herbicide and fertilizer were applied in bands six feet wide and centered over-the-top of seedlings. Second year herbicide and fertilizer applications were broadcast over the entire treatment plot. The same rate and elements were applied both years on plots receiving fertilizer.

Treatment plots were installed in April 1996 and consisted of seven rows with eight seedlings per row. Measurement plots were the internal five rows with six seedlings per row, leaving a single row surrounding each plot as the buffer. Only seedlings in measurement plots were used for analysis.

Herbaceous biomass response to treatments was monitored. Three, 2- X 2-feet wooden squares were randomly located within each measurement plot. Biomass was clipped in early July of the first, second, and third growing seasons. Samples were oven dried and dry weights converted to dry tons per acre. Because year one HWC was

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in bands, year one biomass samples were restricted to the treated bands only. Year two sampling occurred throughout the measurement plot.

All seedlings were measured in April 1996 for initial height and ground line diameter (GLD) and again in November after one, two, and three (DBH) growing seasons. Height measurements were recorded in centimeters and converted to inches (initial, age one and two) and to feet (age three). GLD at initial, and after one and two growing seasons plus DBH at age three were recorded in centimeters and converted to inches for this manuscript. Volume at ages one and two was computed as (total height)(total GLD)^2 and expressed in cubic inches (in^3). Age three volume, reported in cubic feet (ft^3), was computed as (total height)(0.005454 total DBH^2).

This is a 2 X 3 X 2 incomplete factorial experiment with two timings of application, three fertilizers, and two timings of HWC. Treatments were assigned according to a randomized complete block design with four blocks. Data were analyzed in an analysis of variance with means separated using Duncan's New Multiple Range test. All tests were conducted at the $p=0.05$ level.

RESULTS AND DISCUSSION

Rainfall following herbicide application and throughout the first growing season (summer 1996) was ideal for efficacious weed control and seedling growth. HWC provided 95 percent weed-free growing conditions until 90 days after treatment when asters, grasses, and sedges such as common ragweed *(Ambrosia artemisiifolia)*, tickseed sunflower *(Bidens aristosa)*, fireweed *(Erechitites hieracifolia)*, dogfennel *(Eupatorium spp.)*, false boneset *(Kuhnia eupatorioides)*, goldenrod *(Solidago* spp.), crabgrass *(Digitaria* spp.), panicums *(Panicum* spp.), paspalums *(Paspalum spp.)* and sedges *(Carex* spp. *Cyperus* spp.) re-invaded test plots. Legumes (partridge pea *(Cassia* spp.), beggar lice *(Desmodium* spp.), lespedeza *(Lespedeza* spp.), and wildbean *(Strophostyles* spp.) were tolerant to herbicides and increased in prevalence over the two growing seasons. Late in the season, species of groundcover *(Hype&urn* spp., *Rhexia* spp. and *Polypremum* spp.) commonly invaded plots. Differences in herbaceous vegetation on treatment plots were apparent the year following treatment (for both timings). Visually, there appeared to be an increased early-prevalence of sedges (Carex *spp.; Cyperus* spp.), followed by increased *Andropogon* spp. and a general increase in the quantity of herbaceous biomass. Rainfall during the summer of 1997 was below average for July, August, September, although average for the year.

Survival

Survival was excellent at 92 percent or higher for all treatments after three growing seasons (table 1). No statistical differences were detected.

FM-Year Growth

Best total height was achieved with HWC; check seedlings were numerically the shortest (table 1). Largest ground line diameters were recorded on plots receiving HWC alone or HWC plus P fertilizer. Greatest volume was observed for seedlings treated for HWC alone. All treatments provided more ground line diameter and volume than untreated checks. Plots scheduled for first- or first- and second-year treatments were in the same stage of treatment at this point, thus statistical differences between equivalent treatments are due to noise. For example, some noise does exist for height and GLD on plots receiving HWC during year one and HWC during years one and two. Elsewhere, noise is minimal with plots logically positioned for a meaningful interpretation of subsequent growth.

In July of 1996, herbaceous biomass on treated plots was approximately 10 percent that of the untreated check (table 2). Although significantly less than the untreated check, biomass was statistically greater on plots receiving HWC+N fertilizer than HWC+P alone. Data suggests residual herbs benefitted from the additional water and nutrients resulting from treatments. If residual herbs survived treatment due to herbicide tolerance, then fertilizer favors the development of a tolerant subpopulation. To avoid developing a tolerant subpopulation, the brand of herbicide should be rotated for successive treatments.

Second-Year Growth

Two years of HWC plus NPK was the only treatment providing largest seedling heights and ground line diameters (table 1). Best total volume resulted from herbicide and NPK applications during years one and two. This performance was more than 1,100 percent better than the untreated check, 47 percent better than one year of HWC and 24 percent better than two years of HWC. Intermediate volume occurred with two years of HWC alone or combined with two years of NP or P.

The best year-one treatment was HWC alone (table 1). One year of HWC provided more seedling volume than HWC plus one year of fertilizer. All treatments yielded more seedling volume than the untreated check.

Magnitudes of 1997 herbaceous biomass varied greatly as herbs were deliberately controlled on some plots and not others (table 2). Biomass levels on plots receiving a first-year HWC+NPK treatment, and now in the second growing season (July 1997), had returned to untreated check levels (table 2). The same was true for HWC+NP in July 1997 if $p=0.10$. Data suggests that nutrients were available during the post-treatment year to increase herbaceous competition over that of using HWC alone. Perhaps, fertilizer utilization by young seedlings would be better if an N-fertilizer treatment was also followed with HWC.

Third-Year Growth

The best height, diameter, and volume resulted from two years of, HWC plus NPK fertilizer. This treatment provided 750 percent more cubic feet per tree than checks (table 1). Please note that 131 of a possible 132 trees receiving two years of HWC plus NPK fertilizer reached 4.5 feet in height. In contrast, only 59 of 135 of the check trees had a DBH. Over time, the gap between check and treated trees is expected to increase as more short check trees exceed 4.5 feet in height and are used to compute volume. Two years of HWC provided 80 percent and one year of HWC provided 67 percent of the resultant volume from two years of HWC+NPK. Intermediate volume resulted from two years of HWC with two years of NP or P.

The best year-one treatment was HWC alone. All treatments yielded more seedling volume than the untreated check.

Table l-First- (1996). second= (1997), and third-year (1998), loblolly pine seedling responses (S = survival at ages 1, 2, and 3, Ht = total height at ages 1, 2, and 3, D = ground line diameter for ages 1 and 2, d.b.h. = diameter at breast height at age 3, V = total volume at ages 1, 2, and 3, n = volume sample size) to 1 or 2 years of herbicide[a] and fertilizer[b] treatments on a southeastern Arkansas (Bradley County) flatwoods site (treatment n = 144)

Treatment[c]	S1	s2	s3	Htl	Ht2	Ht3
	------ Percent ------			----- Inches -----		Feet
Initial	100			6.1		
HWC 1,2 + NPK 1,2	94a	92a	92a	21.5bc	60.9a	8.7a
HWC 1,2 + NP 1,2	97a	97a	97a	20.1cd	57.4b	8.2bc
HWC 1,2 + P 1,2	96a	96a	96a	22.0b	60.1ab	8.4b
HWC 1,2	96a	96a	96a	22.0b	57.7ab	8.4b
HWC 1	96a	94a	94a	24.2a	58.4b	8.0c
HWC 1 + P 1	94a	94a	94a	22.3b	53.9c	7.5d
HWC 1 + NP 1	97a	95a	94a	21.8b	51.8c	7.4de
HWC 1 + NPK 1	96a	96a	94a	21.1bc	51.9c	7.16
Untreated check	95a	94a	94a	19.0d	35.1d	5.97f

Treatment[c]	D1	D2	DBH3	VI	v2	v3	n
	--Inches---			------ Inch[3] ------		Ft[3]	
Initial	.17			.18			
HWC 1,2 + NPK 1,2	.66bc	1.9a	1.5a	11 .Obc	232.7a	.15a	131
HWC 1,2 + NP 1,2	.63c	1.8b	1.3bc	9.5c	207.6b	.llbc	137
HWC 1,2 + P 1,2	.68ab	1.7b	1.3b	11.8b	196.5b	.12b	132
HWC 1,2	.64c	1.7b	1.3b	10.5bc	188.0b	.12b	135
HWC 1	.71a	1.5c	1.2c	14.2a	158.1c	.10c	130
HWC 1 + P 1	.69ab	1.5d	1 .0d	12.1b	125.4d	.06d	133
HWC 1 + NP 1	.63c	1.30	1 .0d	10.8bc	109.5d	.06d	124
HWC 1 + NPK 1	.62c	1.4e	1.0d	9.5c	106.5d	.06d	129
Untreated check	.37d	.7f	.6e	3.3d	20.66	.02e	59

[a] A single application of Arsenal+Oust (4 oz+2 oz) was used for first- and second-year herbaceous weed control (HWC) for all plots.
[b] Fertilizer was applied at 40, 50, and 50 pounds/acre of elemental N, P, or K, respectively. The same rate and elements were used for years one and two.
'Treatment means in a column and sharing a common letter are not significantly different (Duncan's New Multiple Range test p = 0.05).

Table P-First- (July 1996), second- (July 1997), and third- (July 1998) year herbaceous biomass following 1 or 2 years of herbicide[a] and fertilize? treatments on a chemically prepared flatwoods site in southeastern (Bradley County) AR

	Herbaceous biomass		
Treatment[c]	July 1996	July 1997	July 1998
Herbaceous weed control year 1 + NPK year 1	**0.36bc**	**1.40ab**	**1.36a**
Herbaceous weed control year 1 + NP year 1	**.30bc**	**1.23bc**	I.llabc
Untreated check	**1.85a**	**1.58a**	**1.32ab**
Herbaceous weed control year 1 only	**.13d**	**1.13bc**	**.98bc**
Herbaceous weed control years 1,2 + P years 1,2	**.13d**	**.13d**	**.88c**
Herbaceous weed control years 1,2 + NPK years 1,2	**.25cd**	**.23d**	**.96abc**
Herbaceous weed control year 1 + P year 1	.lld	**1.07c**	**.90c**
Herbaceous weed control years 1,2 only	.lld	**.33d**	**.80c**
Herbaceous weed control years 1,2 + NP years 1,2	**.41b**	**.27d**	**1.15abc**

[a] A single application of **Arsenal+Oust** (4 **oz+2** oz) was used for first- and second-year herbaceous weed control (HWC) for **all** plots.
[b] Fertilizer was applied at **40, 50** and 50 pounds/acre of elemental **N,** P, or K, respectively. The same rate and elements were used for years one and two.
'Treatment means in a column and sharing **a** common letter are not significantly different (Duncan's New Multiple Range test p = 0.05).

Several treatments exhibited 1998 herbaceous biomass levels that were statistically similar to the untreated check (table 2). Among those similar were four treatments containing N fertilizer (HWC 1 year+NPK 1 year, HWC 1 year+NP 1 year, HWC 1,2 years+NP 1,2 years, and HWC 1,2 years+NPK 1,2 years). Biomass recovery in the post-treatment year reached untreated check levels on the HWC+NPK plots receiving treatment for both one or one and two years.

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MANAGING LEAF AREA FOR MAXIMUM VOLUME PRODUCTION IN A LOBLOLLY PINE PLANTATION[1]

Shufang Yu, Quang V. Cao, Jim L. Chambers, Zhenmin Tang, and James D. Haywood[2]

Abstract-To manage loblolly pine (*Pinus taeda* L.) stands for maximum volume growth, the relationships between volume growth and leaf area at the tree and stand level under different cultural practices (thinning and fertilization) were examined. Forty-eight trees were harvested in 1995, six years after treatment, for individual tree measurements, and 336 standing trees were used for stand measurements each year from 1991 to 1994. Thinning significantly increased annual ring width, tree leaf area, and tree volume growth during the six years following treatment, but reduced stand leaf area index and stand volume growth. Fertilization increased leaf area and volume growth at both the tree and the stand level, but significant tree level effects were only apparent during the first three years following treatment. The combination of thinning and fertilization was the optimum overall treatment. The relationship between volume growth and leaf area was linear and positive at the both of tree and stand level across treatments.

INTRODUCTION

Studies of leaf area and growth dynamics of loblolly pine stands in response to silvicultural practices are currently in progress as part of the USDA Forest Service, Southern Global Change Program. Leaf area is a key measurement variable in ecophysiology studies of both individual trees and forest stands, because it reflects the amounts of energy and material exchange between the forest canopy and the atmosphere. The leaf area of tree crowns and stands has a direct effect on photosynthetic capacity by affecting the surface area for carbon fixation, and an indirect effect on photosynthetic capacity by influencing the radiation, temperature, water vapor, wind, and carbon exchange within the canopy (Drew and Running 1975, Gholz and others 1991). Numerous studies have established a positive relationship between leaf area and forest productivity (Brix 1983, Shelburne and others 1993, Vose and Allen 1988). Silvicultural practices such as thinning and fertilization may increase leaf area, above-ground tree growth, and root growth in many conifers (Brix 1981, Dougherty and others 1995, Haywood 1994, Sword and others 1998 and 1998, Vose and Allen 1988). Brix (1981) examined the effects of thinning and fertilization on annual leaf biomass and total leaf biomass per tree in Douglas-fir. He found that thinning and fertilization increased both annual leaf biomass and total leaf biomass. Increases in annual leaf biomass peaked 2-3 years after fertilization, while the greatest differences in total leaf biomass were not found until 4-7 years after fertilization alone. Short-term fertilization responses in loblolly pine leaf area have also been reported (Gillespie and others 1994, Vose 1988). Vose and Allen (1988) found that fertilization increased the leaf area index (LAI) of loblolly stands 2 years after treatment in nutrient-limited stands and that LAI varied with stand density. Stemwood volume growth was positively and linearly related to LAI across treatments and stands. However, the long-term effects of thinning and fertilization on loblolly pine leaf area and the relationship between leaf area and volume growth at tree and stand levels have not been reported. The objectives of this study were to (1) identify impacts of thinning and fertilization on tree volume growth; (2) assess the cultural practice effects on leaf area of individual trees and stands; and (3) determine the relationship between leaf area and volume growth.

MATERIALS AND METHODS

Study Site

The loblolly pine (*Pinus taeda* L.) plantation in this study is located on the Palustris Experimental Forest in central Louisiana (31°07'N, 93°17'W). It was established in May 1981 when Ibweek-old container-grown loblolly pine seedlings were planted at a spacing of 1.83 m by 1.83 m (2990 trees per ha). Twelve research plots, uniform in terms of tree size and spacing, were established within the plantation in the fall of 1988. Each plot was 23.8 m by 23.8 m (0.08 ha) and consisted of 13 rows of 13 trees. Two levels each of thinning and fertilization treatments were randomly assigned to 12 plots in a two by two factorial design resulting in four treatment combinations (thinned-fertilized, thinned-unfertilized, unthinned-fertilized, and unthinned-unfertilized) with three replications of each. On the thinned plots, 75 percent of the trees were removed in November 1988 by harvesting every other row of trees and every other tree in the remaining rows to produce a density of 731 trees per hectare. On the fertilized plots, diammonium phosphate at 744 kg per hectare (150 kg P + 134 kg N ha") was broadcast in April 1989. The soil is a Beauregard silt loam (fine-silty, siliceous, thermic, Plinthaquic Paleudults). Soil drainage was adequate and slope was sufficient to prevent water from standing on the site (Haywood 1994).

Sampling and Measurements

Individual tree measurements-In early spring 1995, 48 trees were harvested from 12 plots (two dominant or codominant trees and two intermediate trees (lower in basal area) from each plot). Immediately after felling each sample tree, the height, live crown length and diameter at breast height (d.b.h.) were measured. Three disks were cut from each tree (one at breast height, one at the base of the live crown and one at the middle of the crown). The disks were placed in plastic bags, taken to the laboratory, and placed in cold storage until they were analyzed. The ring width and

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inside bark diameter for each year between 1988 to 1994 were measured to the nearest 0.1 mm in two vertical directions on the disk and then averaged.

Specific leaf area (projected leaf area per unit dry weight) was calculated from 96 sample shoots per treatment combination (Yu, 1996). Projected leaf area was measured to 0.01 cm^2 using a LI-3000 Leaf Area Meter (LI-COR Inc., Lincoln, NE USA). Needles of each shoot were oven-dried (60 ^oC) to a constant mass and weighed to 0.01 g. Mean tree projected leaf area was calculated based on needlefall dry weight, specific leaf area, and number of trees per plot.

Tree heights in the previous years were predicted from d.b.h. using the following equation:

$$\ln(H)=a_0+a_1(1/D) \qquad (1)$$

where H = total height, D = diameter at breast height, and a_0, a_1 = coefficients. Tree volumes in each year were calculated separately for thinned and unthinned treatments based on Baldwin and Feduccia's volume equations (1987).

Stand measurements-The measurement plot was the interior portion of each treatment plot originally occupied by the central 7 rows of 7 trees each (0.015 ha). A total of 336 trees from the measurement plots were used to assess d.b.h. and 144 of these trees were used to measure total tree heights at the end of each growing season from 1991 through 1994. Stand volumes for each treatment and each year were obtained by summing tree volumes and expanding to a per hectare basis. Needlefall was collected, oven-dried (60 ^oC) to a constant mass, and weighed each week from four litterfall traps per plot (i.e. 12 traps per treatment combination) in 1993, 1994, 1995, and 1996. Each trap was 0.92 m^2. Litterfall dry weights were expanded to the plot level. Total leaf area per year and plot was estimated based on specific leaf area and two years of needlefall dry weights per plot (needlefall per year was summed from April to the following March) (Dougherty and others 1995, Vose and Allen 1988). Leaf area index was calculated from total leaf area per plot divided by plot ground area.

Statistical Analysis

The statistical significance of the thinning and fertilization main effects and the thinning by fertilization interaction effect was determined using analysis of variance (Statistical Analysis System, SAS V 6.12, SAS Institute Inc., Cray, NC, USA). Treatment effects on d.b.h., tree volume, stand volume, leaf area, and leaf area index in different years were analyzed by a two by two factorial in a completely random design. Treatment effects and their interaction with year on annual ring width, annual increment for diameter, tree height, tree volume, and stand volume were determined by a two by two factorial repeated measurements. Main and interaction effects were tested for statistical significance at the 0.1 probability level due to the low number of sample trees and large natural variation in forests. If the interaction of thinning by fertilization was significant, the simple effects were tested (Stehman and Meredith 1995) using adjusted Tukey test (Geaghan, J.P., personal communication, Department of Experimental Statistics, Louisiana State University).

RESULTS AND DISCUSSION

Individual Tree Level

Thinning and fertilization significantly increased d.b.h. (fig. IA). The effects of thinning or fertilization on annual ring width significantly interacted with year. In 1988 before treatment, annual ring width was uniform. After treatment beginning in 1989 and continuing through 1994, thinning significantly increased annual ring width by 113, 191, 236, 145, 165, and 107 percent by year, respectively, compared to the unthinned treatment (fig. 1 B). Fertilization significantly interacted with thinning during the first two years after treatment (table 1). Fertilization increased annual ring widths by 36 and 50 percent within the thinned plots in 1989 and 1990, but had no significant effect on the unthinned plot tree ring widths. In 1991, fertilization increased annual ring width by 35 percent. After 1992, the fourth year after treatment, fertilization effects on annual ring width were not significant. Annual ring width on the unthinned plots decreased after 1988 (fig 1 B), which indicated that crown closure occurred approximately 7-8 years after plantation establishment.

Tree height growth was significantly increased by fertilization ($P=0.0421$) but was reduced by thinning ($P=0.0001$). Mean tree height in 1994 was 14.99 m, 13.85 m, 15.24 m, and 14.18 m for the thinned-fertilized, thinned-unfertilized, unthinned-fertilized, and unthinned-unfertilized treatments, respectively. Tree height growth was immediately affected by the thinning treatment. However, fertilizer effects on height growth were delayed until the second year after treatment (Haywood, 1994).

Tree volume and tree volume growth were increased by thinning (fig. 1 C and 1 D). On the thinned plots, mean tree volume growth varied from 116 to 315 percent greater than in the unthinned plots over the period from 1989 to 1994. Fertilization significantly increased mean tree volume growth from 30 to 45 percent during the first three years after treatment. After 1991, fertilization effects decreased, and no significant differences between the fertilized and unfertilized treatments were found (table 1). These results are similar to those of Brix (1983). He found that thinning and fertilization increased individual tree annual stemwood growth in the first three to four years and then the effect of the fertilized treatment decreased.

Tree projected leaf area was not significantly different within treatments between 1993 and 1994. Interaction of thinning and fertilization did not significantly affect tree leaf area during this period. The trend in tree leaf area across treatments is shown in Figure 2. Thinning increased tree leaf area by 123 percent ($P=0.0001$), but fertilization had no significant effect on leaf area ($P=0.1134$) in 1994, 6 years after treatment (fig. 3). Brix (1981) reported that fertilization alone had little or no significant effect on foliage biomass 4 or 5 years after treatment, but the combination of thinning and fertilization increased foliage biomass per tree by 271 percent 7 years after treatment in a Douglas-fir stand. The difference between his results and ours related to the interaction effects of thinning by fertilization could be attributed to difference among tree species. Loblolly pine needles remain on the trees for about two years, while Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) needles are retained for 5-8 years. Thinning increased tree leaf area mainly by improving light transmission to the lower crown,

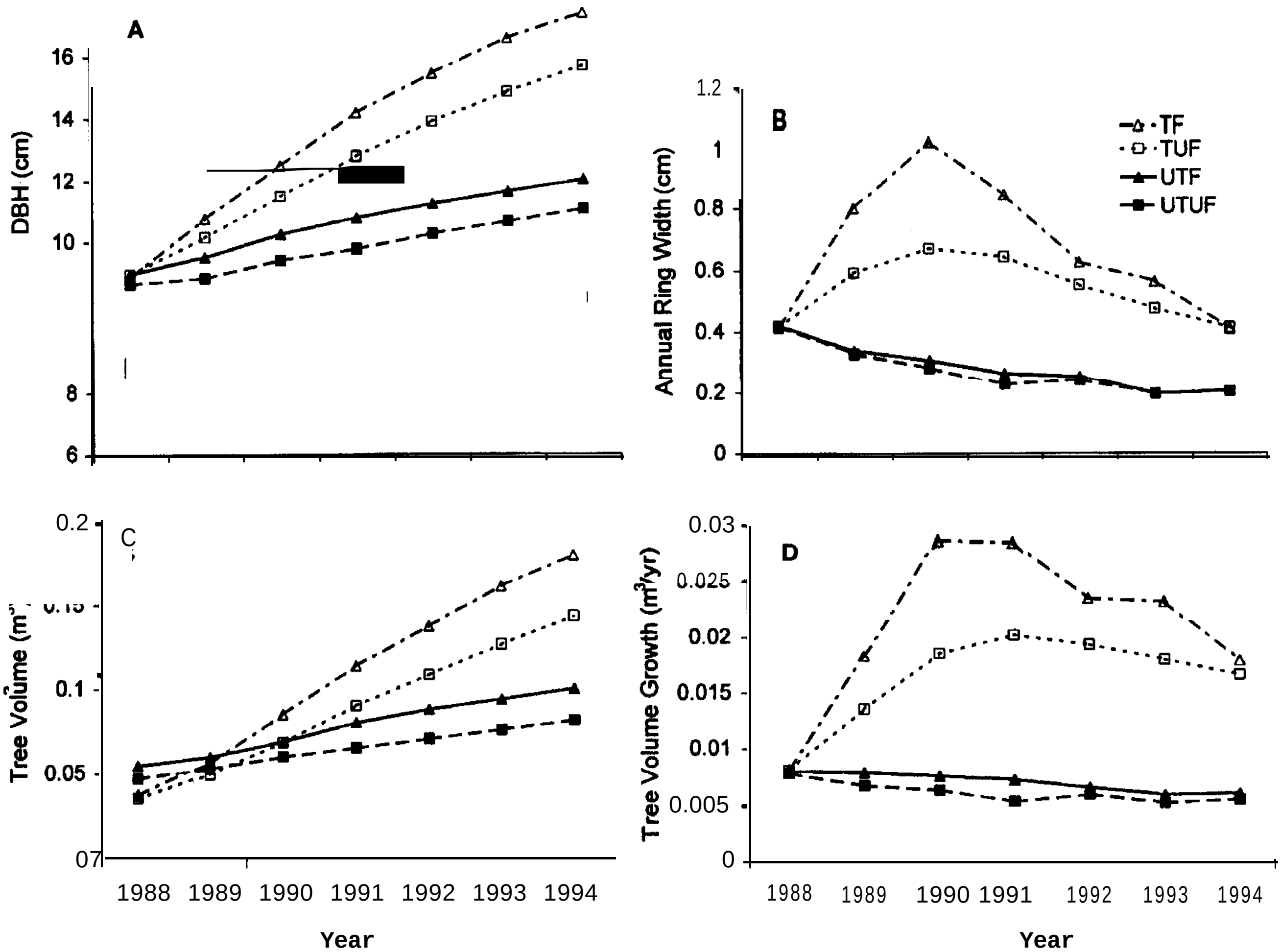

Figure I-Mean diameter at breast height (d.b.h.) (A), annual ring width (B), tree volume (C), and annual tree volume growth (D) during 1988 (pre-treatment) through 1994 (TF = Thinned × Fertilized, TUF = Thinned × Unfertilized, UTF = Unthinned × Fertilized, UTUF = Unthinned × Unfertilized).

More light increased photosynthesis and led to more shoots per branch, branches per whorl, and whorls per tree after the thinning treatment (Ginn 1989, Gillespie and others 1994, Yu 1996).

Tree leaf area was linearly and positively related to volume growth **(R^2=0.84)** across treatments. When light and nutrient availability were increased, tree leaf area and volume growth were greater. Therefore, volume growth was the greatest on the thinned-fertilized treatment (fig. 4). Improved light availability on the thinned plots was associated with significant increases in shoot elongation and branch leaf area in the lower crown (Ginn 1989, Gravatt and others 1997, Tang and others 1999, Yu 1996) and stimulated early seasonal root growth (Sword and others 1998). Fertilization increased fascicle needle length and leaf area in the upper crown but not in the lower crown (Tang and others 1999, Yu 1996). In the thinned-unfertilized treatment tree leaf area and tree volume growth were less than those in the **thinned-**fertilized treatment. The lowest tree leaf area and tree volume growth occurred in the unthinned-unfertilized treatment. This response was likely due to nutrient deficiency and low light levels.

Stand Level

Small tree size at the time of thinning meant that the thinned trees were non-merchantable. Therefore, the volume of the thinned tree was not included in the stand volume data presented. Thinning and fertilization significantly affected residual stand volume. Fertilization increased stand volume on both the thinned and the unthinned plots (fig. 5A). In contrast, thinning resulted in less stand volume because 75 percent of the trees were harvested at the time of thinning. In 1992, the fertilized treatment significantly increased stand volume growth by 37 percent **(P=0.0075),** and the thinned treatment decreased stand volume growth by 40 percent **(P=0.0005).** As the period after tree removal increased, the negative effects on stand volume growth in the thinned treatment become less. The thinned treatment had only 31 **(P=0.0046)** and 29 percent **(P=0.0146)** lower stand volume growth in 1993 and 1994, respectively, than those in the unthinned treatment. In 1993, fertilized treatment had 41 percent **(P=0.0067)** greater stand volume growth than the unfertilized treatment. When treatments were combined as on the thinned-fertilized plots, stand volume growth was similar to the unthinned-unfertilized treatment (fig. **5B).** Thus the fertilization compensated for the loss of stand volume

Table I-Statistical summary (Probability >F) of treatment effects on ring width (cm), annual diameter growth (cm/yr) at breast height, tree volume growth (m^3/yr)

Variable	Thinning	Fertilization	Thinning × fertilization
	1988	**(pre-treatment)**	
Ring width	0.9156	0.9675	0.9935
Diameter growth	.9035	.9628	.9126
Tree volume growth	.6805	.4643	.5379
		1989	
Ring width	.0001	.0008	.0007
Diameter growth	.0001	.3048	.0335
Tree volume growth	.0001	.0473	.2270
		1990	
Ring width	.0001	.0114	.0159
Diameter growth	.0001	.0239	.0346
Tree volume growth	.0001	.0427	.0116
		1991	
Ring width	.0001	.0288	.3216
Diameter growth	.0001	.0303	.3790
Tree volume growth	.0001	.0401	.3232
		1992	
Ring width	.0003	.6202	.4567
Diameter growth	.0001	.5707	.3946
Tree volume growth	.0001	.3256	.4644
		1993	
Ring width	.0001	.6425	.3511
Diameter growth	.0001	.3715	.3803
Tree volume growth	.0001	.2388	.3751
		1994	
Ring width	.0001	.7831	.8839
Diameter growth	.0001	.8488	.9196
Tree volume growth	.0001	.6566	.8586

caused by thinning. The thinned-fertilized treatment was the optimum siivicultural practice for enhancing tree volume growth and potential productivity. Even though thinning reduced the number of trees per hectare remaining, trees on the thinned-fertilized treatment used the fertilizer to increase stand volume growth. Six years following treatment, although tree volume growth was no longer significantly affected by fertilization, stand volume growth continued to be significantly increased (30 percent, P=0.0619) by fertilization. A fertilization-induced increase in stand volume

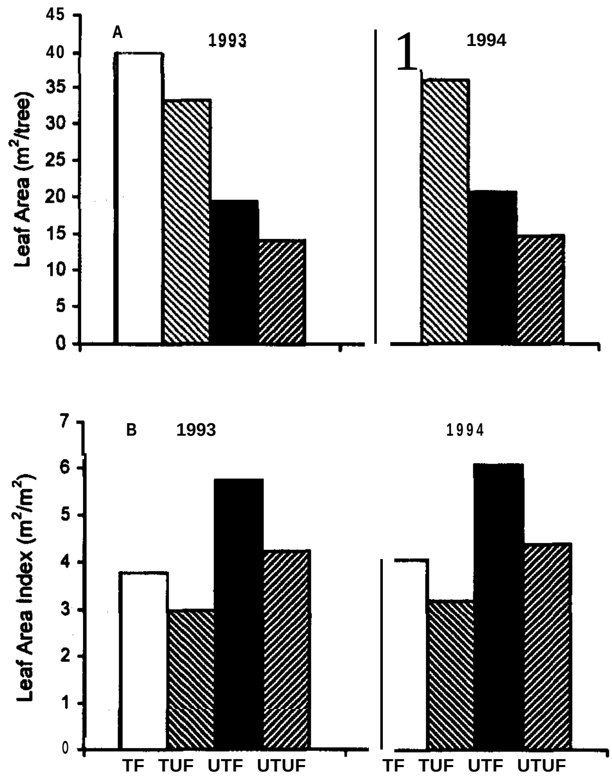

Figure Z-Mean tree leaf area (A) and stand leaf area index (B) in 1993 and 1994 (TF = Thinned × Fertilized, TUF = Thinned × Unfertilized, UTF = Unthinned × Fertilized, UTUF = Unthinned × Unfertilized).

growth was also reported by Vose and Allen (1988) and Albaugh and others (1998).

LAI (projected leaf area index) differences among treatments were similar in 1993 and 1994 (fig. 2B). Thinning and fertilization had a slight but not significant interaction effect on LAI (P=0.1247). The largest LAI occurred in the unthinned-fertilized treatment while the thinned-unfertilized treatment had the smallest LAI. Even though the thinned treatment had fewer trees than the unthinned treatment, the LAI in the thinned-fertilized treatment was similar to the LAI in the unthinned-unfertilized treatment. The similar LAI values indicate that fertilization stimulated leaf expansion and development, which compensated for fewer trees and thus helped recapture solar radiation and stand volume growth lost by thinning. in 1994, the fertilized treatment significantly increased LAI by 34 percent (fig. 3B). However, the thinned treatment had an overall negative effect on LAI, reducing LAI by 31 percent. The results from our study are similar to those from previous studies. Binkiey and Reid (1984) reported that in a 53-year-old Douglas-fir plantation, fertilization increased stand leaf area and stem growth per hectare, and thinning reduced stand leaf area but increased stem growth per leaf area resulting in little difference in stem growth per hectare over a 5-year measurement period 13 to 18 years after treatment. Aibaugh and others (1998) stated that fertilization increased LAI during a 4-year period after treatment in an 8-year-old lobloily pine stand.

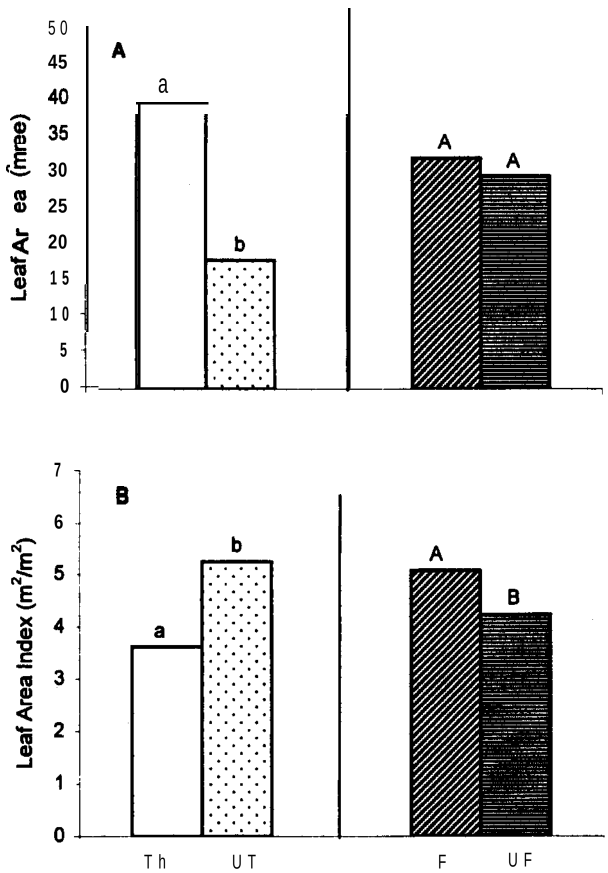

Figure 3—Thinning and fertilization main effects on mean tree leaf area (A) and stand leaf area index (B) in 1994. Different lower case letters indicates a significant difference between thinned and unthinned treatment, and different upper case letters indicates a significant difference between the fertilized and unfertilized treatments (Th = Thinned, UT = Unthinned. F = Fertilized. UF = Unfertilized).

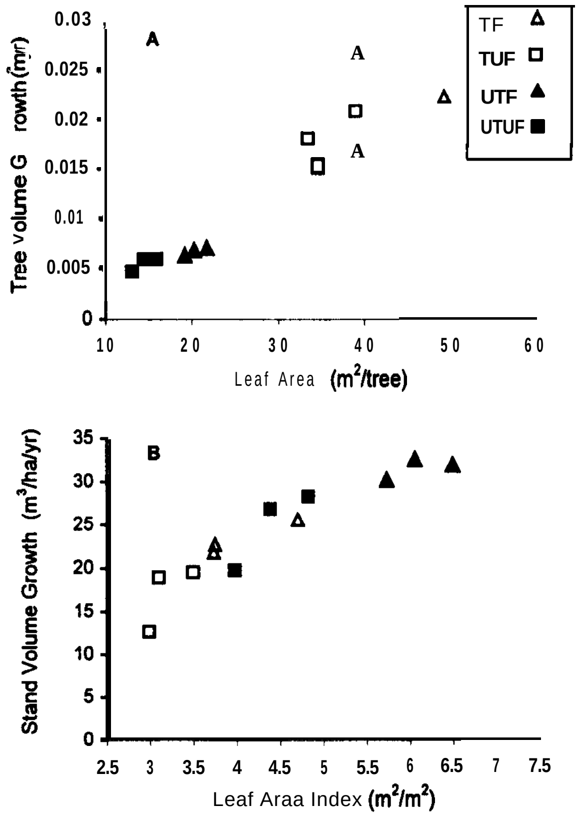

Figure 4-Relationship between annual tree volume growth and leaf area per tree (A) and annual stand volume growth and stand leaf area index (B) in 1994 (TF = Thinned × Fertilized. TUF = Thinned × Unfertilized, UTF = Unthinned × Fertilized, UTUF = Unthinned × Unfertilized).

Vose and Allen (1988) found that fertilization increased LAI of loblolly pine 2 years after treatment and LAI varied with stand density. They reported that stemwood volume growth was positively and linearly related to LAI across treatments and stands. In our study, LAI was also linearly correlated to stand volume growth across treatments (R^2=0.78). The unthinned-fertilized treatment had the largest LAI and also had the highest stand volume growth (fig. 4B). In contrast, the thinned-unfertilized treatment had the smallest LAI and the lowest stand volume growth. The thinned-fertilized treatment improved nutrient availability, and therefore increased both LAI and stand volume growth compared to the thinned-unfertilized treatment. A strong linear relationship between LAI and stand volume growth has also been demonstrated in other studies (Albaugh and others 1998, Binkley and Reid 1984).

SUMMARY

Thinning and fertilization are very useful silvicultural treatments. Thinning significantly increased tree leaf area and volume growth, but had negative effects on leaf area index and stand volume growth. These negative effects become less 4 years after treatments on the plots that were fertilized at the time of thinning. Fertilization increased leaf area and volume growth at both the tree and stand level, especially during the first three years following treatment. There were linear and positive correlations between leaf area and volume growth at both the tree and stand levels. The combination of thinning and fertilization was an optimum silvicultural practice for sawtimber production on our study site. However, the choice of cultural treatment for managers depends on product market (fiber vs. sawtimber) and potential interaction between cultural practices and environment.

ACKNOWLEDGMENTS

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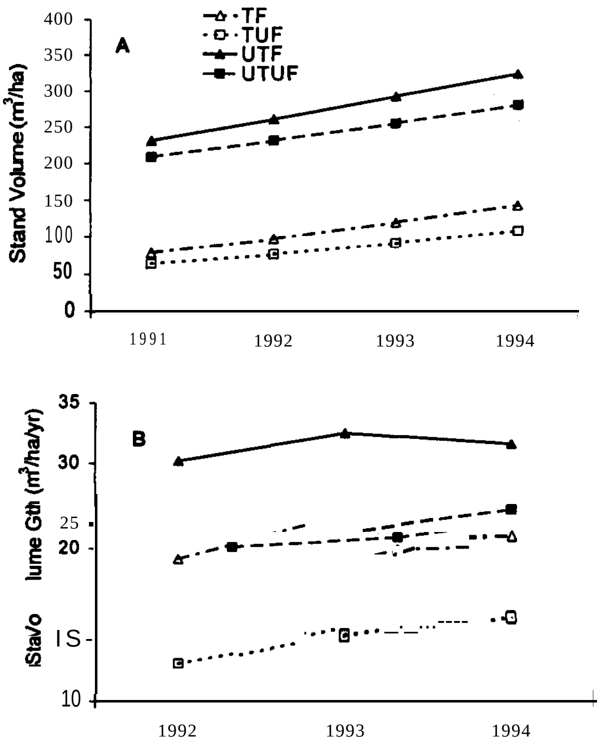

Figure 5—Mean stand volume for 1991 through 1994 (A) and annual stand volume growth for 1992 through 1994 (B) (TF = Thinned x Fertilized, TUF = Thinned x Unfertilized, UTF = Unthinned x Fertilized, UTUF = Unthinned x Unfertilized).

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VELPAR IMPREGNATED FERTILIZER: EARLY RESULTS OF FIELD TRIALS'

Barry D. Shiver, Mike Link, and Burton M. **Dial**[2]

Abstract-Fertilization and weed control are commonly used cultural treatments in both young and mid-rotation aged stands. Application costs may represent one third or more of the total cost of these treatments and often they are needed at about the same time. A product that combines the two treatments would cut application cost by about 50 percent. Beginning in **Spring** 1996, the University of Georgia and **duPont** have cooperated on a study to examine the herbicide effectiveness and pine response in loblolly pine ***(Pinus taeda*** L.) plantations treated with fertilizer impregnated with hexazinone. A total of eight stands ranging from the coastal plain to the Piedmont have been treated. Four of the treated stands were less than three years old and four were between ten and twenty-five years old. Early results indicate that pine growth response on the combination of fertilizer and hexazinone is higher than on either treatment separately or the untreated check.

INTRODUCTION

Over the past 20 years researchers across the South have demonstrated the growth responses in iobloiiy pine plantations from control of competing vegetation and fertilization. These two treatments together form the cornerstone of intensive forest management. Response to the two treatments has been demonstrated across a wide variety of sites in both young and midrotation stands. **Of** course forest managers must always keep costs in mind and the cost of applying fertilizer and herbicides can typically make up **30-50** percent of the total cost of the treatment.

The advantage of a product combining weed control and fertilization is that application costs could be cut up to 50 percent. DuPont has developed a product which combines some fertilizers with hexazinone. **Velpar®,** a **duPont** product with hexazinone as the active ingredient, is compatible with di-ammonium phosphate (DAP) and urea. it is not compatible with triple super phosphate (TSP). The Wamell School of Forest Resources has been working with **duPont** since 1996 to evaluate product effectiveness and crop response to the impregnated product when applied to loblolly pine plantations of different ages.

METHODS

A total of eight locations have been established since 1996. Three locations were established in 1996 and form the basis for the discussion in this paper. One of the three locations was established in Clay county, Georgia with the other two in Taylor county, Georgia.

The experimental design was the same for all locations and consisted of a randomized complete block with three blocks. Treatment plots were **¼** acre in size with a 1110 acre measurement plot. There were four treatments in each block: (1) a check plot where nothing was done to the existing plantation, (2) a fertilize only plot, (3) a herbicide only plot with a hexazinone rate prescribed for the stand, and (4) hexazinone impregnated fertilizer using the same fertilization rate as in treatment 2 and the same hexazinone rate as in treatment 3. One of the stands in Taylor county was just beginning its second growing season, and the fertilizer rate for it was 250 Ibs DAP. The other two stands were in their teens and received 25 Ibs of phosphorus from DAP plus 200 ibs of nitrogen from the DAP plus urea.

Measurements were made on pines and competition at time of establishment. Total height **(ft)** was measured on every pine and dbh (0.1 in) was measured on every tree of the older locations. Total stem volume was developed using equations published by Harrison and Borders (1996). Competition measurements were made on nine subplots, each four **ft** in radius, systematically located on the measurement plots. Every hardwood on the subplots was measured for total height (cm), crown length (cm), crown width (cm), dbh if **>1 .5** in., and species was recorded. Several hardwood quantity variables were calculated from the hardwood measurements including the total amount of crown area assuming that the crown is circular. **Remeasurements** of the competition subplots were made three months after treatment. Pines were remeasured **after** one growing season.

An analysis of variance was conducted on average total height, average total height growth, average dbh, average dbh growth, total volume per acre, total volume per acre growth, and mortality for the pines. The initial size of the dependent variable was used as a covariate in the analyses. Tukey's mean separation test was used to determine significant differences. An a level of 0.05 was used to determine statistical significance.

RESULTS

The analysis of variance for average total height indicates no significant differences after one growing season for the older age stands. Figure 1 indicates that the average total height for the four treatments varies by less than one ft in Clay county. Figure 2, for Taylor county, also indicates very low variability in average total height. There is a significant difference in average total height for the young stand (fig. 3). Plots which received either the hexazinone treatment or the combination **hexazinone/fertilizer** treatment had significantly taller trees at age two, one growing season after treatment, than did the check or fertilized only plots.

Results of the analysis for average height growth look much like those from the analysis of average total height. There are no statistically significant differences in average height growth by treatment for the older age installations (figs. 4 and 5). The average growth on either of the two installations varies across treatments by 0.5 **ft** or less. On the other hand,

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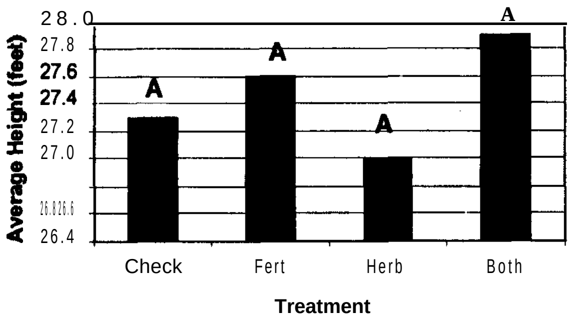

Figure l-Average loblolly pine total height (ft) by treatment on the Clay county site one growing season after treatment. Treatments with the same letter do not differ significantly (α=.05) in average total height.

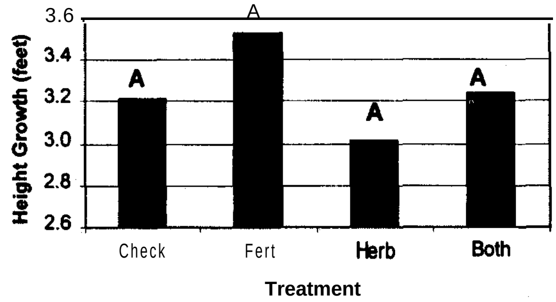

Figure 4-Average loblolly pine total height growth (ft) by treatment on the Clay county site one growing season after treatment. Treatments with the same letter do not differ significantly (α=.05) in average total height growth.

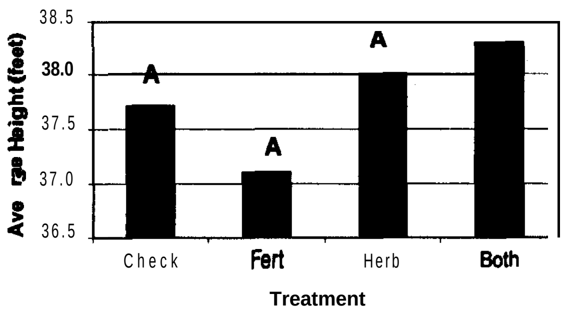

Figure P-Average loblolly pine total height (ft) by treatment on the older age Taylor county site one growing season after treatment. Treatments with the same letter do not differ significantly (α=.05) in average total height.

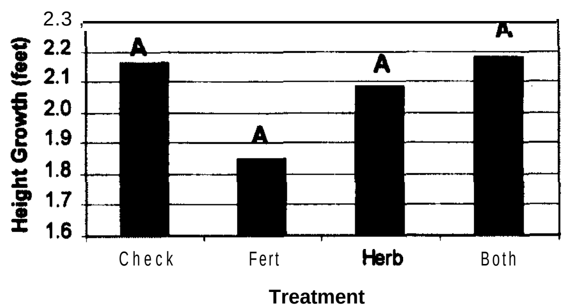

Figure 5—Average loblolly pine total height growth (ft) by treatment on the older age Taylor county site one growing season after treatment. Treatments with the same letter do not differ significantly (α=.05) in average total height growth.

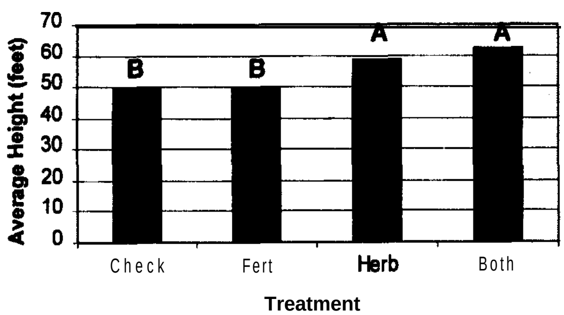

Figure 3-Average loblolly pine total height (ft) by treatment on the young plantation Taylor county site one growing season after treatment. Treatments with the same letter do not differ significantly (α=.05) in average total height.

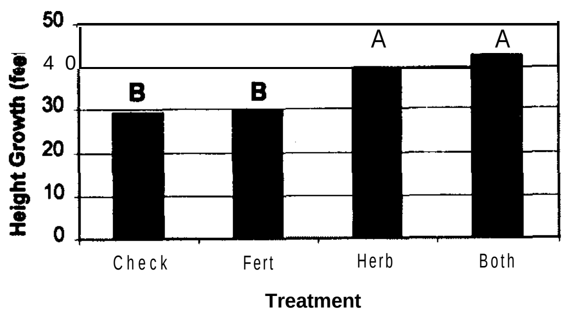

Figure 6—Average loblolly pine total height growth (ft) by treatment on the young plantation Taylor county site one growing season after treatment. Treatments with the same letter do not differ significantly (α=.05) in average total height growth.

the young stand again had significantly higher average height growth on the hexazinone only and combination **hexazinone/fertilizer** treatments (fig. 6).

There were no significant differences detected in the analysis for average dbh, dbh growth, or pine mortality for any of the locations. Surprisingly though, there were the differences in total volume between treatments for both of older age installations after only one growing season and in spite of the failure to find significant differences in dbh, total height, or height growth on those locations. Volume was not calculated for the young stand due to the small tree size.

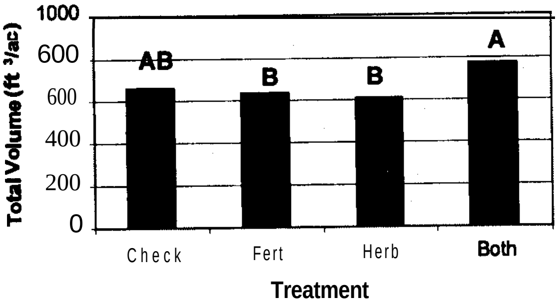

Figure 7-Average loblolly pine total volume (ft^3) by treatment on the Clay county site one growing season after treatment. Treatments with the same letter do not differ significantly (α=.05) in average total volume.

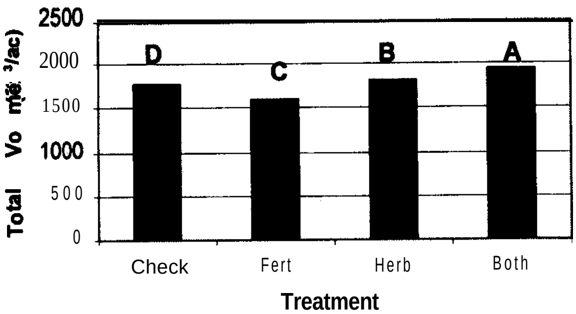

Figure 6-Average loblolly pine total volume (ft^3) by treatment on the older age Taylor county site one growing season after treatment. Treatments with the same letter do not differ significantly (α=.05) in average total volume.

In both Clay county (fig. 7) and Taylor county (fig. 8), the combination of **hexazinone/fertilizer** has significantly higher total volume only one growing season after treatment.

The herbicide treatments, using release rather than site preparation rates, reduced, but did not eliminate the hardwood competition. The pine volume/competition relationship was not well defined after one growing season (fig. 9). It will be interesting to follow the relationship through several growing seasons to see if a trend develops.

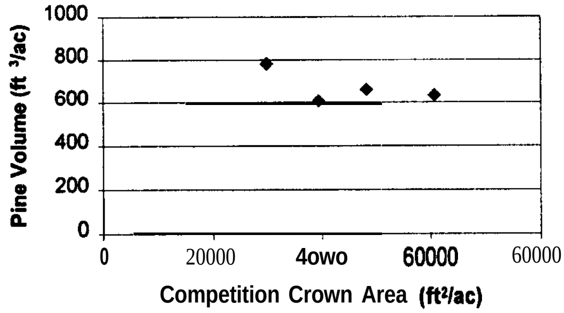

Figure 9-Average pine volume (ft^3) vs competition crown area (ft^2) on the Clay county site one growing season after treatment.

CONCLUSIONS

After only one year, many responses which may become significant are not yet statistically significant. The combination treatment incorporating both hexazinone and fertilizer on the same material for application almost always ranked at the top. So the trend is encouraging and it was probably unrealistic to expect significant differences after only one year.

Though many studies have shown the effects of complete elimination of competition, this study indicates that a growth response is probable with only a reduction in hardwood competition. This is particularly true when fertilization is combined with the hardwood reduction.

Within the next year, we should have much more information on these installations and begin to analyze data from the other five installations. Based on our early results, there is promise of a new product in the future which will combine hardwood release and fertilization and thus lower application costs for forest managers who want to practice intensive forest management by using both treatments.

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EFFECT OF INORGANIC AND ORGANIC FERTILIZATION ON LONGLEAF PINE TREE GROWTH AND PINE STRAW PRODUCTION[1]

E. David Dickens[2]

Abstract-A forest land application of inorganic fertilizer and lime stabilized biosolids project was initiated in 1995 on the Sand Hills State Forest in SC to determine longleaf pine tree growth and pine straw production response. Two study areas were located: a 1963 and 1966 established longleaf stands on a deep sand (Alpin soil series, Typic Quartzipsamments). The inorganic fertilizer treatment (1500 lbs/ac of 10-10-10) increased two-year diameter growth by 50 and 67 percent over the control and volume per tree growth by 11 and 36 percent in both longleaf stands. The high biosolids level (3.2 dry tons/ac; 85 lb available-N/ac, 48 lb P/ac, 9 lb K/ac, and 1900 lb Ca/ac) increased two year diameter growth by 25 and 33 percent over the control in both longleaf stands. Two-year volume per tree increment was 11 percent greater in the high biosolids plots versus the control in the younger longleaf stand but no volume gain was realized in the older stand. Two-year growth increment for the longleaf pine in the low biosolids plots was overall very similar to the control. Litter layer dry weights from the inorganic fertilizer treatment were 90 and 84 percent greater than the control two and three winters after application, respectively in the 1963 established longleaf stand. The biosolids treated plots litter layer dry weights were 49 and 50 percent (low biosolids; 2.0 dry tons/ac) and 60 and 62 percent (high biosolids) greater than the control two and three years after application, respectively in the 1963 established longleaf stand. Litter layer dry weights from the inorganic fertilized plots were 48 and 93 percent greater than the control two and three winters after application, respectively in the 1986 established stand. The biosolids treated plots litter layer dry weights were 54 and 28 percent (low biosolids) and 86 and 97 percent (high biosolids) greater than the control two and three winters after application, respectively in the same stand. Fourth year litter layer dry weights from the fertilized plots were 27 to 35 percent greater than the control in the 1963 stand. Litter layer dry weights in the 1986 planted stand four years after fertilization were essentially the same when comparing the control to the fertilized plots. A typical return on selling pine straw raking rights under non-fertilized conditions on the Sand Hills State Forest is $100/ac. Under fertilized conditions this return can be increased by $28 to $97/acre•yr (@ $1 .00/bale) for a period of 2 to 3 years on these deep sandy soils.

INTRODUCTION

Forest soils are generally low in fertility and southern pine plantations often respond to fertilization (Wells and Crutchfield 1974, Wells and Allen 1985, Jokela and others 1991). Pine straw production is a multi-million dollar industry in South Carolina. Little work has been done to determine the beneficial use of lime stabilized biosolids (lime treated municipal sewage sludge) to increase longleaf pine straw production. Furthermore, the literature is scarce on quantifying the magnitude and duration of longleaf pine straw production response to side-by-side trials of inorganic fertilizer versus biosolids.

A forest land application of inorganic fertilizer and lime stabilized biosolids project was initiated in 1995 on the Sand Hills State Forest in South Carolina. The main objective was to determine the magnitude and duration of longleaf pine straw production response to these two fertilizer materials. The effect of fertilizer forms, biosolids application levels, and the untreated control plots pine straw production through four growing seasons after application and tree growth through two growing seasons will be addressed in this paper.

METHODOLOGY

The study areas are located on the South Carolina Forestry Commission Sand Hills State Forest in the Sandhills physiographic region. Two sites were located: a 1963 and 1986 established longleaf stand. The soil series on each site, the Alpin soil series (Typic Quartzipsamments or deep sand), was delineated and verified by a NRCS soil mapper prior to plot installation. The 1963 planted site previously supported a scattered natural pine stand with a heavy turkey oak understory. This stand was cleared and planted to watermelons for 1 year, then planted to longleaf in 1963. The prior stand in the 1986 planted longleaf site was a 38-year-old slash pine stand that was clearcut in 1984-85. Site preparation on this site was disking and v-blading prior to planting. South Carolina Forestry Commission bareroot longleaf seedlings were planted at both sites. The experimental design was randomized complete block design with two replications in the younger stand and three replications in the older stand. One-half acre gross treated plots were installed with a 40-foot untreated buffer around each plot. One-quarter acre permanent measurement plots were then installed in the center of each gross treated plot. Eight plots were established in the 1986 planted (8 x 9 feet spacing) stand and twelve plots in the thinned twice older stand. All trees within each permanent measurement plot (0.25 acres each) were aluminum tree tagged (at 4.5 feet above groundline), measured for d.b.h. (measured just above each tree tag for consistency from year to year with a d-tape) and total height (height pole in the young longleaf stand and clinometer in the older stand) in March 1995, February 1997, and March 1999. Volume per tree was estimated by using the following volume equation: $ft^3 = 0.0014793 * dbh^{1.821} * ht^{1.1629}$ (Bailey and others 1985). Volume per acre was not included in the tree growth summary tables due to differences in number of trees per acre by treatment (175 to 205 TPA in the older stand and 426 to 490 TPA in the younger stand). Baseline soil (@ O-6 and 6-12 inches), forest floor (litter and fermentation+humus layers), and foliage samples were taken in February 1995 prior to plot treatment and each winter thereafter (February 1996, 97, 98, and 99). Litter layer dry weights were used as a relative measure of pine "straw" production. Pine straw bales per

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acre were estimated by year from each treatment by dividing the litter layer dry weight per acre (in pounds) by 25 (assumes 25 pounds/bale on a dry weight basis, Blevins and others 1996). Soil samples were analyzed for soil pH, buffer pH, CEC, percent organic matter, and extractable (Mehlich I) P, K, Ca, Mg, Cu, Mn, and Zn. Forest floor samples, six per plot, were randomly collected from one square foot grids. These samples were separated into litter (upper forest floor layer: fresh brown needles) and fermentation + humus layers (lower layer; gray needles and decomposed biomass), bagged, labeled, field weighed, oven dried @ 160° F for 48 hours, dry weighed and analyzed for N, P, K, Ca, Mg, Cu, Mn, and Zn. Foliage samples from three dominant trees per plot (south side, upper 1/3 crown: first flush of previous years' growth), were bagged, labeled, oven dried, and analyzed for the same nutrients as the forest floor samples. Each plot received one of the following randomly assigned treatments: control (no-fertilizer treatment), 10-10-10 fertilizer (@ 1500 lbs/ac or 150 lbs N, P_2O_5, and K_2O per acre), low biosolids (2.0 dry tons/ac; 130 lb TKN, an estimated 52 lbs plant available-N, 68 lbs P_2O_5, 7 lbs K_2O, and 1900 lbs Ca per acre), and high biosolids (3.2 tons/ac; 210 lbs TKN, an estimated 85 lbs plant available-N, 110 lbs P_2O_5, 11 lbs K_2O, and 1900 lbs Ca per acre) in May 1995. Subsequent fertilizer applications are planned for May 1999 and 2001.

The biosolids were lime stabilized. Lime stabilization is a form of chemical stabilization of residuals where the pH is raised to 12 or higher for 2 hours and remains above 11.5 for 22 additional hours. This process is one of ten procedures that meet vector attraction reduction (VAR) and is a process to further reduce pathogens (PFRP) requirements to land apply biosolids. Quicklime (CaO) is used at the Town of Cheraw at an average dose of 2 parts quicklime to 3 parts biosolids. Dewatered solids are preheated in an insulated, heated screw conveyor prior to being mixed with dry quicklime. The solids/lime mixture is heated in an insulated pasteurization vessel for 30 minutes @ 170° F with subsequent pathogen destruction. The lime stabilized biosolids had a final 22.5 percent agricultural lime value based on a Calcium Carbonate Equivalency test. The sandy soil had a low buffer capacity so the biosolids application level was based on the lime value and not the plant available nitrogen estimate. The subsequent biosolids application levels will be higher in the biosolids plots of the older stand. The soil pH monitoring part of this project discerned the peak pH value/time (0.4 to 1 .O unit increase occurring 9 to 18 months after application) and subsequent decrease to background levels (about 30 to 36 months after application) and is summarized in another paper (Dickens 1998).

RESULTS AND DISCUSSION

Fertilization Effect on Tree Growth

Total height measurements where a clinometer was used 1963 longleaf stand presented some problems between measurement years in some plots as there was negative height growth in the high level biosolids plots between 1995 and 1997 (table 1). D.b.h. measurements taken just above each aluminum tree tag, appeared to be much more accurate and precise than height measurements taken with a clinometer when performing a random check on individual diameter growth by tree number. Generally tree diameter response to fertilization (organic or inorganic) is much greater and occurs sooner than any height growth response to fertilization (Dickens and Miller 1997).

Fertilization of the 1963 established longleaf stand (Alpin soil, Typic Quartzipsamments) with 1500 lbs/ac of 10-10-10 increased two year (1995 to 1997) diameter growth by 67 percent (0.2 inches), height growth by 11 percent, and volume per tree by 36 percent over the control (table 1). The biosolids at the high level increased diameter growth over the control by 33 percent(0.1 inches) between 1995 and 1997. Numbers of trees per acre in 1997 were as follows: 10-10-10 (175 trees/ac), biosolids high (188), control (195), and biosolids low (205 trees/ac).

Fertilization of the 1986 longleaf pine stand (Alpin soil; Typic Quartzipsamments) with both the 1 O-l O-l 0 fertilizer and the biosolids at the high level increased two year diameter growth by 50 and 25 percent over the control, respectively (table 2). Two year height growth in the 1 O-l O-l 0 fertilized and high biosolids plots was 5.2 feet and 5.8 feet, respectively; lower than the control plot height growth of 6.2 feet between March 1995 and March 1997 (table 2). This height growth reduction in the 10-10-10 and high biosolids plots is due in part to tree losses from tractor damage (biosolids plots) and late winter 1996 ice damage and

Table l--Mean diameter (d.b.h.), total height, volume per tree, and two year growth increment in the 1963 established longleaf stand on an Alpin soil

	D.b.h.			Height			Volume/tree		
Trt[a]	1995	1997	Grow	1995	1997	Grow	1995	1997	Grow
	Inches			*Feet*			*Ft³*		
Cont	7.4	7.7	0.3	50.1	51.9	1.8	5.61	6.30	0.69
Fert	7.3	7.8	.5	49.6	51.6	2.0	5.39	6.33	.94
L.Bio	7.5	7.3	.3	51.1	52.5	1.4	5.96	6.57	.61
H.Bio	7.3	7.7	.4	51.1	50.6	- .5	5.67	6.10	.43

[a] **Trt=treatments;** Cont = control (no treatment), Fert (10-10-10 @ 1,500 lb/ac), L.Bio (2 dry tons biosolids/ac), H.Bio. (3.2 dry tons biosolidslac).

Table 2—Mean diameter (d.b.h.), total height, volume per tree, and two year growth increment in the 1988 established iongieaf stand on an Aipin soil

Trt[a]	D.b.h. 1995	D.b.h. 1997	D.b.h. Grow	Height 1995	Height 1997	Height Grow	Volume/tree 1995	Volume/tree 1997	Volume/tree Grow
	------- *Inches* -------			-------- *Feet* ________			--------- *Ft³* ---------		
Cont	3.1	3.9	0.8	17.1	23.3	6.2	0.386	0.781	0.395
Fert	2.8	4.0	1.2	16.0	21.2	5.2	.323	.762	.439
L.Bio	3.0	3.9	.9	16.9	23.3	6.3	.351	.773	.422
H.Bio	3.0	4.0	1.0	17.0	22.8	5.8	.359	.796	.437

[a] Trt=treatments; Cont = control (no treatment), Fert (10-10-10 @ 1,500 lb/ac), L.Bio (2 wet tons biosolids/ac),H. Bio. (3.2 wet tons biosolids/ac).

excessive foliage production (1 O-l O-l 0 plots) of the more dominant trees. Two year volume per tree growth in the 1 0-IO-IO and high biosolids plots was 11 percent greater than the control. Tree numbers per acre in 1997 are as follows: control (426 trees/ac), biosolids low (438), biosoiids high (476), and IO-l O-l 0 (490 trees/ac).

Fertiiiration Effect on Pine Straw Production

There was no significant litter layer production increase in the fertilized plots the first winter after application (February 1996, tables 3 and 4) in either iongieaf stand. Litter layer dry weights from the inorganic fertilizer treatment were 90 and 84 percent greater than the control two and three winters after application (February 1997 and 1998), respectively in the 1963 established longieaf stand (table 3). The biosoiids treated plots litter layer dry weights were 49 and 50 percent (low biosolids; 2.0 dry tons/ac) and 60 and 62 percent (high biosolids; 3.2 dry tons/ac) greater than the control two and three years after application, respectively in the 1963 established iongieaf stand. Litter layer dry weights from the inorganic fertilized plots were 46 and 94 percent greater than the control two and three winters after application, respectively in the 1986 established stand (table 4). The biosoiids treated plots litter layer dry weights were 53 and 28 percent (low biosoiids) and 85 and 94 percent (high biosoiids) greater than the control two and three winters after application, respectively in the same stand. Fourth year litter layer dry weights from the fertilized plots were 27 to 35 percent greater than the control in the older stand. Litter layer dry weights in the younger stand four years after fertilization were essentially the same when comparing the control to the fertilized plots.

Fermentation plus humus layer dry weights were not significantly greater in the fertilized plots when compared to the control plots the first winter (February 1996) after application in both the 1963 and 1986 planted stands. Fermentation plus humus layer dry weights were 25 to 27 percent greater in the inorganic fertilized and biosolids plots when compared to the control the second winter (February 1997) after application in the 1963 planted stand. Three winters after application (February 1998) fermentation plus humus layer dry weights from the biosoiids plots were an average of 10 percent less than the control while the inorganic fertilizer dry weights were 22 percent greater than the control. Fermentation plus humus layer dry weights from the 1986 planted stand were 19, 46, and 88 percent greater than the control in the inorganic fertilizer, low, and high biosolids plots, respectively two winters (February 1997) after application. Three winters after application, fermentation plus humuslayer dry weights were 35, 67, and 55 percent greater than the control in the 1 O-l O-l 0, low and high biosolids plots, respectively in the 1986 planted stand.

SUMMARY AND CONCLUSIONS

The inorganic fertilizer treatment increased two-year diameter growth increment by 50 percent (0.4") and 67 percent (0.2") over the control and volume per tree by 11 and 36 percent in the younger and older iongieaf stands, respectively. The high biosoiids level increased two-year diameter growth increment by 25 percent (0.2") and over the control and volume per tree two-year growth increment by 11 percent in the younger longieaf stand but no increase was realized in the older stand. Overall the low biosoiids application did not increase two-year growth in either iongieaf stand. Subsequent biosolids applications at higher N and P levels (plus associated macro- and micronutrients) may increase incremental growth in the older stand to similar levels as the 1 O-l O-l 0 fertilizer level.

Year four post application (February 1999) forest floor litter layer collection and weighing determined that the pine straw production response (maximum bales/acre) to fertilization (inorganic and biosoiids) peaked third winter after fertilization in the older stand. This past winter's (February 1999) fertilized litter layer dry weights declined by 6 percent (high biosolids) and 22 percent (10-10-10) compared to the previous winter's fertilized litter layer dry weights. The control plot litter layer dry weight increased by an average of 15 percent per year between 1996 and 1999 in the 1963 established stand. Total extra pine straw production from the 1 O-l O-l 0 treated plots was 155 bales/acre versus the control in 1997 and 1998. The high biosolids treatment increased pine straw production by 102 bales/acre over the control during this same period. The extra pine straw bales per acre production over the control declined from 73 and 54 bales in 1998 to 27 and 35 bales in 1999 in the 10-10-10 and high biosoiids plots, respectively.

Table 3-Mean pine straw[a] production in a 1963 planted longleaf pine stand, Alpin soil, on the Sand Hills Forest in Chesterfield County, South Carolina

Year	Treatment	Litter layer dry wt/ac	Bales/ac	Gain (-loss) vs control	Extra bales/ac
		Lbs		*Percent*	
1996	Control (C)	1,650	66		
	10-10-10	1,475	59	-11	-7
	Low Biosolids (LB)	1,750	70	6	4
	High Biosolids (HB)	1,325	53	-20	-13
1997	C	2,000	80		
	10-10-10	3,800	152	90	72
	LB	2,975	119	49	39
	HB	3,200	128	60	48
1998	C	2,200	88		
	10-10-10	4,025	161	84	73
	LB	3,300	132	50	44
	HB	3,550	142	62	54
1999	C	2,475	99		
	10-10-10	3,150	126	27	27
	LB	3,225	129	31	30
	HB	3,350	134	35	35

[a] Pine straw = forest floor litter layer dry weight + 25. Assumes a bale of pine straw is 25 lbs dry weight. This stand was thinned twice, most recently in 1994 prior to fertilization (May 1995). Stand had approximately 60 BA/ac at fertilization.

Table 4-Mean pine straw[a] production in a 1986 planted longleaf pine stand, Alpin soil, on the Sand Hills State Forest in Chesterfield County, South Carolina

Year	Treatment	Litter layer dry wt/ac	Bales/ac	Gain (-loss) vs control	Extra bales/ac
		Lbs		*Percent*	
1996	Control (C)	1,675	67		
	10-10-10	1,325	53	-21	-14
	Low Biosolids (LB)	1,950	78	17	11
	High Biosolids (HB)	1,650	66	-1	-1
1997	C	1,775	71		
	10-10-10	2,625	105	48	34
	LB	2,725	109	54	38
	HB	3,300	132	86	61
1998	C	2,500	100		
	10-10-10	4,825	193	**93**	**93**
	LB	3,200	128	28	28
	HB	4,925	197	97	97
1999	C	3,825	153		
	10-10-10	3,775	151	-1	-2
	LB	4,100	164	7	11
	HB	3,975	159	4	6

[a] Pine straw = forest *floor* litter layer dry weight + 25. Assumes a bale of pine straw is 25 lbs dry weight. This stand was planted @ 8x9 feet with an average of 460 stems/acre at fertilization (May 1995).

The young stand followed a similar trend as the older stand with peak pine straw production occurring three winters after fertilization (February 1998). Year four post application (February 1999) litter layer dry weights declined by 19 percent (38 **bales/ac)** and 22 percent (42 bales/acre) compared to winter 1998 values for the 1 O-l O-l 0 and high biosolids plots, respectively. Pine straw production in 1999 was essentially the same between the control and fertilized plots in the young stand. The pine straw fertilizer response duration was 2 years in this young stand on these deep sands of the Sandhills **physiographic** region. Part of this was due to the fact that the control plot litter layer greatly increased between 1997 and 1998 (1775 to 2500 **lbs/ac** dry weight) and again between 1998 and 1999 (2500 to 3825 **lbs/ac** dry weight). This is an average increase of 47 percent per year between 1997 and 1999. Basically, the unfertilized plot trees "grew" into the pine straw producing stage in 1998 at age twelve. Fertilization (inorganic or organic) did reduce the age at which this young **longleaf** stand could have straw raked by one to two years. It is feasible that the litter layer may have been rakable one or two years earlier if fertilization was initiated sooner. Fertilization increased pine straw bale production by 127 (1 O-l O-l 0) and 158 (high biosolids) bales/acre over the control between 1997 and 1998 in the 1986 planted stand.

Approximately 15 to 20 percent of the **longleaf** pine in the 1986 planted stand 10-10-10 plots **(@** 150 lbs N, P_2O_5, and K_2O/**ac)** became top-heavy, bent over, and never recovered. This loss is apparently due to the large increase in foliage production and the stems not able to take the extra weight. Due to the 15 to 20 percent losses, only 75-100 lbs of N per acre (plus 25 lbs **P/ac** and 50 lbs **K/ac)** would be recommended for these younger **longleaf** stands on these deep sands. The older **longleaf** stand **(32-years-old** at fertilization) had no losses due to increased foliage production at 150 lbs **N/ac** fertilizer level.

In 1995 the Sand Hills State Forest generated $250,000 in pine straw revenues. The average return on selling pine straw raking rights under non-fertilized conditions on the Sand Hills State Forest is $1 **00/ac** (with a range of $75 to **$175/ac).** Under fertilized conditions this return can be increased by $28 to **$97/acre** starting two years after fertilization. The 1 O-l O-l 0 and high biosolids produced and extra 165 and 124 **bales/ac,** respectively in the older stand and 111 and 163 **bales/ac,** respectively in the younger stand between 1996 and 1999 when compared to the control.

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CHICKEN LITTER AS A NUTRIENT SOURCE FOR SLASH PINE ESTABLISHMENT IN THE GEORGIA COASTAL PLAIN[1]

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Abstract-Slash pine (*Pinus elliottii*) regeneration plots were established in the Coastal Plain at Glennville, Georgia to evaluate broiler litter as a potential P source for pine regeneration. The experimental design consisted of seven treatments by three replications of approximately 0.1 acre plots (-100 trees/plot). Treatments consisted of: 1) Control (no litter or industrial-standard fertilizer), 2) 1 ton litter/acre (80 Ibs N/acre, 28 Ibs P/acre, 33 Ibs K/acre), 3) 2 tons litter/acre, 4) 440 Ibs diammonium phosphate (DAP)/acre at N rate equivalent to Treatment 2, 5) 880 Ibs DAP/acre at N rate equivalent to Treatment 3, 6) Industrial-standard fertilization rate (125 Ibs DAP/acre), 7) Industrial standard plus micronutrients. Pelletized litter applied at the 1 and 2-ton rate significantly increased plant growth (height and ground-line diameter) over the control and was comparable to the industry-standard DAP application. Results of plant tissue analysis showed an increase in P level from a control of 0.131 to 0.139 percent and 0.183 percent for the 1 and P-ton/acre litter application rate, respectively. All other plant tissue constituents (N, Ca, Mg, Cu, Zn) were not significantly different from the control. Phosphorus soil test levels determined 1 year post-treatment increased from control levels of 8.0 Ibs/acre to 10.8 Ibs/acre and 18.4 Ibs/acre P for the 1 and 2-ton litter application rates, respectively. Assuming application costs for chicken litter are similar to application costs for other forest-applied organic materials, application will cost approximately $3.60/ton and hauling costs for up to 50 miles will add $7.00/ton. These costs, plus $5.00/ton material cost, total $15.80 and compare favorably with costs for aerial application of DAP at $24.38/acre.

INTRODUCTION

Georgia's forest and poultry industries are two of the largest industries in the State, contributing an estimated 26 billion dollars to the annual economy and directly employing 175,600 workers (Georgia Forestry Commission 1995, Mauldin and others 1993). Favorable soil and climatic conditions and the availability of rural expanses in the State have fostered the development and success of these two industries. The annual production of approximately one billion birds generates 1.5 million tons of litter. With the potential implementation of P-based nutrient management plans for litter disposal, alternatives to the current practice of pasture application need to be developed. The recent expansion of the poultry industry into south Georgia has also generated concern over waste and nutrient management on the sandy Coastal Plain soils.

A previous study (Bush and others 1998) demonstrated that broadcast application of broiler chicken litter at a rate of 1 ton/acre produced pine growth comparable to current industrial intensive-management fertilizer treatments and significantly greater than the control. Plant tissue analysis showed a linear P increase with increasing application rates of chicken litter. It also showed that several micronutrients (B, Cu, Zn) are marginal on industrial pine plantations. Utilizing chicken litter as a P source during stand establishment would also supply N and micronutrients. Previous attempts at broadcast application of chicken litter at stand establishment have resulted in aggravated weed problems due to increased fertility and improved soil conditions. This problem may be circumvented by the use of herbicides currently prescribed in intensive pine management. It is, therefore, of interest to evaluate graded levels of chicken litter as a macro and micronutrient source.

Previous work at The University of Georgia (W. C. Merka, University of Georgia Department of Poultry Science, unpublished data) determined that a blend of fine fraction/middle fraction litter material produced a better pellet and the energy required to produce a "fine" pellet was much less than that required to produce a pellet of whole, ground litter. By separating the litter fractions prior to pelleting, the pelletizing mill was able to 1) decrease the material flow through a hammermill process, thereby reducing energy costs and maintenance on the hammermill itself, and 2) produce a uniform product with a nutrient (N, P_2O_5, K_2O) analysis of 4.6, 3.9, and 2.9 percent, respectively. The pelletized litter had a higher nutrient content than untreated broiler litter (table 1).

Use of pelletized chicken litter as a fertilizer source for pine establishment could produce 1) a new market for a waste product (chicken litter), 2) a balanced fertilizer source, 3) a "natural" fertilizer which would be considered "environmentally friendly," 4) savings in fertilizer costs to the forest industry, and 5) new jobs and/or increased profits for the rural poultry and timber producers.

This project was designed to follow up on the use of poultry litter as the P source during pine establishment in this region. The project compared the growth rate of pine seedlings fertilized with poultry litter at two rates to seedlings fertilized with chemical fertilizer presently used in intensive pine silviculture. Specific objectives of this study were to: 1) compare broadcast application of poultry litter with application of industrial-standard fertilizer for early pine stand development and 2) evaluate chicken litter as a possible source of micronutrients.

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Table I-Unprocessed broiler litter nutrient content analyzed by the UGA Agricultural and Environmental Services Laboratories 1994-1997 (463 samples).' Results are reported on an as-received basis

Nutrient	Level	Range	Lbs/acre[b]
	- - - - - - Percent - - - - - -		
N	2.70	0.03-5.74	54.0[c]
P	1.24	.01-3.78	24.8
K	1.86	.09-5.18	37.2
Ca	1.94	.60-5.70	38.8
	-- - - - - - ppm - - - - - - -		
B	37.80	.5-951	.07
cu	266	.25-1010	.53
Zn	287	15-2030	.57
Na	4683	l-10,200	9.36
Pb	3.93	<1.2-214	< .01
Ni	9.32	<1.o-73	.02
Cr	5.77	<1.o-293	.01
Mo	4.64	< .5-30.2	.009

[a] All elements except N were determined by dry ashing at 600C, followed by ICP analysis. N was determined by Kjeldahl digestion and ammonia titration.
[b] When applied at 1 ton/acre rate.
[c] Twenty-seven lbs N available.

EXPERIMENTAL DESIGN

Results of nutrient analysis conducted on chicken litter samples submitted to the University of Georgia Agricultural and Environmental Services Laboratories from 1994 to 1997 are summarized in table 1. All litter samples were dry ashed (Isaac and Johnson 1985) and levels determined by inductively coupled plasma (USEPA 1994). Nitrogen was determined by the Kjeldahl method (AOAC 1996).

A field study plot was established in 1997 on a Fuquay soil on private land in Tattnall County, GA. The pretreatment soil test indicated that the soils were low in P for pine production and had a pH of 5.2. The experimental design consisted of seven treatments and three replications. Plots consisted of IO trees in each of 10 adjacent rows (-100 trees/plot). Tree spacing was 4 by 12 ft. The treatments consisted of:

1) Control (no litter or industrial-standard fertilizer),
2) 1 ton litter/acre (80 Ibs N/acre, 26 Ibs P/acre, 33 Ibs K/acre),
3) 2 tons litter/acre,
4) 440 Ibs diammonium phosphate (DAP: 18-46-0)/acre at N rate equivalent to Treatment 2,
5) 880 Ibs DAP/acre at N rate equivalent to Treatment 3,
6) Industrial-standard fertilization rate (125 Ibs DAP/acre),
7) Industrial standard plus micronutrients at 200 lbs/acre (table 2).

Pelletized litter was used as a chicken litter source, since it is a uniform product that can be applied easily to 0.1 acre test plots. Treatments were applied as a surface broadcast application using a tractor-mounted cyclone fertilizer spreader in the spring of 1997. The pelletized litter used in this study was more nutrient-rich than the litters analyzed in table 1. Analysis of pelletized litter used in this experiment showed that N = 4.08 percent: P = 1.32 percent: K = 2.23 percent: Ca = 1.84 percent; Mg = 0.46 percent; B = 37 ppm; Cu = 366 ppm; Zn = 224 ppm; Mo = 5.1 ppm. Screening and pelletizing provide nutrient enrichment. The micronutrients' source was Super Rainbow-Pine (O-7-21), manufactured by IMC Rainbow, a division of IMC Global Operations, Inc., P.O. Box 607, Americus, GA 31709 (micronutrient analysis: P_2O_5 = 7.0 percent; K_2O = 21 percent; Ca = 8 percent; Mg = 2 percent: S = 9 percent; B = 0.5 percent; Cu = 0.75 percent: Mn = 1.3 percent and Zn = 0.75 percent). All treatments received one application of Velpar L®/Oust® for weed control during the first year and plots were rotary mowed between rows in the fall of the first and second years.

Tree growth was evaluated by measuring tree height and ground-line diameter at 1 year and by tree height only at the end of the second year. Due to slope conditions, initial treatment replications were treated as blocks, and individual rows within each treatment were treated as subsample

Table 2—List of treatments and nutrients applied

Treatment	N	P	K	Estimated cost/acre* [b]
	- - - - - - - -Lbs/acre - - - - - - -			- - $ - -
1 Control (no litter or industrial-standard fertilizer)	0	0	0	0
2 1 ton litter/acre (80 Ibs N/acre, 26 Ibs P/acre, 33 Ibs K/acre)	80	26.2	33.3	8.60
3 2 tons litter/acre	160	52.4	66.6	17.20
4 DAP at N rate equivalent to Treatment 2	80	89	0	50.97
5 DAP at N rate equivalent to Treatment 3	160	178	0	93.20
6 Industrial-standard fertilization rate (125 Ibs DAP/acre)	22.5	24.9	0	24.38
7 Industrial standard plus micronutrients	22.5	28.4	43.7	46.87

[a] Assuming DAP @ $190/ton and an aerial application cost of $0.10/lb.
[b] Litter cost (table 6).

locations. Growth was compared between all treatments and results were analyzed by ANOVA at the 0.05 level of significance. Outside guard treatment rows, as well as the first and last trees in a row were discarded. Composite samples of pine needles from each treatment and initial replication were collected in January from the last fully-formed flush of needles in the upper third of the crown (21 samples). A sample consisted of three fascicles/tree in the treatment block. Macronutrient analyses were conducted at the UGA Agricultural and Environmental Services Laboratories, Athens, GA.

RESULTS

Chicken litter was equivalent to a 2.7 N, 2.8 P_2O_5, 2.2 K_2O fertilizer, but has the advantage of being a slow-release fertilizer and also supplies some micronutrients (0.07 Ibs B, 0.53 Ibs Cu and 0.57 Ibs of Zn/ton). Factors that affect litter nutrient levels are 1) the number of chicken grow-outs on litter, 2) use of alum to control litter pH, 3) use of B for darkling beetle control, 4) composted vs. non-composted litter and 5) feed formulation. Studies have shown that only 50 percent of the N applied as broiler litter is available for plant uptake during the first year (Gould and others 1996). Thus 1 to 2 tons of broiler litter will provide a good nutrient source to meet initial plant requirements at establishment without nutrient overload.

Pelletized chicken litter applied at the 1 and 2-ton rate produced growth comparable to the industrial-standard DAP application rate (125 Ibs/acre) and greater than the untreated control 1 and 2 years after establishment (table 3). The significant growth increase of the industrial-standard application vs. the untreated control was not observed in the second year. This may reflect the lower sensitivity of height than ground-line diameter as a response variable. The P-ton application rate did not give an additional growth response over the l-ton litter rate. Addition of DAP at N rates equivalent to the litter rates did not produce additional height growth over the litter rate. Pine survival and growth were excellent.

First-year foliar tissue analysis showed a significant response to P fertilization but the response was not significant at the end of the second year (table 4). No significant treatment-related effects were observed for foliar N, K, Cu and Zn at Years 1 *or* 2 (tables 4 and 5). Boron levels were significantly lower in pines receiving supplemental N fertilization (Treatment 5). Boron deficiency has been observed in the Coastal Plain of the Southeast. In most plants, the average B content is 20 $mg \cdot kg^{-1}$ (ppm) on a dry-weight basis with 8-12 ppm being considered the critical range for slash pine (*Pinus elliottii*). Applications of N have induced B deficiency in plants when soil B levels are low, evidently the result of a dilution of B and its failure to move from older to developing meristematic tissues. Boron deficiency is expressed as an abnormal or retarded elongation of growing points and/or apical meristems. Young leaves are misshapen, wrinkled, thicker and darker in color. Eventually, terminal growing points die (Mills and Jones 1996).

The second-year plant tissue analysis did not show significant differences in N, P or K levels by treatment. The N, P and K are at minimal nutrient levels for sustained growth responses, namely 1.2, 0.12 and 0.4 percent, respectively (Moorhead 1998). Tissue levels of Cu were below sufficiency levels (table 5) at the end of the second year. Due to the slope/replication effect observed in the second-year tree growth, significant differences in foliar tissue levels may have been masked by growth responses.

Chicken litter contains N, P, K and micronutrients (B, Cu, etc.) necessary for plant growth. Its use increases soil organic matter, increases soil water-holding capacity and

Table 3-Evaluation of l- and 2-year pine growth

Treatment	Height		Stem diameter at soil line
	Year 1[a]	Year 2	Year 1
	------- Feet -------		*Inches*
1 Control (no litter or industrial-standard fertilizer)	4.28C	6.66C	1.68C
2 1 ton litter/acre (80 Ibs N/acre, 26 Ibs P/acre, 33 Ibs K/acre)	4.87AB	7.91AB	1.82AB
3 2 tons litter/acre	4.75AB	7.24BC	1.788
4 DAP at N rate equivalent to Treatment 2	4.78AB	7.66AB	1.75BC
5 DAP at N rate equivalent to Treatment 3	5.10A	8.10A	1.90A
6 Industrial-standard fertilization rate (125 Ibs DAP/acre)	4.708	7.12BC	1.798
7 Industrial standard plus micronutrients @200 Ibs/acre	4.50AB	7.43ABC	1.66C

Plot design: 7 treatments, 3 replications/treatment. Since there was a significant replication effect, replications were treated as a block; row averages within replications were treated as individual replications. The error term was replication by treatment sum of squares.
Soil type: Fuquay; Pretreatment soil test: pH = 5.2; P = 7 (low); K = 47 (low); Ca = 363 (adequate); Mg = 49 (low).
[a] Means within column followed by same letter are not significantly different at 0.05 level of significance as determined by Duncan's Multiple Range test.

Table 4—Plant tissue analysis for years 1 and 2

Treatment	N[a]		P[b]		K[c]	
	Year 1[d]	Year 2	Year 1	Year 2	Year 1	Year 2
	Percent					
1 Control (no litter or industrial-standard fertilizer)	0.92A	1.22A	0.131C	0.110A	0.735A	0.424A
2 1 ton litter/acre (80 ibs N/acre, 26 Ibs P/acre, 33 Ibs K/acre)	.88A	1.27A	.139BC	.106A	.894A	.499A
3 2 tons litter/acre	1.OOA	1.21A	.157AB	.126A	.934A	.536A
4 DAP at N rate equivalent to Treatment 2	.93A	1.30A	.140BC	.132A	.717A	.465A
5 DAP at N rate equivalent to Treatment 3	1.04A	1.25A	.163A	.126A	.779A	.501A
6 Industrial-standard fertilization rate (125 Ibs DAP/acre)	.96A	1.28A	.139BC	.107A	.779A	.434A
7 industrial standard plus micronutrients	.87A	1.23A	.137C	.110A	.910A	.488A

[a] Critical range in slash pine = 0.8-1.2 percent (Moot-head 1998).
[b] Critical range in slash pine = 0.08-0.09 percent (Moorhead 1998).
'Critical range in slash pine = 0.25-0.30 percent (Moorhead 1998).
[d] Means within column followed by same letter are not significantly different at 0.05 level of significance as determined by Duncan's Multiple Range test.

Table 5—Micronutrient plant tissue analysis for years 1 and 2

Treatment	B		cu		Zn		Mo	
	Year 1[a]	Year2	Year 1	Year 2	Year 1	Year2	Year 1	Year 2
	ppm							
1 Control (no litter or industrial-standard fertilizer)	18.4AB	22.2A	3.1	IA	2.23A 41.1A	32.9A	<0.5	co.5
2 1 ton litter/acre (80 Ibs N/acre, 26 Ibs P/acre, 33 Ibs K/acre)	12.6BC	15.6A	2.54A	2.27A	37.1A	30.4A	< .5	< .5
3 2 tons litter/acre	14.4ABC	16.4A	3.87A	2.27A	39.5A	29.5A	< .5	< .5
4 DAP at N rate equivalent to Treatment 2	14.7ABC	16.2A	3.69A	1.77A	40.3A	28.7A	< .5	< .5
5 DAP at N rate equivalent to Treatment 3	12.3C	14.4A	3.62A	1.41A	37.8A	27.2A	< .5	< .5
6 industrial- standard fertilization rate (125 Ibs DAP/acre)	15.4ABC	15.5A	4.24A	1.19A	39.5A	28.8A	< .5	< .5
7 Industrial standard plus micronutrients	19.2A	19.5A	4.77A	1.30A	41.1A	29.6A	< .5	< .5

Sufficiency foliar range: B = 10-50 ppm, Cu = 3-7 ppm, Zn = 15-50 ppm, Mo = <detection limit (Mills and Jones 1996).
[a] Means within column followed by same letter are not significantly different at 0.05 level of significance as determined by Duncan's Multiple Range test.

stimulates the growth of beneficial soil organisms. Litter application can be managed to maximize the economic advantage of the nutrients and minimize the adverse impacts on the environment.

The University of Georgia recommends application of 20 to 50 ibs/acre of P and <50 Ibs of N at stand establishment in Coastal Plain soils if P soil-test levels are low (<8 lbs/acre) (Moorhead 1998). Application of 2 tons of litter (nutrient levels for unprocessed litter given in table 1) would add -50 ibs P/acre and 54 ibs N/acre (assuming N is 50 percent available). This addition of 1 to 2 tons of unprocessed litter/acre or 1 ton of pelietized litter meets the requirements of a reasonable nutrient management plan and produces a significant growth response comparable to current forest fertilization practices. if litter nutrients are concentrated by further processing, then the application rate should be reduced accordingly. Addition of higher rates should be considered a waste disposal rather than litter utilization. Additional loading may result in nutrient movement to groundwater or surface water resources.

ECONOMIC ASSESSMENT

For poultry litter to be adopted as a nutrient source for pine stand establishment, it must increase the growth greater than or equal to the standard fertilization practice of applying 125 lbs of DAP (18-48-O) and the cost of procuring, transporting and applying litter must be equal to or less than the cost of procuring and applying DAP. At $190/ton for DAP (1999 bulk dealer price) and an aerial application cost of $0.10/lb, the total cost per acre for an industrial application rate would be $24.38/acre (table 6). Assuming application costs for chicken litter are similar to application costs for other forest-applied organic materials, application will cost approximately $3.60/ton and hauling costs for up to 50 miles will add $7.00/ton (Personal communication. Roger James. 1999. Custom fertilizer applicator, Airgrowers, Inc., P.O. Box 417, Homerville, GA 31634.). These costs, plus $5.00/ton material cost, total $15.60 and compare favorably with costs for aerial application of DAP at $24.38/acre (table 6). Pelletizing litter to obtain a more uniform, nutrient-rich product would add approximately $8.00/ton.

Limitations on the use of poultry litter include 1) the limited number of acres that can receive applications per day due to time considerations for hauling and handling, 2) the difficulty of operating traditional spreader trucks on uneven and poorly prepared sites, and 3) the convenience of procurement and aerial application of DAP, which may offset cost savings of using poultry litter.

SUMMARY

Field studies conducted in the Georgia Coastal Plain indicated that pelletized chicken litter applied at a rate of 1 to 2 ton/acre served as a P source for pine stand establishment. Leaf tissue N levels did not increase with increased litter level. Economic estimates indicated that chicken litter applied at a rate of 1 ton/acre would cost $15.60/acre. This compared favorably with the current DAP application cost of $24.38/acre. Weed control measures currently used in intensive stand management would minimize the potential increase in weed populations from litter applications.

Table 6—Cost breakdown for poultry litter application'

Item	cost
	--- $ ---
Litter	5.00/ton[a]
Transportation	
<10 miles (included in spreading cost)	—
1 O-50 miles	7.00/ton[a]
Spreading	3.60/ton[a]
Pelletizing	8.00/ton[b]
DAP application	24.38/acre

[a] Source: Personal communication. Roger James. 1999. Custom fertilizer applicator, Airgrowers, Inc., P.O. Box 417, Homerville, GA 31634.
[b] Source: Personal communication. James Tatum. 1999. Mill owner, Glennville Mills, Glennville, GA 30427.

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VECTOR ANALYSIS IDENTIFY LOBLOLLY PINE (*PINUS TAEDA* L.) PHOSPHORUS DEFICIENCY ON A BEAUREGARD SOIL[1]

A. Bekele, W.H. Hudnall, and A.E. Tiarks[2]

Abstract-We studied the response of densely stocked one-year-old loblolly pine (*Pinus taeda* L.) to N and P fertilizers on a Beauregard silt loam (fine silty, siliceous, thermic, Plinthaquic Paleudults). A "continuous function" experimental design with three replications was used. Each replication consisted of 12 m X 12 m plots, with three trees planted within a square meter area for each treatment. Ten levels each of N and P were applied. Application rates ranged from: 0 to 240 Kg ha^{-1} N, and 0 to 900 Kg ha-' P. Potassium was applied at a uniform rate of 50 Kg ha^{-1}. Phosphorus and K application rates were based upon adsorption isotherms, while N application rates were based upon a previous study on the same soil. Vector analysis provides an opportunity to simultaneously compare plant growth, nutrient concentration and nutrient content on one graph. Vector analysis revealed that P application increased P concentration, P content and dry weight showing unfertilized trees were deficient in P. Nitrogen-only application had an antagonistic effect on P by decreasing P concentration, P content and dry weight. Enhanced growth was observed when both N and P were applied in combinations.

INTRODUCTION

Fertilizer application has been shown to significantly enhance the productivity of forest stands on soils where nutrients have become deficient and limit growth (Pritchett 1979, Shoulders and Tiarks 1990, Vann 1984). Its effect is more pronounced on young trees when the fertilization program is targeted to overcome nutrient deficiencies during early growth stages (Torbert and Burger 1984). The rationale is that young trees have greater nutrient demand than mature trees. When a tree is fully grown, most of the nutrient demands for growth will be met by nutrient cycling and within tree translocation (Bowen and Nambiar 1984, Vann and Brooks 1983). Therefore, the early correction of nutrient deficiencies may, in some cases, mean the difference between total crop failure and a highly productive plantation(Ballard 1984).

Foliar analysis has been the preferred method of evaluating tree nutrient status because it provides an integrated assessment of the many factors that influence nutrition. Data from foliar analysis can be interpreted using vector analysis. Vector analysis provides an opportunity to simultaneously compare plant growth, nutrient concentration and nutrient content on one graph (Haase and Rose 1995). This technique allows to detect dilution effects, nutrient imbalances and interactions. Vector analysis was applied to interpret loblolly pine response to applied N and P on a Beauregard silt loam in central Louisiana. The objective of this study was to determine the response of loblolly pine to combined N and P fertilizers in the presence of applied K on a Beauregard silt loam.

MATERIALS AND METHODS

Description of the Area

Three 12-m X 12-m visually homogeneous plots were selected for the study at the Kisatchie National Forest, Rapides Parish, Louisiana. The site receives an average annual rainfall of 1270 mm and has a mean annual temperature of 20 °C. The soil is a Beauregard silt loam. A loblolly pine plantation had previously occupied the site. Duplicate auger soil samples from O-l 5 cm and 15-30 cm depths were randomly obtained from the three plots and bulked for base line nutrient analysis (table 1). Samples were analyzed for pH (1:2 in deionized water), exchangeable bases by 1 M NH_4OAc (Thomas 1982), Al by 0.1 M $BaCl_2$-NH_4Cl (Barnhisel and Bertsch 1982), CEC by NH_4OAc at pH 7 (Soil Survey Laboratory Staff 1992), organic matter by acid-dichromate oxidation (Nelson and Sommers 1982), Bray II P (Bray and Kurtz 1945) and particle size by hydrometer method (Gee and Bauder 1986).

Design and Fertilizers

The study employed the "continuous variable design" that was previously tested by Shoulders and Tiarks (1982) for loblolly pine fertilization. The design was replicated three times. The advantages and disadvantages of the design for exploratory fertilizer trials were described by Fox (1973) and Shoulders and Tiarks (1982). Each replication (block) had a 10-m X 10-m area for 10 P and 10 N rates. Each l-m square represented a cell (fig. 1). A buffer space of 2 m was left on each side of the blocks. Buffer spaces received the same fertilizer treatment as the adjacent cells. Three loblolly pine seedlings were planted in a triangular arrangement with spacing of 0.6 m between seedlings within a cell. The closest spacing between seedlings in adjacent cells was 0.7 m. A half-sib source was seeded into containers in April 1995 and out planted in January 1996.

The rate of P and K was derived from P and K adsorption curve of the soil, while N was based on a previous study by Tiarks (1982) on the same soil. Ten levels of P and N were applied with the rates of P increased in one direction (vertical) and N in another (horizontal). The application rates of N in kg ha^{-1} were 0 (control), 10, 20, 30, 40, 80, 120, 160, 200, and 240. The rates of P in Kg ha-' were 0 (control), 100, 200, 300, 400, 500, 600, 700, 800, and 900. The two border cells at the beginning and end of each row was fertilized at the same rate as the adjacent measurement cell (fig. 1). From the P adsorption curve, the application of 100 Kg ha^{-1} (45 ug P g^{-1} soil) was approximated to give 0.2 ug ml^{-1} equilibrium P solution. A comparable rate of 104 to 115 Kg ha^{-1} P was recommended by Tiarks (1982) to increase soil solution P to a level that gave 90 percent dry weight yield of greenhouse grown loblolly pine on the same soil series.

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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Table I-Selected physical and chemical characteristics of the study soil. Given values are means and standard deviations (SD) for two depths from three plots

	Depth (cm)			
	0-15		15-30	
Property	Mean	SD	Mean	SD
Organic matter, percent	1.6	0.1	0.5	0.1
pH	4.9	.1	4.8	.1
P, mg kg"	1.6	.2	1.1	.2
K, $cmol(+)kg^{-1}$	.1	.o	.1	.o
Ca, $cmol(+)kg^{-1}$	1.4	.3	1.1	.1
Mg, $cmol(+)kg^{-1}$	.5	.0	.5	.1
Al, $cmol(+)kg^{-1}$	.5	.5	1.5	.8
CEC, $cmol(+)kg^{-1}$	10.7	1.7	8.5	.8
Clay, percent	7.0	1.0	6.3	1.2
Silt, percent	59.3	2.1	61.0	3.0
Sand, percent	33.7	4.0	31.7	.6

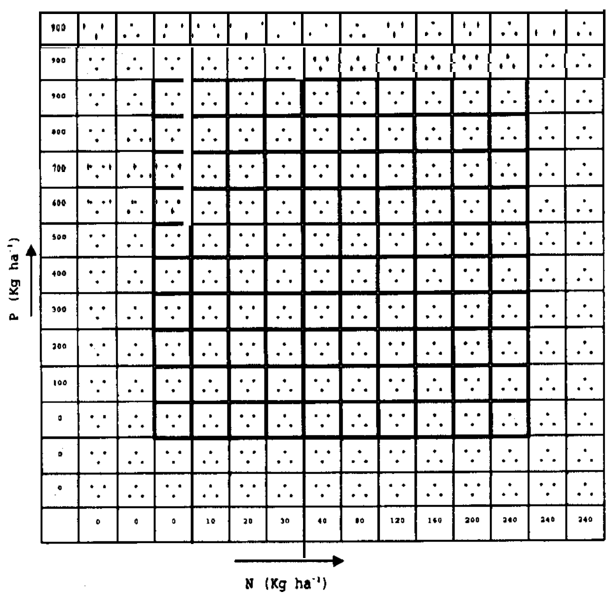


Figure I-Experimental plot layout. * Pine seedlings; distance between trees in a cell is 0.6 m and in adjacent cells is 0.7 m; 50 kg ha" K for all cells. Nitrogen rates increase horizontally from 0 to 240 kg ha" and P rates increase vertically from 0 to 900 kg ha^{-1}. This plot is replicated three times with a 2-m distance between each plot. Double line cells contain measurement trees.

About 0.22 mg L^{-1} of P in soil solution was required for the targeted maximum yield. Potassium was applied at constant rate of 50 kg ha-' to maintain nutrient balance in the plant. The rate was based on the soil's adsorption-desorption characteristics of K.

The plots were sprayed with Glyphosate (Roundup) and Sulfometuron (Oust) prior to planting and after fertilization to reduce weed competition. The appropriate amount of fertilizer was broadcast by hand four weeks after seedling planting. Nitrogen was applied as urea (45-0-O) phosphorus as triple superphosphate (0-46-0), and potassium as muriate of potash (O-0-60).

Growth Measurements and Sampling

After one year of growth, one randomly selected tree from each cell was measured for height and ground level diameter, and harvested. Each harvested tree was partitioned into foliage, and wood (stem and branches) and dried for 48 h at 70 °C in a convection oven. The foliage and wood were separately weighed and ground with a Wiley mill to pass a 1 mm mesh in preparation for elemental analysis.

Tissue Analysis

Foliage and wood were analyzed for N by a CHN analyzer (EA 1108 Elemental Analyzer, Fison Instruments). Concentrations of P and K were determined by inductively coupled plasma-atomic emission spectroscopy (ICP) after samples were digested in HNO, and H_2O_2 using a temperature-controlled digestion block (Huang and Schulte 1985). The following modifications were made for this study (Personal communication. Paul Bell. 1997. Professor, Agronomy Dept., Louisiana Agricultural Experiment Station, Agricultural Center, LSU, 104 MB Sturgis, Baton Rouge, LA 70802): I) tissue samples that adhere to the inside wall of digestion tube, due to frothing caused by the reaction between acid and tissue sample were rinsed down with deionized H_2O; ii) contents were heated until 2 to 3 ml extractant remained; and iii) final solution was diluted to 25 ml instead of 50 ml. The modification allows for more complete digestion.

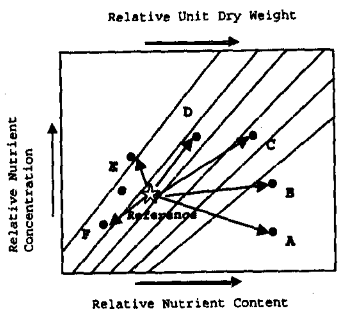
Data Analysis

Vector analysis was employed to graphically diagnose for presence of nutrient interaction and/or dilution as described by Hasse and Rose (1995). The data were normalized and the control (the cell without N and P treatment) was given a relative value of 1 .O. The interpretations, based on nutrient shifts (fig. 2), were made according to Hasse and Rose (1995).

RESULTS AND DISCUSSION

Nitrogen

Vector diagrams are presented for N in foliage (fig. 3a) and N in wood (fig. 3b). Vectors to all points were not drawn because of the many data points (97 points, three data points missing). For N, most of the data points (about 80 percent in foliage and 90 percent in wood) exhibited an "A" and a "B shift". This is interpreted as N not being limiting. The few "F shifts" (antagonistic) were associated with N application without P, but these did not occur for all treatments of N without P. At higher N levels and P levels, a "C shift", a sign of N deficiency, was observed. The antagonistic effect of N-only application on N uptake was more prominent for wood than for foliage (fig. 3). This is possibly a result from more N demand in the foliage than in wood at the early stage of plant development, where the production of photosynthate is at its maximum (Gosz 1984).



Direction of shift	Response in			Interpretation	Possible Diagnosis
	Dry weight	Nutrient			
		Conc.	Content		
A	+	-	+	Dilution	Non-limiting
B	+	0	+	Sufficiency	Non-limiting
C	+	+	+	Deficiency	Limiting
D	0	+	+	Luxury consumption	Non-toxic
E	-	++	±	Excess	Toxic
F	-	-	-	Excess	Antagonistic

Figure 2—Interpretation of directional shifts in nutrient concentration, nutrient content, and dry weight (Haase and Rose, 1995).

The mean N concentration in foliage for unfertilized trees was 1.57 percent. At the highest N-only application, the mean was about 2.00 percent, and at the highest N and P combination, it was 1.88 percent. In general, an increase in N concentration was not noted until rates of N applied exceeded 180 Kg ha-'. For most cases, addition of a deficient nutrient induces a rapid increase in plant growth and its concentration (Timmer 1991). For semi-mature loblolly pine, the critical foliar N concentration is 1 .1 percent (Allen 1987). The N concentration in unfertilized trees exceeded the critical level, but it is recognized that for younger trees critical concentration may be higher than 1 .1 percent.

Phosphorus

Vector diagrams for foliage P (fig. 4a) and wood P (fig. 4b) show similar patterns for nutrient P shift. The combined N and P, and P-only treatments invariably resulted in a "C shift"; showing that the trees would be P deficient if left unfertilized. A decrease in relative P concentration and relative P content ("F shift") was observed for trees fertilized with N alone, indicating the antagonistic effect of N on P uptake. Teng and Timmer (1994) demonstrated the antagonistic effect of N-only application in a study designed to test the nursery performance of white spruce [*Picea glauca* (Moench) Voss] with combined N and P fertilization. They attributed the antagonistic effect of N-only treatments to lower specific absorption rates of roots and suspected depletion of rhizospheric P. They also noted a synergistic effect of N and P uptake when these nutrients were applied together. Olykan and others (1995) also reported a significant decline in P concentration in the current needles of four-year-old *P. radiata* one year after fertilization with N alone.

Potassium

Figures 5a and 5b show major "A shift" (dilution). This dilution was caused mainly by combination of N and P. The "C shift" was associated with P-only application as well as P and N combination at low N levels. Nitrogen-only application

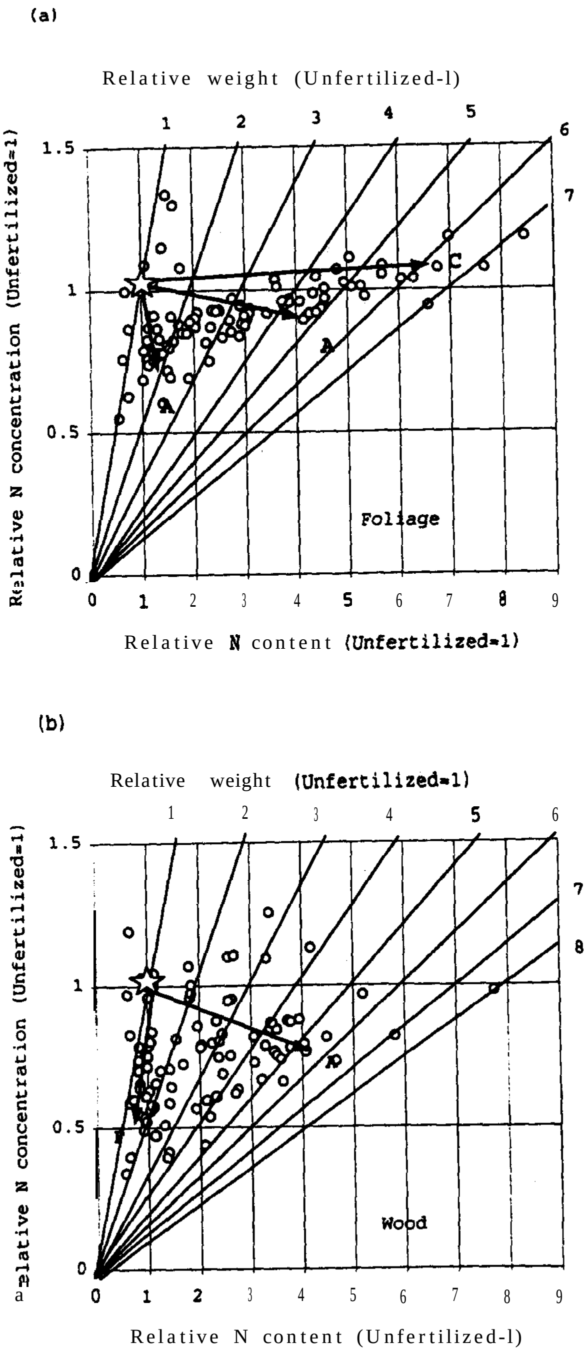


Figure 3—Relationship between N concentration, N content and d weight of (a) foliage and (b) wood on a relative scale as affected t various rates of applied N and P. A = Dilution, C = Deficiency. (☆ = unfertilized trees).

had an antagonistic effect ("F shift") on K uptake both in oliage and wood. Relative K concentration was greater in foliage than in wood showing greater dilution in wood tha oliage (table 2). Since K is mobile within the plant, it can transported to the foliage (Tisdale and others 1985). In general, K appears to be sufficient for the ranges of N an combination rates studied.

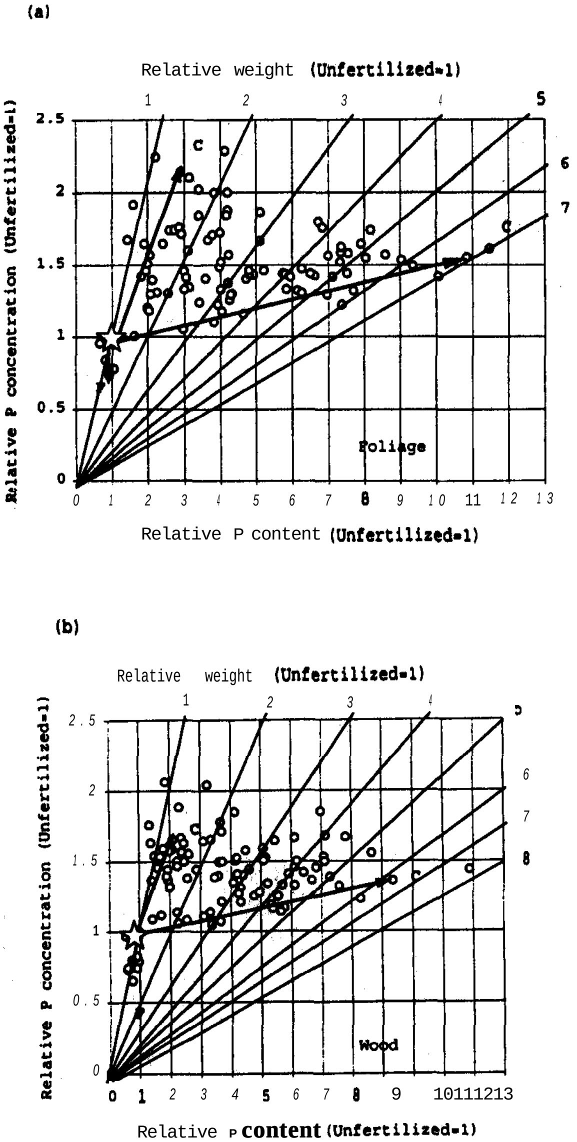


Figure 4—Relationship between P concentration, P content and dry weight of (a) foliage and (b) wood on a relative scale as affected by various rates of applied N and P. C = Deficiency, F = Antagonistic. (a = unfertilized trees).

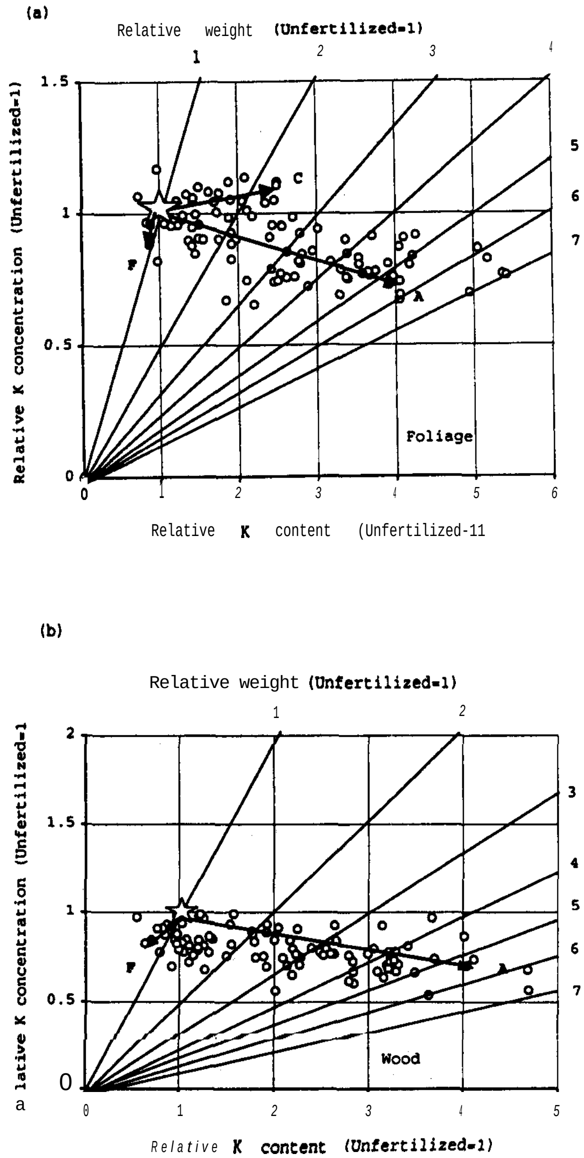


Figure 5—Relationship between K concentration, K content and dry weight of (a) foliage and (b) wood on a relative scale as affected by various rates of applied N and P. A = Dilution, C = Deficiency, F = Antagonistic. (☆ = unfertilized trees).

Calcium

The vector diagrams for foliage Ca and wood Ca are given in Figures 6a and 6b, respectively. The vectors were an "A shift", a "B shift" a "C shift" and an "F shift" for both foliage and wood. The observed "C shift" was not related to any particular N and P combination. Nitrogen-only fertilization had an antagonistic effect upon Ca uptake. In general, combined N and P application resulted in increased Ca utilization by the plant. Foliage Ca concentrations of unfertilized and fertilized trees was comparable (table 2) while a decrease was noted for wood part of fertilized trees. Thus, there was sufficient soil Ca (table 1) to sustain tree growth at the rates of N and P studied.

Table 2—Summary of nutrient concentration in foliage of unfertilized and fertilized trees at 240 kg ha" N and 900 kg ha" P application, and critical nutrient level obtained from literature

	Unfertilized		Fertilized		Critical level
Nutrient	Foliage	Wood	Foliage	Wood	Foliage[a]
	- - - - - - - - - - - - - - Percent - - - - - - - - - - - - - -				
N	1.57	0.75	1.86	0.71	1.10
P	.09	.07	.16	.10	.09–0.10
K					
Ca	.25	.21	.25	.17	.25–0.12

[a] For semi-mature loblolly pine, Allen (1987).

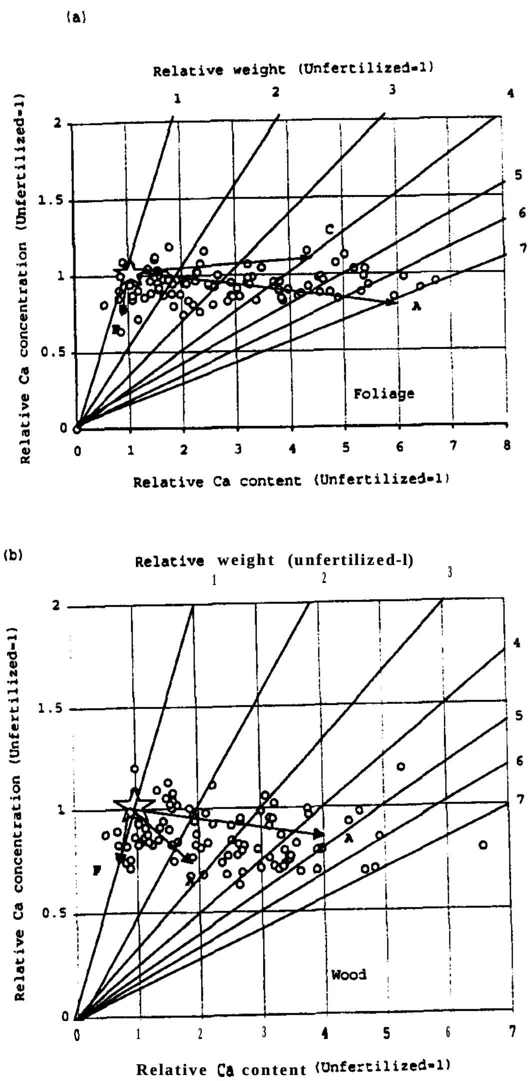


Figure 6—Relationship between Ca concentration, Ca content and dry weight of (a) foliage and (b) wood on a relative scale as affected by various rates of applied N and P. A=Dilution, C=Deficiency, F=Antagonistic. (☆ = unfertilized trees).

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UTILITY AND LIMITATIONS OF CHLOROPHYLL FLUORESCENCE FOR THE DETERMINATION OF GROWTH LIMITATIONS IN TREES[1]

John A. Peterson, John W. Groninger, John R. Seiler, and Mou Pu[2]

Abstract-To aid in silvicultural decision making, a fast, accurate and inexpensive means to determine the effects of environmental stresses, especially tree nutrition, on tree vigor is needed. In the past several years, chlorophyll fluorescence technologies have been developed that are both inexpensive and easily used under field conditions. To explore the applicability of fluorescence measures to southern industrial forests, a series of pilot studies were established. It was determined that photochemical efficiency vanes with the nutritional status of loblolly pine (*Pinus taeda)* and sweetgum (*Liquidambar styraciflua*) seedlings, with the water status of loblolly pine but not sweetgum seedlings, and with crown position in loblolly pine plantations. With further refinement and field testing, chlorophyll fluorescence may be a useful tool in tree nutrition management.

INTRODUCTION

Chlorophyll fluorescence is a relatively new technology that in recent years has become much easier to utilize as a field measurement. It is a physiologically based measurement that measures the efficiency of the light harvesting mechanism associated with photosystem II. As such, fluorescence has been shown to be sensitive to water (Lenham 1994, Oogren 1990), mineral nutrition, chilling (reviewed in Mohammed and others 1995) and light intensity (Groninger and others 1996). Fluorescence can be measured rapidly, usually taking only 30 seconds (following a 1 O-30 minute dark acclimation period) and is nondestructive, allowing for repeat measures on one leaf. Further, chlorophyll fluorescence can be very consistent, with coefficients of variation of 3 percent not uncommon. Finally, the instrumentation described within this paper was relatively affordable, with a purchase price of under $10,000. While the sensitivity of fluorescence parameters to environmental stresses is well known, the role of chlorophyll fluorescence in silvicultural decision making is largely unexplored. To apply fluorescence-based measures to silvicultural problems, a large body of data, under a variety of experimental conditions are needed. The pilot studies described in this paper were intended to provide information on potential uses and shortcomings of ahlorophyll fluorescence as a silvicultural tool. Specifically, four studies are described in this paper. Study 1 examined the influence of varying fertilizer levels on chlorophyll fluorescence over time for sweetgum seedling sprouts. Study 2 examined the influence of drought on both loblolly pine and sweetgum seedling fluorescence. Study 3 examined fertilizer levels and shade on both loblolly pine and sweetgum seedling fluorescence. Study 4 examined fluorescence characteristics in the upper and lower crowns of thinned and unthinned loblolly pine stands.

The overall objectives of these studies were to: Determine the sensitivity of loblolly pine and sweetgum chlorophyll fluorescence to several stresses; To determine whether fluorescence can be used alone or in combination with other measures to make diagnoses in multiple stress situations; Finally, to determine the feasibility of developing a fluorescence-based diagnostic tool to identify growth limitations in southern forests.

METHODS

Four separate studies are described in this paper. All fluorescence measurements were taken with a PK Morgan CF-1000 Chlorophyll Fluorescence Measurement System (PK Morgan Instruments, Inc., Andover, MA) after at least a 15 minute dark acclimation period. Three greenhouse studies described below were undertaken in the Virginia Polytechnic Institute and State University climate-controlled greenhouse in Blacksburg, Virginia. The one field study was conducted at the Reynolds Homestead Forest Resource Research Station in Critz, VA.

Study 1—Sweetgum Nutrition

On June 28, 1996 15 sweetgum seedlings that had been greenhouse-grown in peat moss and sand in 1 liter pots for approximately one year were transplanted into pure sand in 8 inch pots. All seedlings received an initial dose of Peters Soluble Trace Element Mix (Peters Fertilizer Products, Fogelsville, PA). After transplanting, the seedlings were placed in five blocks, and fertility treatments were randomly assigned to the three seedlings within each block. Fertility treatments included no, low, and high fertilization rates applied weekly as 20-20-20 NPK Peter's Professional Water Soluble Fertilizer (Peters Fertilizer Products, Fogelsville, PA). This equaled 0.0442 grams N, 0.0190 P and 0.0367 K per week for the high treatment and 0.0133, 0.0057, and 0.011 grams per week N, P, and K, respectively, for the low fertilizer treatment. The seedlings were top-clipped on July 12, leaving an 8 centimeter "stump". After the seedlings resprouted and leaves appeared to be fully expanded (59 days after top-clipping), fluorescence measurements commenced. Measurements were taken at irregular intervals, including 59, 105, 130,203, and 221 days after top-clipping. For the first measurement, the uppermost fully expanded leaves were measured. All measurements taken on or after the 105th day after top clipping were taken on leaves that were at 75 percent of the total height of the seedling. Fluorescence measurements were taken over 30 seconds, with an incident light level of 800 micromoles per meter squared per second. Statistical analysis consisted of a one-way ANOVA with five blocks.

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-I 8, 1999.

[2] Research Specialist, Research Associate, Professor, Assistant Professor, Virginia Polytechnic Institute and State University, Blacksburg, VA, respectively.

Study 2—Influence of Drought on Loblolly Pine and Sweetgum

Twelve seedlings each of loblolly pine and sweetgum seedlings were grown from seed in 1 liter pots in a 2:1:1 volume:volume:volume mixture of peatmoss, perlite and vermiculite. Treatment consisted of induction of drought by withholding water, followed by daily measurements until the individual seedling exhibited net negative carbon exchange rates (Lenham 1994). The loblolly pine and the sweetgum seedlings were 391 and 174 days old, respectively when droughting began. Fluorescence measurements were taken over 15 seconds, with an incident light level of 1000 micromoles per meter squared per second. Seedling Fv/Fm was regressed against days of drought.

Study 3—Influence of Shade and Nutrition on Loblolly Pine and Sweetgum

On March 16, 1996, 40 loblolly pine and 40 sweetgum germinals were transplanted into 5 gallon pots containing pure sand. One half of the seedlings of each species were then placed in either full greenhouse sun or under 75 percent shade cloth. One half of each of these sets of seedlings received high amounts of fertilizer, one half received low fertilizer. The high fertilizer treatment received 14.73 grams 6-month time release Sierra 15-10-10 time release fertilizer plus micros (Grace Sierra, Milpitas, CA), which equaled 0.0752 grams N, 0.0432 P and 0.0567 K per week. The low fertilizer treatment received one half of this amount. Fluorescence measures were taken prior to harvest, on September 9, 1996. Fluorescence measurements were taken over 30 seconds, with an incident light level of 800 micromoles per meter squared per second. Statistical analysis consisted of a two-way ANOVA with two fertilizer levels and two light levels.

Study 4—Influence of Thinning and Crown Position on Loblolly Pine

In March of 1980, one-half of three replicate eight-year-old loblolly pine stands were mechanically thinned by 50 percent from an initial 10 x 10 foot spacing. Scaffolding was erected to permit access to both the upper and lower crown foliage (Ginn and others 1991; Peterson and others, in press). In May of 1992 (four years after thinning), fluorescence measurements were taken in both the upper and lower crown of two sample trees within each treatment x block combination. Fluorescence measurements were taken over 10 seconds, with an incident light level of 1000 micromoles per meter squared per second.

RESULTS AND DISCUSSION

A variety of fluorescence measurements describing a Kautsky fluorescence induction curve can be obtained from the PK Morgan CF-1000 (Greaves and others 1991). The photochemical efficiency of photosystem II is an ideal measurement for measuring environmental stresses on the health of the photosynthetic mechanism. The photochemical efficiency of photosystem II is estimated by Fv/Fm, which is the ratio of variable fluorescence (Fv) to maximum fluorescence (Fm). Most forest trees usually exhibit Fv/Fm values of 0.6 to 0.8. Further, Fv/Fm provided the most consistent results with regards to fertility and other environmental stresses. For these reasons, Fv/Fm will be the primary fluorescence parameter discussed in this paper.

Study 1—Sweetgum Nutrition

Greaves (1991) reported that saturating light is necessary to estimate Fv/Fm, but maintained that Fv/Fm should not vary over a wide range of measurement light intensities. Mohammed and others (1995) indicated that the measurement light intensity should be tested with the plant material under study. In our measurements of sweetgum seedlings it was determined that Fv/Fm was reduced when incident light was increased from 800 to 1000 micromoles per meter squared per second across all three fertilizer treatments. To maintain light levels close to saturation and to reduce the drop in efficiency associated with very high light levels, measurements were taken at 800 micromoles per meter squared per second.

Across all fertilizer levels there was little difference in Fv/Fm between lower and upper crown leaves when measured 105 days after top clipping. However, it was determined that leaves that originated at 75 percent of total shoot height expressed less variation and greater differences between treatments than very young leaves.

Differing levels of fertilizer had a large effect on seedling height and diameter growth. Seedling height and diameter were significantly greater with high fertilization (table 1). Examining photochemical efficiency over a greenhouse "growing season", several trends become apparent (fig. 1). \v/Fm values for these seedlings ranged from 0.6 to 0.73. The highest fertilization level consistently had the highest Fv/Fm values of the three fertilizer levels, and the low fertilizer treatment was consistently greater than the non-fertilized treatment. Further, the difference in Fv/Fm between levels was significant (p = 0.10) on all but the last sampling date. Under controlled environmental conditions, the nutritional status of sweetgum sprouts influences photochemical efficiency.

Overall, a general increase followed by a decrease in Fv/Fm was observed over time across all three treatments, with the high fertilizer treatment expressing the highest values later in the season (fig. 1). The largest differences in Fv/Fm between the three treatments were observed during the greenhouse equivalent of "mid- to late-summer". A possible explanation for the late season decrease in Fv/Fm values may be leaf senescence. The leaves of unfertilized trees were changing color and abscising by the end of the study.

Table l-Height (from sprout attachment) and diameter (measured 2.5 centimeters above attachment) of greenhouse-grown sweetgum sprouts provided with three levels of fertilizer

Fertilizer level	Height	Diameter
	cm	*mm*
High	33.3 a	7.34 A
Low	14.2 b	3.18 B
None	3.5 b	2.42 B
P-value	.0001	.0002

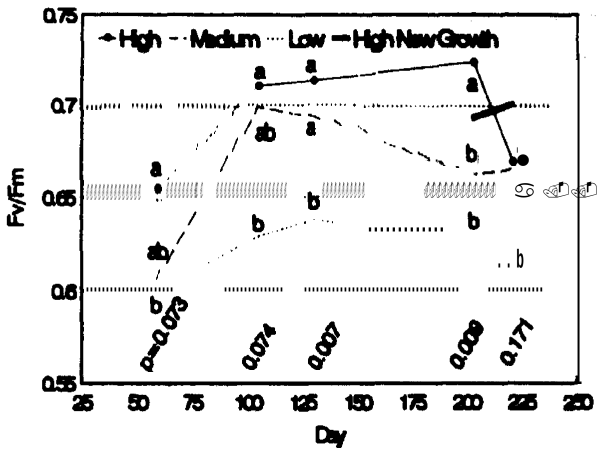

Figure l-Change in Fv/Fm over time for greenhouse-grown **sweetgum** sprouts grown under high, medium and low fertilizer levels.

Interestingly, when fluorescence was measured on the new, late season flushes of two well-fertilized trees, relatively high Fv/Fm values were observed (fig. 1).

Study 2—Influence of Drought on Loblolly Pine and Sweetgum

Sweetgum photochemical efficiency apparently did not change significantly in response to drought ($p = 0.117$) even though the seedlings had net negative carbon exchange rates after several days (fig. 2). In contrast, loblolly pine photochemical efficiencies declined as the seedlings became increasingly stressed ($p = 0.005$). This has two implications. First, if fluorescence is to be used to determine the nutritional status of loblolly pine, drought stress may result in an artificially low Fv/Fm value. Second, the decrease in Fv/Fm over time during a drought indicates that chlorophyll fluorescence may be a useful tool in measuring the water status of loblolly pine.

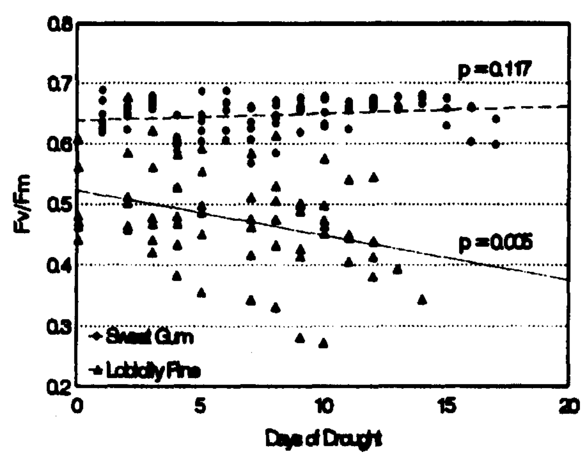

Figure 2—Change in Fv/Fm with drought for greenhouse-grown loblolly pine and **sweetgum** seedlings.

The usefulness of chlorophyll fluorescence as an indicator of water stress apparently varies by species. Oogren (1990) found that Fv/Fm did not provide any useful drought stress information, and that photochemistry in *Salix* leaves is unaffected except by severe drought stress. Conroy and others (1986) did not directly report Fv/Fm, but found that a variety of other fluorescence parameters in *Pinus radiata* were affected by drought stress. Further, these parameters often interacted with P deficiency.

Study 3-Influence of Shade and Nutrition on Loblolly Pine and Sweetgum

Shade did not significantly change seedling photochemical efficiency in either sweetgum or loblolly pine (table 2). Groninger et. al (1996) found that the Fv/Fm change with shading apparently varies by species. Fv/Fm values of loblolly pine and *Liriodendron tulipifera* did not change with shade, but *Pinus strobus* and *Acer rubrum* Fv/Fm values were reduced by shade.

The fertilizer levels used in this study were overall quite high. Consequently, there was no difference in sweetgum mass between fertilizer treatments (table 2). Pine mass was greater with the high fertilizer treatment, but no difference in Fv/Fm was detected between the two fertilizer treatments (table 2). However, under full sun conditions (table 3) seedling biomass was significantly greater with high amounts of fertilizer and Fv/Fm was significantly greater for the high fertilizer treatment. This indicates that loblolly pine chlorophyll fluorescence is sensitive to tree nutrition, even under very fertile conditions.

Apparently the actual amount of nutrition applied to the seedlings is closely related to observed Fv/Fm. The highest Fv/Fm values observed in Study 1 (fig. 1) ranged from 0.711 to 0.723. Sweetgum in this study had mean Fv/Fm values of 0.723 for the low fertilizer treatment and 0.726 for the high fertilizer treatment. The actual amount of fertilizer applied weekly was very similar to the amount of fertilizer applied to the high fertilizer treatment in study one. The low fertilizer treatment had only 15 percent less N, 14 percent more P, and 22 percent less K than in study one.

Study 4—Influence of Thinning and Crown Position on Loblolly Pine

When averaged over crown position, thinning did not change photosynthetic efficiency, with an overall mean Fv/Fm value of 0.788. If the greenhouse results of study 3 are scalable to large trees in the field, an Fv/Fm value of 0.788 is expected to be reflective of adequate nutrient availability. Indeed, the site index at base age 25 years was 80 feet (with weed control), and foliar analysis of these trees indicated that the foliar N content was greater than 1.2 percent (Ginn and others 1991), which is considered to be above the critical level for loblolly pine (Wells and Allen 1985).

Upper crowns were found to have significantly greater Fv/Fm values than lower crowns (0.8 vs. 0.775; $p = 0.05$). As indicated by study 3, the decreased Fv/Fm values in the lower crown are probably not solely induced by shading. Lower needles were likely in overall poorer health, which is reflected in lower photochemical efficiency.

Table 2—Fv/Fm and total seedling mass (g) of green-house grown sweetgum and loblolly pine seedlings grown under two light levels and two fertilizer levels

Treatment levels	Sweetgum Fv/Fm	Sweetgum Mass	Loblolly pine Fv/Fm	Loblolly pine Mass
Fertilizer				
High	0.726	35.8	0.819	19.9
Low	.723	33.3	.804	13.9
P-value	.826	.550	.142	.041
Light				
High	.736	45.7	.815	28.4
Low	.713	23.4	.807	4.2
P-value	.119	.0001	.422	.0001

Table 3—Fv/Fm and total seedling mass (g) of green-house grown loblolly pine seedlings grown under full sun and two fertilizer levels

Fertilizer levels	Fv/Fm	Mass
High	0.827	33.3
Low	.803	23.5
P-value	.075	.069

A significant interaction between crown position and thinning was observed (p = 0.033). In control stands the upper crown had very high mean Fv/Fm values (0.806) and the lower crown had relatively low mean values (0.772). Thinning tended to decrease the difference between the upper and lower crowns. In thinned stands the upper crown had a mean value of 0.795 and the lower crowns averaged 0.778. This suggests that thinning may influence fluorescence results if samples are taken from only one crown position.

CONCLUSIONS

Chlorophyll fluorescence is a fast, accurate and inexpensive measurement that has developing applications in commercial forestry (Hawkins and Binder 1990). The fluorescence parameter Fv/Fm, which estimates photochemical efficiency appears to vary with sweetgum and loblolly pine nutrition status, leaf age, loblolly pine water status, and crown position. Bjorkman and Demmig (1987) suggest a theoretical maximum Fv/Fm of 0.832 for a wide variety of C3 species under specific measurement conditions. If the theoretical maximum of loblolly pine and sweetgum can be determined for a standardized set of field measurement conditions, and if Fv/Fm values of field trees consistently vary with nutrition as do the greenhouse seedlings utilized in this experiment, fluorescence may prove to be a useful tool that can be used in conjunction with leaf area, and soil and foliar nutritional analyses in both loblolly pine and sweetgum nutrition management. Especially encouraging is the variation of sweetgum fluorescence with soil nutrition coupled with a lack of sensitivity to water stress.

Before the effectiveness of fluorescence as a management tool can be evaluated, several important issues remain to be addressed. It is not known if field nutritional deficiencies can be detected, which portion of the crown of larger trees offer the most consistent or early results, how much fluorescence vanes between individuals, stands, or on a regional basis, or to what extent the influence of nutritional deficiencies is masked by drought, heat or other field stresses.

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Biometrics

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MODELING FOREST TIMBER PRODUCTIVITY IN THE SOUTH: WHERE ARE WE TODAY?[1]

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Abstract-The current southern species growth and yield prediction capability, new techniques utilized, and modeling trends over the last 17 years, were examined. Changing forest management objectives that emphasize more non-timber resources may have contributed to the continuing general lack of emphasis in modeling the timber productivity of the South's largest forest types-mixed pines and mixed pine-hardwood stands. Less than 10 percent of the literature during the period of this review pertained to growth and yield predictions of that resource. On the other hand, 45 percent of the literature centered on predicting the productivity of loblolly pine, almost all in plantations. Clearly the modeling emphasis has been, and continues to be, on the results of intensive management of the South's commercially valuable species, although some notable work has been done for other species and other forest types. Several new procedures have been developed for projecting tree and stand growth using whole stand, diameter distribution, and individual tree modeling approaches. New distribution-free and stand table projection techniques have also been presented. Basic information on the available complete growth and yield prediction systems produced for southern species during this review period is presented and summarized.

INTRODUCTION

In any endeavor periodic evaluation of where we are and where we have been helps determine where we should go. Evaluation is especially important in growth and yield research because it is long term in nature. Because many years of data collection are required to develop the most useful prediction models, the results of changed objectives come slowly. The authors felt that determination of the current status of growth and yield modeling in the Southern U.S. and an examination of modeling trends over the last several years would be both timely and useful to researchers and practitioners.

The growth and yield capability for southern species currently available to the public was examined using the forestry literature from the last 17 years. The most recent general review of this subject was published in 1983 (Hotvedt and Jackson 1983) although other excellent, but more narrow, reviews have been published since then (e.g., Bolton and Meldahl 1989; Buford 1987; Burkhart 1986, 1987, 1990; Farrar and Murphy 1990; Farrar and others 1986; Feduccia 1982). The following focuses on forests in the Southern U.S.; however models developed for some species, especially hardwoods, may also include other areas. The literature reviewed is placed into species-forest type categories and the complete newly-developed or recently-revised models for these categories are listed and referenced.

The specific objectives of this investigation follow: (1) to catalog and present the complete Southern U.S. growth and yield prediction systems developed or updated during the selected period, (2) to note new modeling procedures, and (3) to present overall modeling trends. Therefore, the component models are not covered in this paper. A future publication will include a more complete and in-depth review of the Southern U.S. growth and yield literature.

OVERVIEW OF NEW OR REVISED PROCEDURES AND SYSTEMS

Several new techniques to project and/or predict tree or stand growth were introduced during this period. Many emphasize growth and yield compatibility at different levels of resolution. For example, in diameter distribution models Hyink and Moser (1983) showed that compatibility could be achieved by using a parameter recovery process. Tang and others (1997), noted that these techniques emphasize finding ways to project growth of individual trees or tree size classes so that the aggregation of their growth equals predicted stand level growth (e.g., Daniels and Burkhart 1988) or they desegregate stand growth into the growth of the individual trees or tree size classes (e.g., Harrison and Daniels 1988, Nepal and Somers 1992, Somers and Nepal 1994, Zhang and others 1993).

In all modeling arenas, tree size-class information was recognized as the most desirable output which led to development of many more diameter distribution models (e.g., Bailey and others 1985, Baldwin and Feduccia 1987, Burk and Burkhart 1984, Lenhart 1988, Matney and Sullivan 1982, Zarnoch and others 1991). Most of the models use the Weibull distribution and various parameter recovery techniques. A bivariate distribution approach using Johnson's S_{BB} distribution (Hafley and Buford 1985, Hafley and others 1982) was also introduced. Some combine techniques such as diameter distribution and stand table projection (e.g., Pienaar and Rheney 1993). Significant progress has been made in developing distribution independent systems (Borders and others 1987, Tang and others 1997) and stand table projection models (e.g., Cao and Baldwin, in press; Nepal and Somers 1992; Pienaar and Harrison 1988) that individually update each size class in the previous stand table.

The (PTAEDA) model (Daniels and Burkhart 1975), apparently the only distance-dependent individual tree model developed for the South, was updated (PTAEDA2,

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-16, 1999.

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Burkhart and others 1987). Distance-independent individual tree models developed include (G-HAT)(Harrison and others 1986), (GATWIGS)(Bolton and Meldahl 1990), (SETWIGS[3]), (FVS)(Teck and others 1996), and (TRULOB)(Amateis and others 1995). Some existing models were reworked to expand their usefulness. Green and Strawderman (1996) created a Bayesian version of a slash pine yield model (Zarnoch and others 1991) that provides users with a measure of the variability of the yield estimates. This information is not available from the original model.

Almost all of this work was devoted for single species in even-aged stands. However, some significant new work was accomplished for mixed species stands (softwoods, hardwoods, or both) and uneven-aged management of single or multiple species. The work of Mengal and Roise (1990) and Schulte and others (1998a, b) is notable. Both teams used matrix modeling (Harrison and Michie 1985, Leslie 1945), which predicts a future stand diameter distribution based on a matrix of transition probabilities and the current diameter distribution. Diameter distribution modeling was also used to predict growth and yield in these kinds of stands (e.g., Knoebel and others 1986, Murphy and Farrar 1982 a,b; 1988). The remaining prediction systems developed during this period were individual-tree or stand-level models.

Additional publications compare models, evaluate model performance, and describe procedures for testing models and their parameters and new parameter estimation techniques. Several papers compare loblolly pine models (Borders and Patterson 1990, Buford 1991, Cao 1998, Clutter and Gent 1993, Harrison and Michie 1985). Shortt and Burkhart (1996) specifically compare models useful for inventory updating. Other studies include a quality assessment of a Weibull-based growth projection system (Gertner and others 1995); a description of procedures for selecting models, testing their goodness-of-fit, and estimating error in model predictions (Reynolds 1984, 1988); and a report on the spatial autocorrelation properties of diameter and height increment prediction from two loblolly pine stand simulators (Liu and Burkhart 1994). Borders and Bailey (1986), and Borders (1989) showed how some econometric techniques could be used to estimate parameters in sequentially related or seemingly unrelated systems of equations used in growth and yield modeling. Grender and others (1990) published their theory regarding Weibull parameter probability-weighted moment estimators and showed the derivation of these estimators. They thus provided a way to place more emphasis on larger sized, and more valuable trees in a diameter distribution modeling context. Amateis and McDill(1989) showed how the physical concept of dimensional compatibility could be achieved in growth and yield modeling. Lloyd and Harms 1986 applied the rule of self thinning in an individual stand growth model for mean plant size, and Zeide (1993) analyzed growth equations and reduced them into three general equation forms.

Density management diagrams were developed to help users schedule thinnings and the final harvest in loblolly and slash pine plantations (Dean and Baldwin 1993, Dean and Jokela 1992). A spreadsheet was developed to simplify these procedures for loblolly pine plantations (Doruska and Nolen 1999). A stand density index was also published for natural stands of shortleaf pine (Wittwer and others 1998).

COMPLETE PREDICTION SYSTEMS AVAILABLE

In this paper, a complete growth and yield prediction system contains all the components required to initially describe a stand and project growth of that stand into the future. Complete models are available for loblolly, slash, longleaf, shortleaf, mixed pine, mixed pine-hardwood, and hardwood stands (table 1). Most of them have been developed for loblolly pine, followed by slash pine, and then various hardwood species. All types of modeling approaches are represented (Harrison and Michie 1985, Munro 1974, Nepal and Somers 1992).

Two of the prediction systems, the Forest Vegetation Simulator (FVS) and The Timber Yield Forecasting and Planning Tool for Windows (WINYIELD), are quite different from the others and from each other. Forest Vegetation Simulator, the primary system currently used by the National Forest System of the USDA Forest Service (Teck and others 1996), is a system of several distance-independent individual tree model-based equation modules called variants. The variants represent different species and forest types within 19 geographic regions across the United States. The Southeastern (SE) geographic variant within FVS is based on the (GATWIGS) (Bolton and Meldahl 1990) and later (SETWIGS[1]) models. USDA Forest Service Inventory and Analysis data for Georgia, Alabama, and South Carolina were used in the database. These models include prediction equations for many softwood and hardwood species. WINYIELD (FORS 1997), formerly the Timber Yield Forecasting and Planning Tool (YIELD) (Hepp 1982) and then YIELDPLUS, is a computer program that enables selection from among 13 growth and yield models according to species and geographic location. The actual growth and yield prediction systems were developed by other researchers. Therefore WINYIELD might be more appropriately called a growth and yield model management system.

SOME OBSERVATIONS AND TRENDS

1. The amount of research done for a species or forest type appears to be highly correlated with the commercial value, manageability, and availability of the species (e.g., loblolly and slash pine). Political priorities or perceived importance are probably the next most important motivators for research. Prevalence of a species or forest type or the absence of growth and yield information are the least important factors (e.g., mixed species forests).

2. As a corollary to the previous observation, the most progress has been made in predicting the growth and yield of plantation forests, which cover the least area, and the least emphasis has been placed on naturally regenerated and mixed species stands, which cover the most area in the Southern U.S. and are directly owned by the greatest number of people. This is not a new, but a continuing phenomenon. Farrar and others (1986) observed the same situation 13 years ago and table 1 shows little progress has been made.

[3] Bolton, R.K.; Meldahl, R.S. User's guide to a forest growth projection system for southeastern forests: SE-TWIGS. Unpublished guide available from the Auburn University, School of Forestry, Auburn, AL.

Table I- A summary of the complete Southern United States growth and yield models developed or revised since 1981 and available to the public

Spec.	Program reference	Organi-zation	Model type	Original site type	Mgmt. type	Geographic location	Stand trtmt.	Predictable data range: Age	Site index'	Basal area	Number
								Years	Feet	Ft²/acre	Trees/acre
Lob	Murphy 1983 (Farrar 1992)[b]	FS	WS	Ns	Ea	AR, LA, MS	Ut,T	8-75	68-127[d]	7-137	
Lob	Baldwin and Feduccia 1987 COMPUTE P-LOB	FS	Dd	CP	Ea	LA, MS, TX	Ut, T	5-45	40-78	47-128	
Lob	Clutter and others 1984	UGA	Dd	SPP	Ea	Cp of NC, SC, GA, FL	ut	10-30	40-80		300 -900
Lob	Bailey and others 1985	UGA	Dd	SPP	Ea	P and Cp of AL, GA, SC	ut	10-70	40-70		300-1500
Lob	Martin and Brtster [in press] Shiver and Brtster 1998	UGA	ws	Ns	Ea	GAP	Ut	24-83	68-109[d]		59-408[c]
Lob	Matney and Sullivan 1982 OFLOBLOLLY	MSU	Dd	Ofp	Ea	AR, MS, TN	Ut, T	9-34	55-83	46-210	
Lob	Ledbetter and others 1988	MSU	ws	SPP	Ea	AR, AL, LA, MS	ut	4-28	42-80		185-907
Lob	Matney and Belli 1995 Matney and Farrar 1992 CLOBLOLLY	MSU	Dd	Spp	Ea	AR, MS. LA, AL	Ut, T	5-30	50-70		150-900
Lob	Hafley and Buford 1985 Hafley and others 1982	NCSU	Dd	P	Ea	NC, SC. LA, IL	Ut, T	5-44	48 -93		100-2722
Lob	Cao and others 1982 Burk and others 1984 PCWTHIN	VPI	Dd	Ofp	Ea	VA P and CP	T	12-30	50-70		115-1305
Lob	Burkhart and Sprinz 1984 (Farrar 1992)[b]	VPI	ws	Ofp	Ea	VA P and CP	T	10-40	50-70	70-130	
Lob	Burk and Burkhart 1984 NATLOB	VPI	Dd	Ns	Ea	VA P and Cp, NC Cp	Ut	13-77	50-102		90-1220
Lob	Burkhart and others 1987 PTAEDA2	VPI	Ddit	SPP	Ea	S	Ut. T	8-25	34-97		275-950
Lob	Amateis and others 1998 TAUYIELD	VPI	ws	spp	Ea	S	Ut, T	a-37	40-85		194-528
Lob	Amateis and others 1995 TRULOB	VPI	Diit	SPP	Ea	S	Ut, T	8-37	40-85		194-528
Lob	Amateis and others 1904 COYIELD	VPI	Dd	SPP	Ea	S	Ut, T	8-25	34-97		275-950
Lob	Schulte and others 1998a Schulte and others 1998b SOUTHPRO	UW	gm	Ns	Ua	S	Ut. T		I-7'		

Table I- A summary of the complete Southern United States growth and yield models developed or revised since 1981 and available to the public (continued)

Spec.	Program reference	Organi- zation	Model type	Original site type	Mgmt. type	Geographic location	Stand trtmt.	Predictable data range: Age	Site index'	Basal area	Number
								Years	Feet	Ft²/acre	Trees/acre
Lob and Slash	Bailey and Zhou' Dangerfield and Moorhead 1998 GAPPS	UGA	Dd, Stp	SPP	Ea		Ut. T				
Lob and Slash	Lenhart 1988	SFA	Dd	Cp	Ea	T X	Ut	3-19	29-129		104-1002
Lob and Slash	Lenhart 1996	SFA	ws	Cp	Ea	TX	Ut	5-24	22-99		87-1002
Slash	Nance and others 1983	FS	Dd	Cp	Ea	TX, LA, MS	Ut. Ri	8-47	30-85'		250-1500
Slash	Zamoch and others 1991 COMPUTE P-SLASH (CSLASH - Matney)	FS MSU	Dd	Cp	Ea	TX, LA, MS	Ut. Ri	8-47	30-85		50-1500
Slash	Bailey and others 1982	UGA	Dd	SPP	Ea	GA, FL, SC	Ut, T	10-30	45-75		250-650
Slash	Grider and Bailey 1984 THEECIS	UGA	Dd	Ofp, SPP	Ea	GA, FL, SC, AL, MS	Ut. Ri	9-32	45-80	25-150	250-650
Slash	Borders and Bailey 1986	UGA	WS	SPP	Ea	VA, NC, SC, GA, FL, AL, MS	Ut	2-25			100-1800
Slash	Bailey and others 1989 Martin and others 1999	UGA	Dd, Stp	SPP	Ea	GA, FL	Ut	10-18	43-78		303 - 795
Slash	Pienaar and Rheney 1993 Pienaar and others 1990	UGA	Dd, Stp	SPP	Ea	GA, FL, SC	Ut, T	10-30	48-73		300 -600
Long	Farrar and Matney 1994 NLONGLEAF	FS	Dd	Cp, Ns	Ea	MS, AL, GA, FL	Ut. T	15-95	45-95[d]		50-1050
Long	Farrar 1985a (Farrar 1992)[b]	FS	ws	Cp, Ns	Ea	MS, AL, GA, FL	Ut, T	10-20	70-80[d]		300-1500
Long	Farrar 1985b (Farrar 1992)[b]	FS	WS	Cp, Ns	Ea	MS, AL, GA, FL	Ut. T	15-95	45-95[d]		10-1050
Short	Murphy and Beltz 1981 (Farrar 1992)[b]	FS	ws	NS	Ea	AR, LA, MO, OK, TX	Ut	14-81	44-101[d]	II-127	
Short	Murphy and Farrar 1985 (Farrar 1992)[b]	FS	ws	Ns	Ua	AR					
Short	Murphy 1982 (Farrar 1992)[b]	FS	ws	Ns	Ea	AR, LA, MO, OK, TX	Ut	14-81	44-101[d]	11-127	
Short	Huebschmann and others 1998 Lynch and others [in press] SLPSS	osu	Diit	Ns	Ea	AR. OK	T	20-80	50-80[d]	30-170	

Table I- A summary of the complete Southern United States growth and yield models developed or revised since 1981 and available to the public (continued)

Spec.	Program reference	Organi-zation	Modal type	Original site type	Mgmt. type	Geographi location	Stand mmt.	Predictable data range Age	Site index'	Basal area	Number
								Years	Feet	Ft^2/acre	Trees/acre
Lob and Short[g]	Murphy and Farrar 1982b, 1983 Farrar and others 1984 (Farrar 1992)[b]	FS	Dd	Ns	Ua	AR			80-90[f]	20-100	
Lob and short[g]	Murphy and Farrar 1988 (Farrar 1992)"	FS	Dd	Ns	Ua	AR				6-126	5-390
Mix	Kelly 1989	FS	Ws	Ns	Ua	IA. MS. AL			50-120[c]	10-100	
Pop	Knoebel and others 1988 YPOP	VPI	Ws, Dd	NS	Ea	ApmNC, VA, GA	T	17-76	74-138[d]	44-209	
Hard	Harrison and others 1986 G-HAT	VPI	Diit	Ns	Ea	Apm of NC, TN, VA, GA	T	19-83	62-96[d]		384-1517
Hard	Bowling and others 1989	VPI	Ws, Dd	Ns	Ea	NC, GA	T	IQ-66	51-81[d]		40-1517
Oak	Graney and Murphy 1994	FS	ws	Ns	Ea	Bm. AR	Ut. T	11-75	46-82[d]		
Oak	Murphy and Graney 1998	FS	it	Ns	Ea	Bm, AR	Ut, T	11-75	46-82[d]		
Bhard	Perkins, 1994 Perkins and others 1995	MSU	Diit	Ns	Ea	Stream bottoms of MS	Ut	IQ-93	75-124	44-240	102-741
Bhard	Mengel and Roise 1990 Mengel and Young 1993 BYPS	NCSU	dcm	NS	Ea	SE					
Bhard	Kenney 1983	NCSU		Ns							
Hard	Gardner and others 1982 Roeder and Gardner 1984	NCSU		Ns		S		20-40	IO-60	70-250	
Oakgum	Franco 1988	MSU	ws	Ns		Stream bottoms of MS	ut	19-82	75-124	44-240	102-741
Oakfs	Zahner and Myers 1964	CU	ws	Ns	Ea	SC	Ut	5.39	46-89	38-113	450-2600
cot	Cao and Durand 1991	LSU	Ws	P	Ea	MS	ut	3-15	40-90"		
sosp	Bolton and Meldahl 1QQ0 GATWIGS Bolton and Meldahl[i] SETWIGS Teck and others 1996 FVS	AU	Diit	P		AL. GA, SC		Based on FIA data collections over several years			
sosp	McClure and Knight 1984	FS	ws	Ns	Ea	S	ut	5-85	20-85		51-600
Sosp	Hepp 1982 FORS 1997 WINYIELD (YIELD and YIELDPLUS)	TVA	Varies	Ns, P	Varies	S	Varies	Dependent on internal model chosen 13 choices available			

Table 1-A summary of the complete Southern United States growth and yield models developed or revised since 1981 and available to the public (continued)

Abbreviations:
Species: Bhard = bottomland hardwoods, Cot = cottonwood, Hard = mixed hardwoods, Lob = loblolly pine, Long = longleaf pine, Mix = mixed species (pine/hardwood), Oak = upland oaks, Oakgum = red oak-sweetgum, Oakfs = oak from sprouts, Pop = yellow-poplar, Short = shortleaf pine, Slash = slash pine, Sosp = southern species.
Organization: AU = Auburn University, CU = Clemson University, FS = USDA Forest Service. UGA = University of Georgia, LSU = Louisiana State University, MSU = Mississippi State University, NCSU = North Carolina State University, OSU = Oklahoma State University, SFA = Stephen F. Austin University, TVA = Tennessee Valley Authority, UW = University of Wisconsin, VPI = Virginia Polytechnic Institute and State University.
Model type: dcm = diameter class matrix, Dd = diameter distribution, Ddit = distance dependent individual tree, Dilt = distance independent individual tree, Stp = stand table projection, Ws = whole stand.
Original site type: Spp = site prepared plantation, Ofp = old field plantations, P = plantations, Ns = natural stands, Cp = cutover plantations.
Management type: Ea = even-aged, Ua = uneven-aged.
Geographic region: Apm = Appalachian Mountains, Bm = Boston Mountains, Cp = Coastal Plain, P = Piedmont, S = southwide, SE = southeast, State postal abbreviations.
Stand treatment: Ri = rust infected, T = thinned, Ut = unthinned.

[a].base age 25 unless otherwise specified.
[b].BASIC and/or SuperCalc/Lotus l-2-3 template gmwth and yield programs written for the models indicated.
[c].pine component only.
[d].base age 50.
[e].site productivity class.
[f].GaPPS is a computer program developed by Bailey, R.L. and Zhou, B. in 1997 and is currently available from: Forest Biometrics Consulting, 200 Robin Road, Athens, GA 30605.
[g].not fully complete model.
[h].base age 10.
[i].Bolton, R.K.; Meldahl, R.S. User's guide to a forest gmwth projection system for southeastern forests: SE-TWIGS. Unpublished guide available from Auburn University, School of Forestry, Auburn. AL.

3. Most (about 65 percent) of the recent publications describe the development and application of new models or techniques for various prediction systems and components. The majority of these models or techniques apply to plantation iobioily and slash pine, and many techniques papers were not tied to any data. The emphasis is on improvement of prediction precision and accuracy, or on provision of more input-output options for users, not on developing or applying even simple models to species or forest types where prediction capability is lacking. And many of the completed models were not packaged within computer programs for convenient delivery to the user.

4. Most growth and yield research emphasizes even-aged rather than uneven-aged management of stands. Validation (test of the model against an independent dataset) of published growth and yield prediction systems has not been emphasized.

5. The development and sophistication of growth and yield models has closely followed the development and improvement of computers and software. Most of the models used were developed some years ago. Although models have been significantly modified, the most notable progress occurs when computing tools and clever algorithms to fit and use the models become available.

6. Many of the management practices built into some older growth and yield studies are not used today. Thus, these data, valuable because of long-term growth and yield measurements, may not be directly applicable to today's management practices. However, great strides have been made in iobioily and slash pine modeling thanks to industry-government-university cooperative ventures and their large regional databases.

7. Recent growth and yield emphases in iobioiiy and slash pine plantations, aside from new technique development, have been on modeling improved tree and stand quantity and quality prediction by including the effects of intensive management practices such as site preparation, vegetation control, genetics, and fertilization (about 17 percent of the publications for those species). Modeling emphasis for extensively managed stands and forests appears to be less rigorous for tree quantity or quality, focusing more on species interaction, diversity, and stand dynamics.

8. The interest is increasing in biological process models to predict forest productivity and to better understand growth processes. Although thorough review of this literature was not possible, the authors believe widespread use of process models is still in the future. increased development and operational application will be closely tied to advances in computer technology as well as to funding needed to collect enough data to develop statistically reliable models. However, linking biological process models and growth and yield models (e.g., Baldwin and others 1993, 1998) and augmenting empirical models with edaphic and climatic variables (e.g. Snowdon and others 1998, Wooilons and others 1997) are perhaps two intermediate steps in the transition.

9. A progressive step in the effective utilization of growth and yield models is their incorporation into more generalized management planning models or decision support or expert systems. Timber production planning

models such as the Forest Planning Tool (FORPLAN)(Hoekstra 1987) and the ecosystem management strategic planning system (SPECTRUM) (USDA 1996) have been evolving for several years. Development of the latter more general decision support models for forest ecosystems is in process (e.g., Rauscher 1999).

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VALIDATION OF VOLUME AND TAPER EQUATIONS FOR LOBLOLLY, SHORTLEAF AND SLASH PINE[1]

Allan E. Tiarks and V. Clark Baldwin, Jr.[2]

Abstract-Inside-bark diameter measurements at **6.6-ft** intervals of 137 loblolly, 52 shortleaf, and 64 slash pines were used to calculate the actual volume and taper of each species for comparison with volumes and tapers predicted from published equations. The loblolly pine were cut in Texas (TX) and Louisiana (LA) while the shortleaf was sampled only in TX. The slash pine were sampled in Mississippi (MS). The models had been developed using trees that had the same diameter and height distributions as the validation data; however, the validation trees were generally older. For loblolly and slash pine, the volume equations over-predicted the average volume by 1.5 and 3.7 **ft^3/tree,** respectively, or about 5 to 10 percent of tree volume. The taper equation for loblolly was adequate, but the slash pine taper equation did not fit the data well. There is no appropriate volume or taper model for shortleaf pine. However, the loblolly equations predicted both volume and taper of the shortleaf pine data as well as or better than they did for the loblolly data. The loblolly and slash pine equations can be used with confidence-about half of the errors appear to be random, indicating that the best equations will have an error of about 1.5 **ft^3/tree** regardless of tree size. Most prediction errors occurred in larger trees, indicating that some improvement could be made in taper-volume models by adding age as a variable. Species seems to be less important, and future modeling efforts should evaluate combined species equations.

INTRODUCTION

Valid volume and taper models are required for estimating tree volumes and stem shapes from simple measurements such as total tree height and diameter at breast height (d.b.h.). The models are used to estimate stand volume and site productivity, as well as to develop growth and yield models. There are numerous volume and taper models available for loblolly pine (e.g., Amateis and Burkhart 1987, Baldwin and Feduccia 1991, **Lenhart** and others 1987) and slash pine (e.g., Lohrey 1985, Thomas and Parresol 1991). The usual procedure to develop a model is to collect data over a suitably wide range of tree sizes, and then fit appropriate regression equations to the data set. Although validation with independent data is desirable, sufficient resources are rarely available to repeat the data collection process.

In the process of establishing long-term soil productivity (LTSP) plots on the national forests, we collected stem analysis data to determine the height growth patterns of existing stands over time. The upper-stem diameters collected as part of stem analysis are also suitable for validation of current volume and taper equations. One of the strengths of these data is that an intensive soil survey was conducted on each site, and the plots within each site were located within a stand on uniform soils. Our objective was to use these data to validate some existing volume and taper models.

METHODS

Sample trees were selected on four LTSP sites on the Kisatchie National Forest in Louisiana (LA), three on the Davey Crockett National Forest in Texas (TX), and three on the **DeSoto** National Forest in Mississippi (MS). Each site consisted of nine l-acre plots within stands that were to be harvested. A tenth plot was established on two sites in LA and one site in MS. After establishing the plots, we measured the d.b.h. of all pines with a diameter tape. Three sample trees on each plot were selected from the low, mid, and highest one-third of the diameter distribution. The sample trees were felled and inside bark diameter was recorded every 6.6 **ft,** beginning at the base. We calculated the volume of each tree using Smalian's formula and recorded total height and species. Tree age was determined by counting the number of rings at the base.

For the validation procedure, tree volume and taper for each tree were estimated using equations for loblolly and slash pine that were developed in IA. The volume equation tested for thinned loblolly pine (Baldwin and Feduccia 1987) was:

$$\ln(V)=-6.885331+2.040995\ln(D)+1.150022\ln(H) \quad (1)$$

where
V = estimated total volume inside bark **(ft^3),**
D = d.b.h. (in.), and
H = total height (ft).

For planted slash pine, we tested the volume equation of Lohrey (1985):

$$\ln(V)=-6.93385+2.07195\ln(D)+1.13645\ln(H) \quad (2)$$

We tested prediction accuracy of both volume models using the Fit Index (Schlaegel **1982),** expressed as:

$$FI=1-\frac{\sum(V_i-\hat{V}_i)^2}{\sum(V_i-\bar{V})^2}, \quad (3)$$

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where
FI = fit index,
"i = measured volume of tree,
$I, \hat{V}_i$ = predicted volume of tree *I*, and
ii = average volume of all trees.

The FI ranges from 0 to 1 with 1 indicating a perfect fit. To estimate inside-bark diameter (d)as inches at a specified height (h) as feet, we used the taper equation for thinned loblolly pine (Baldwin and Feduccia 1991):

$$d = D(1.07996 + 0.28760\ln(1 - 0.9776(\frac{h}{H})^{\frac{1}{3}})) , \qquad (4)$$

where
D = d.b.h. outside bark, expressed as inches; and
H = total height, expressed as feet.

The prediction equation for inside-bark diameters of thinned slash pine taper (Thomas and Parresol 1991) is:

$$\frac{d^2}{D^2} = -0.741(\frac{h}{H} - 1) + 0.0345 sin(1.5\pi\frac{h}{H}) + 0.00391 cotan(\frac{\pi}{2}\frac{h}{H}). \qquad (5)$$

A Fit Index for testing the taper equations was calculated using weighting based on the square of the diameter of each disk sample. The index is:

$$FI = 1 - \sum_{i=1}^{T}\sum_{j=1}^{S}\frac{d_{ij}^2}{\sum_{j=1}^{S} d_{ij}^2}(d_{ij} - \hat{d}_{ij})^2 / \sum_{i=1}^{T}\sum_{j=1}^{S}\frac{d_{ij}^2}{\sum_{j=1}^{S} d_{ij}^2}(d_{ij} - \bar{d})^2 \qquad (6)$$

where
, = the measured inside bark diameter and
4, = the predicted diameter (ib) of **the *j*th** disk of the ***i*th** sample tree,
S = the number of disk samples for the ***i*th** tree, and
T = the total number of trees sampled.

Weighting was based on the square of the diameter, so the Fit Index is an indicator of accuracy in predicting volume rather than diameter.

The 138 loblolly pines sampled for validation on the LTSP plots in LA and TX ranged in age from 21 to 87 years, averaging 48. The average height was 75 ft and ranged from 36 to 105 ft. The d.b.h averaged 12.5 in. and ranged from 4 to 22.5 in. Distribution of the heights and diameters of loblolly pines sampled for validation agreed with the data set used to develop the models (fig 1 a), but the validation data set contained older trees. The age of the original data set averaged 30 years and the maximum age was 55 years (Baldwin and Feduccia 1991).

The age range of the 84 slash pines sampled for validation on LTSP plots in MS was 18 to 62 years, and the average age was 53 years; although the age distribution was concentrated near the mean. Only two trees were under 40 years old. The average height was 84 ft and ranged from 30 to 104 ft. The d.b.h averaged 13.0 in. and ranged from 3.5 to 17.9 in. As with the loblolly pine, height and diameter distribution of the slash pines sampled for validation agreed with the data set used to develop the models (fig 1 b), although the validation data set contained older trees. The age of trees in the original data set averaged 31 years and the maximum age was 48 years (Lohrey 1985).

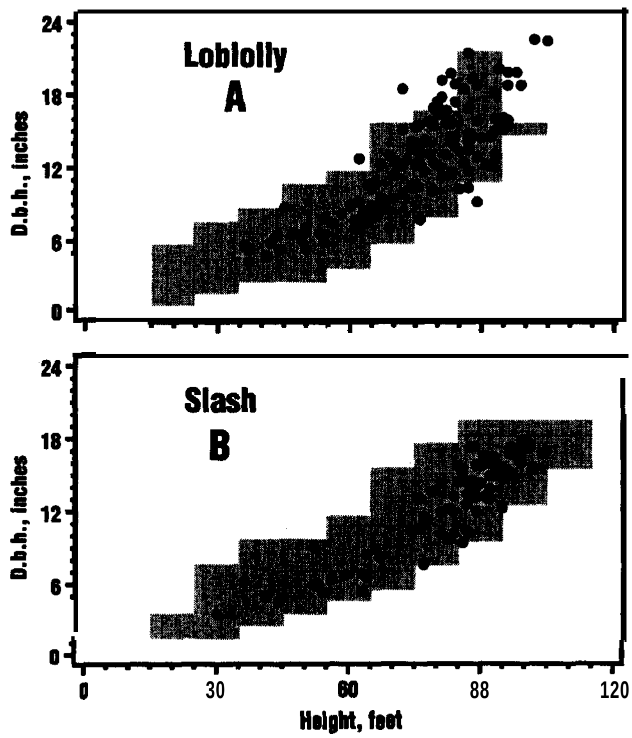

Figure l-Diameter and height distribution of the data sets used to develop volume and taper equations (shaded areas) and data used to validate the equations for loblolly (A) and slash (B) pine.

The age range of the 52 shortleaf pine sampled in TX was 25 to 90 years. Heights ranged from 39 to 103 ft, and d.b.h. ranged from 4.7 to 19.9 in. No shortleaf model was available for validation, so the shortleaf data were compared to predictions of the loblolly models for volume and taper.

RESULTS AND DISCUSSION

Volume Prediction

The Baldwin and Feduccia (1987) equation predicted inside-bark volume of loblolly pine adequately (fig. 2a) with a Fit Index of 0.976. The mean measured volume of the 138 trees was 33.3 ft^3/tree while the mean predicted volume was 31.8 ft^3/tree. The equation under-predicted actual volume, with the greatest discrepancies in the larger trees.

No volume equation was available for shortleaf pine, so we used the loblolly equation to predict the volume of 52 shortleaf pine that were sampled. Like loblolly pine, the prediction of inside-bark volume of shortleaf pine was acceptable (fig. 2b) with a Fit Index of 0.971. Differences between the predicted and measured volumes of shortleaf pine were evenly distributed with tree size, unlike the loblolly pine. Overall, the shortleaf's predicted volume was 30.7 ft^3/acre—the same as its measured volume.

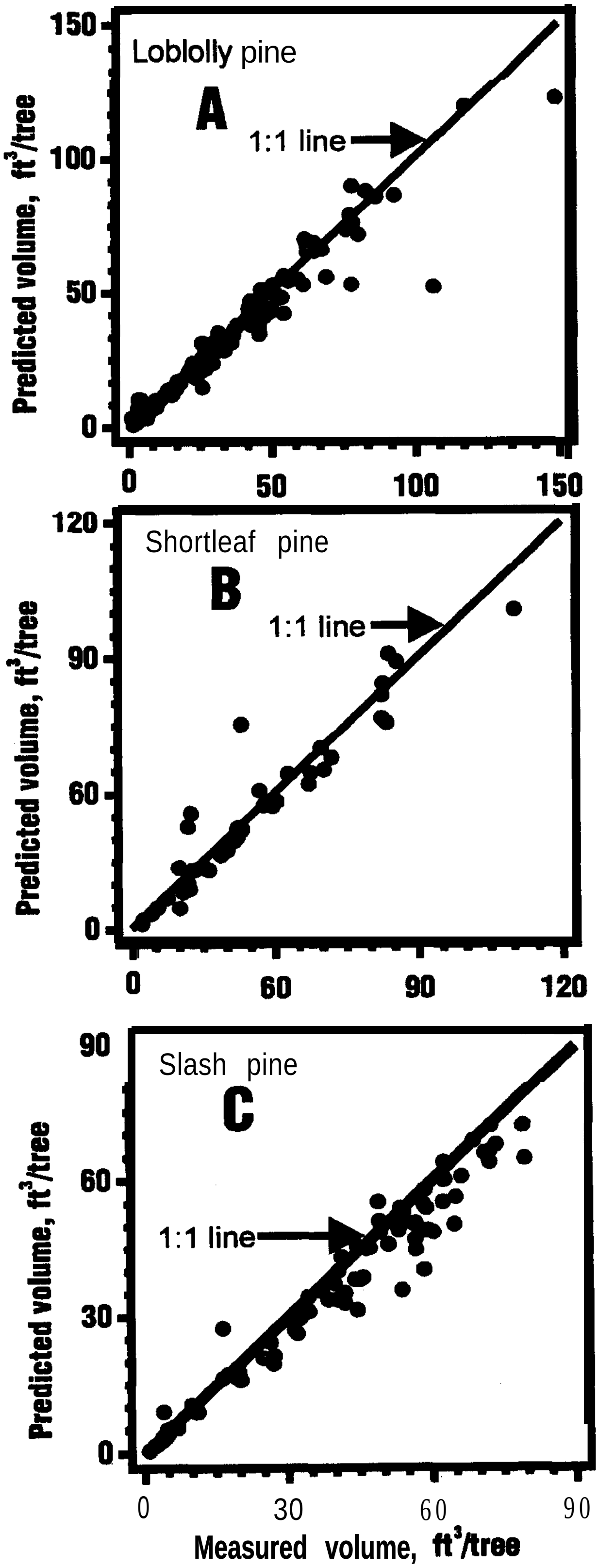

Figure P-Total volume (ib) predicted by volume equations compared to measured volume for loblolly (A) shortleaf (B) and slash (C) pine. A loblolly pine equation was used to predict shortleaf pine volume.

The equation we used to predict slash pine volume (Lohrey 1985) was suitable (fig. 2c) and had the highest Fit Index (0.982). As with loblolly pine, the greatest under-predictions occurred with the largest trees, so the mean predicted volume was 38.5 ft^3/acre when the measured volume was 40.2 ft^3/acre.

Taper Prediction

The taper equation used to predict upper-stem diameters of loblolly pine (Baldwin and Feduccia 1991) fit the validation data well (Fit Index = 0.952). The largest deviations between predicted and measured inside-bark diameters occurred in the upper 80 percent of the stem, where the model predicted diameters too large (fig. 3a). Because the Fit Index was weighted by the square of the diameter, the lack of fit in the upper stem would have a smaller effect than it would in the lower part. Of the 138 trees in the data set, two did not follow the same pattern in the diameter-to-height plot. Field notes do not indicate any problems, but disease or physical damage may have been responsible.

A taper equation was not available for shortleaf pine, so we used the loblolly equation to predict the sample's inside-bark diameters. The loblolly equation fit the shortleaf stem taper with a Fit Index of 0.936. As with loblolly, the greatest error was in the upper part of the stem, where the equation predicted diameters that were too large (fig. 3b).

Of the three species' taper equations, the one used for slash pine was least acceptable, having a Fit Index of only 0.884. Although the fit was adequate for the top and bottom of the trees, the equation under-predicted diameters in the middle portions of the slash pine boles (fig. 3c).

Model Improvement

In general, the species-specific volume and taper equations performed reasonably well, thus validating those equations. However, our analysis indicates that stem volume and taper modeling might be improved in two ways. First, the greatest deviations from the models occurred in larger trees. Although a tree's form may be affected by size, it is more likely that form changes with age and that the largest trees are older. Because the validation data set included sample trees that were older than those used to develop the models, age should be considered as an additional variable. Thomas and others (1995) found age to be an important variable in longleaf pine which ranged to 55 years. In our most extreme case, slash pine in the validation data set was 20 years older than the slash pine used to develop the model. Slash pine volume and taper models had lower Fit Indices than the loblolly pine, where ages of trees in model and validation data sets were more closely matched. We would need to balance the cost of including age in prediction equations with the value of improved predictions.

The second way equations may be improved is by combining species data sets during the modeling process, and statistically testing whether separate taper or volume equations are required for each species. In our study, the volume and taper equations for loblolly pine fit the validation data for shortleaf pine, as well as for the target species. In building models, stand origin- including planted vs direct seeded (Lohrey 1985), natural vs planted (Amateis and Burkhart 1987) and old-field vs cut-over (Lenhart and others

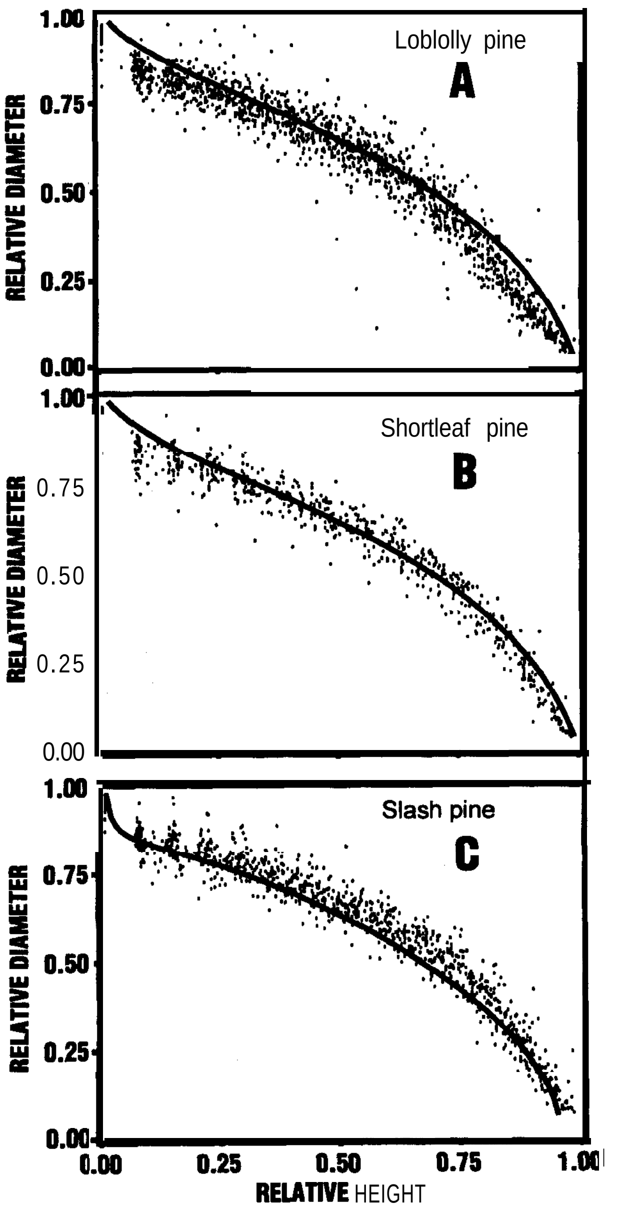

Figure 3-Plots of relative height (height of observation/total height) vs relative diameter (diameter of observation/ diameter at base) for loblolly (A) shortleaf (B) and slash (C) pines, with the line representing the equation used to predict taper for each species.

1987)—has been found to affect volume and taper prediction models. Silvicultural treatments, including thinning (Baldwin and Feduccia 1991, Thomas and Parresol 1991) and fertilization (Shoulders and others 1989), also have been found to significantly affect the taper of pines. The effect of species on tree form is usually assumed to be important, but in this study species had little effect. The Fit Index was always greater than 0.97 when loblolly or slash pine volume equations were used to predict the volume of any of the three species. The fit index of the equation for loblolly taper was 0.954 when used to predict slash taper, compared to 0.952 when used to predict loblolly taper. The slash pine taper equation was slightly better in predicting loblolly (0.896) than slash (0.884). Because of this apparent lack of species effect, we suggest testing groupings of species as models are developed. Such evaluation should examine a wide range of genetic material from each species.

SUMMARY AND CONCLUSIONS

Volume predicted by models agreed reasonably well with measured volume throughout the range of the data. The tested taper equation for loblolly pine was adequate for the lower bole, but predicted less taper than was found in crown portions of the bole. The taper equation for slash pine underestimated diameter, especially in the mid-bole area. In both loblolly and slash pine, measured trees were older than those used to develop the model. Hence, tree age appears to affect taper. Shortleaf pine volume and taper were predicted well using equations developed for loblolly pine-indicating that species may have a small influence on volume. Future modeling efforts should combine similar species and use age as a variable in prediction equations.

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NON-DESTRUCTIVE SAMPLING APPLICATIONS OF THE TELE-RELASKOP IN FOREST INVENTORY[1]

Robert C. Parker[2]

Abstract-The Tele-Relaskop dendrometer permits accurate upper stem measurements of diameter and height on standing trees for volume and fon computations without destructive sampling. Its 8X magnification and system of scales and relative measurement units facilitates measurements from any convenient distance. Horizontal and vertical percentages of the horizontal distance from the instrument to the tree axis are converted to defined units of measure during computations. Practical applications of the Tele-Relaskop are in growth and yield studies, CFI measurements, traditional volume equation construction, and inventory computations where numerical evaluation of tree form and/or volume is desired. Applications involving computations beyond stem diameters at calculated heights require a microcomputer and specialized software containing analytical techniques for the numerical description of tree form, one of which is a polynomial taper model. These software systems are available to link Tele-Relaskop procedures to traditional inventory processing. Single tree taper equations are used to calculate tree volume to user-defined merchantability limits and the volumes are fitted to a combined variable regression model to produce volume equations for use in inventory computations. Coefficients from the volume equations and multiple-tree, species-average taper equations can be used by inventory processors to compute gross tree volumes. Taper coefficients can also be used to compute scaling diameters of variable log length segments within inventory sample trees.

INTRODUCTION

This paper presents expanded applications of the Tele-Relaskop concepts proposed by Bitterlich (1978, 1984). The applications presented are a tribute to the developer of point sampling and the Spiegel Relaskop, and include many mensurational concepts that I have developed. As a student of Dr. Bitterlich's work, I had the rare opportunity to present my concept modifications to him and the gratification of having them accepted. Working with Dr. Bitterlich in Salzburg, Austria was truly a professional and personal highlight.

Early applications of the Tele-Relaskop were discussed by Bitterlich (1978, 1984), but the versatility of the instrument in nondestructive sampling studies has not been widely explored by biometricians and mesurationists. Parker (1983) initially developed microcomputer programs, at the request of Dr. Bitterlich, to facilitate the rapid computation of tree volumes using Bitterlich's single-curve conoid and sine interpretation functions, but found these concepts to be too restrictive and proposed the use of a third degree polynomial taper function (Hesske and Parker 1984). The Tele-Relaskop has been suggested for use in critical height sampling (Iles 1979, McTague and Bailey 1985) and compared to various clinometers for height measurement (Williams and others 1994). However, its applicability for measuring upper stem diameters with nondestructive techniques, developing single tree taper and volume functions, and utilizing the functions in traditional inventory processing has not been thoroughly investigated.

SAMPLE TREE MEASUREMENTS

The Tele-Relaskop is a tripod supported dendrometer with an 8X magnification that facilities accurate measurement of upper stem diameters, heights, and merchantable lengths at any convenient distance up to 1.5 times tree height. Vertical and horizontal scale measurements are obtained in relative percentages of the horizontal distance between the focal point of the instrument (18 cm in front of the objective lens) and the tree axis without reference to a specific unit of measure. The relative measurement units, called Tele Units or TU's, are converted to user-defined units of measure during the numeric computations. Measuring d.b.h. of the sample tree with a diameter tape or caliper is the only contact the observer must make with the tree, and the unit of d.b.h. measure determines the unit of measure for subsequent measurements.

The "horizontal scale" of alternating white and black bands is used to "measure diameters" (fig.1). A white and black band comprise 1 TU which is equivalent to 1 percent of the horizontal distance from the focal point of the instrument lens located 16 cm in front of the lens to the tree axis. There are 4 TU units on the scale. The right most TU unit is divided into tenths of a percent, with a thin black line marking the midpoint or 0.5 percent.

The "vertical scale" located in the center of the horizontal scale that is used for "measuring heights". The vertical scale is graduated in 1 percent TU units, labeled at 5 TU intervals, and measures height in terms of percent slope similar to a conventional clinometer. The scale has positive and negative units for measurements above and below the horizontal axis.

In practical applications, the horizontal and vertical readings would be recorded/tallied as position (along tree bole), horizontal reading, vertical reading; e.g. d.b.h., 2.36 percent, -22.8 percent. Obtaining horizontal and vertical readings at an arbitrary stump (i.e. defined by merchantability standards and tree form) is optional depending upon the intended use of the measurements and the analytical procedures to be employed. Stump height can be assumed at any specified length below breast height during computations.

When Tele measurements are to be used for expressing tree form, a minimum of 4 intermediate horizontal and vertical readings should be taken between the tree top and breast height. Intermediate point 1 should be reasonably close to the desired upper merchantability limit and points 2-4 should be spaced relatively uniformly between breast height and the upper merchantability limit. If a form class

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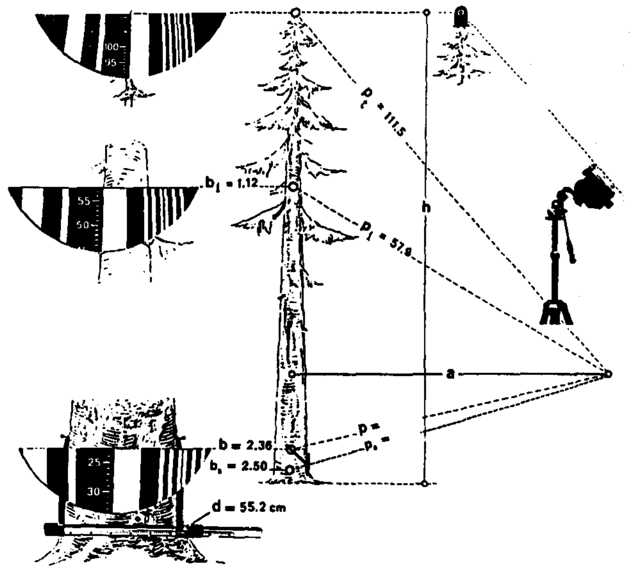

Figure l-Relative measurement scales and sample tree measurements for the Tele-Relaskop.

measurement is desired, a simple calculation in the field can be made to obtain the vertical reading location for intermediate point 4 that equates to the top of the first **16 ft. log.**

SAMPLE TREE CALCULATIONS

The sample tree calculations for horizontal distance (a), diameter (d,) at any intermediate point, height (h,) above or below the horizontal plane, and stem length (sl) between any two arbitrary points are performed from the relationship:

$$UM_i = (\frac{a}{100})TU_i \qquad (1)$$

where

Urn, = unit of measure at the ith point (i.e. d.b.h., stem length, height, etc.),

a = horizontal distance from instrument focal point to tree axis, and

Tu_i = relative Tele-Relaskop unit (vertical/horizontal) at point I.

The quantity $(\frac{a}{100})$ is a "constant" for a specific instrument location only and the unit of measure for "a" determines the unit of measure for the tree in English or metric units.

The relative accuracy of the Tele-Relaskop was stated by **Bitterlich** (1976) as "percentage readings of tree diameters at an accuracy to the nearest **1/100** of 1 percent whilst readings for vertical dimensions only allow estimates to the nearest **1/10** of 1 percent".

Horizontal Distance

The horizontal distance, a, in absolute measurement units from the focal point of the telescope (16 cm in front of the objective lens) to the tree axis is calculated from the measured d.b.h. and the relative horizontal Tele-Relaskop reading at breast height ($TU_{h_{bh}}$) as:

$$dbh = (\frac{a}{100})TU_{h_{bh}} \quad or \qquad (2)$$

$$a = \frac{100dbh}{TU_{h_{bh}}}$$

The unit of measure for "a" is determined by the unit of measure for **d.b.h.;** i.e. inches, centimeters, etc.. For example in Figure 1, tree d.b.h. is 21.7 in. or 55.2 cm; therefore the horizontal distance, a, for the specific instrument location is computed as:

$$a = \frac{100(21.7\ in.)}{2.36\%} = 919.49\ in. = 76.62\ ft \qquad a = \frac{100(55.2\ cm)}{2.36\%} = 2338.98\ cm = 23.39\ m \qquad (3)$$

The quantity $(\frac{a}{100})$ is used as a "constant" for all diameter and height calculations at a specific instrument location and its unit of measure will determine the unit of measure of the calculations; i.e. 9.1949 in., 0.7662 ft, **23.3898cm** or **0.2339m.** It is the conversion value of one relative **Tele-**Relaskop unit **(TU_i)** in equations (1) and (2) for a specific instrument location.

Stem Diameter

The stem diameter, **o.b.,** at any selected point, expressed in inches or cm, is calculated by the relationship:

$$d_i = (\frac{a}{100})TU_{h_i} \qquad (4)$$

where

TU_{h_i} = relative horizontal **Tele-Relaskop** reading at height **I.**

For example, a horizontal stump reading of 2.50 percent at an instrument distance of 919.49 inches (2338.98 cm) would yield diameters of:

d_i = (9.1949 **in.)2.50** or d, = (23.3898 **cm)2.50**
= 22.99 in. = 58.48 cm

and an intermediate point reading of 1 **.12** percent at the **same** instrument distance would yield diameters of:

d_i = (9.1949 **in.)1.12** or d, = (23.3898 **cm)1.12**
= 10.30 in. = 26.20 cm

Relative Helght Above/Below Horizontal Plane

Relative height, (rh,), above or below the horizontal plane, in feet or meters, at any selected measurement point is calculated by the relationship:

$$rh_i = (\frac{a}{100})TU_{v_i} \qquad (5)$$

where

rh_i = relative height above/below horizontal plane, and

TU_{v_i} = relative vertical **Tele-Relaskop** reading at height **I.**

For example, the relative height of the d.b.h. measurement is computed to be:

rh_{bh} = **(0.7662)(-22.8%)**
rh_{bh} = **(0.2339)(-22.8%)**
= -17.45 ft below horizontal plane = -5.33 m

and the relative height of the stump measurement is computed to be:

rh_{stump} = (0.7662)(-28.1%)
rh_{stump} = (0.2339)(-28.1%)
= -21.53 ft below horizontal plane. = -6.57 m

Stem Length and Absolute Height

Stem length or absolute height above an arbitrary point is calculated from the algebraic difference of two relative vertical readings:

$$sl_i = (\frac{a}{100})\ (TU_{v_i} - TU_{v_0}) \qquad (6)$$

where
sl_i = stem length from base point 0 to point I,
TU_{v_i} = relative vertical Tele-Relaskop reading at point I, and
TU_{v_0} = relative vertical Tele-Relaskop reading at base point 0.

For example, the absolute stem length between breast height and the stump is computed with the absolute difference of the two relative vertical readings or as the absolute difference between computed relative heights as:

sl_{bh} = (0.7662 ft)(28.1 - 22.8) or sl_{bh} = (21.53 ft - 17.45 ft)
= 4.06 ft or 4.1 ft = 4.08 ft or 4.1 ft

sl_{bh} = (0.2339 m)(28.1 - 22.8) or sl_{bh} = (6.57 m - 5.33 m)
= 1.24 m or 1.2 m = 1.24 m or 1.2 m

In most applications, the base point is assumed to be the stump height. In applications where stump height is arbitrarily assumed to be 3.5 ft or 4.0 ft below breast height for 1 ft and 0.5 ft stump heights, respectively, equation (6) can be modified to yield stem length above the stump and/or merchantable stem height as:

$$h_i = (\frac{a}{100})\ (TU_{v_i} - TU_{v_{stump}}) + h_{stump} \qquad (7)$$

where
h_i = height above the ground to point I, and
h_{stump} = constant stump height.

For example, with a vertical reading of 57.9 percent to intermediate point 1 and -28.1 percent to the top of a defined stump, the height (stem length) to point 1 above ground is:

h, = (0.7662 ft)(57.9% - -28.1%) + h_{stump}
h, = (0.2339 m)(57.9% - -28.1%) + h_{stump}
= 65.89 ft + h_{stump} = 20.12 m + h_{stump}

If h_{stump} is an assumed stump height of 0.5 ft (.15m), the height of point 1 above ground becomes 66.39 ft (20.27m). Or, the stem length can be calculated from breast height to point 1 and the constant, h_{bh}, is used as stem length from stump to breast height or height above the ground as:

h, = (0.7662 ft)(57.9% - -22.8%) + h_{bh}
h, = (0.2339 m)(57.9% - -22.8%) + h_{bh}
= 61.83 ft + h_{bh} = 18.88 m. + h_{bh}

if the constant height to breast height, h_{bh} , is an assumed height of 4.0 ft (1.22 m) for a 0.5 ft (0.15m) stump, the stem length between the stump and intermediate point 1 is 65.83 ft (20.10 m) and the height of point 1 above ground is 66.33 ft (20.25m).

A VOLUME AND TAPER APPLICATION OF TELE-RELASKOP DATA

The previous discussions have described field application techniques of the Tele-Relaskop and simple computational methods to obtain stem diameters, heights, and lengths from the tree measurements. Subsequent calculations required to yield usable estimates of tree volume to various merchantability limits from the tree measurements are somewhat more complex. The numerical complexity involved in analytically describing tree form and computing segment and tree volumes was the primary limiting factor restricting the practical application of Tele-Relaskop concepts by Bitterlich (1978, 1984). Dr. Bitterlich proposed using the HP-97 programmable calculator to numerically describe stem form with a single-curve conoid function and to interpolate diameters between adjacent measurement points with a sine function. Some mainframe computer programs such as STXMOD incorporated Tele-Relaskop measurements into Grosenbaugh's 3-P inventory procedures (Chehock 1982), but these programs could not be used on microcomputers and therefore were unavailable to the practicing forester. Microcomputer programs were developed by Parker (1983) at the request of Dr. Bitterlich to facilitate rapid computation of tree volumes using the conoid procedures, but it became immediately apparent that these procedures were too restrictive. Parker proposed the use of a third degree polynomial taper function and other computerized data and volume computation procedures to Dr. Bitterlich in Salzburg, Austria in 1983 and he accepted these modifications. The TELE microcomputer system developed by Parker (1983) permitted data manipulation and rapid computation of single- and multi-tree taper equations. The single tree taper equations were used to calculate single, sample tree volumes to user-defined merchantability limits in cubic feet, cords, and board feet, which were subsequently fitted to a combined variable volume model to produce single tree regression equations. The coefficients of the multi-tree, species-average taper equations were used directly in the OMNITALI Inventory Processor System (Parker 1984) to calculate single tree volumes during inventory computations.

Sample Tree Data

Sample tree measurements from the Tele-Relaskop can be entered into the TELE microcomputer system via the keyboard or electronically transferred via an RS-232 connection from a Husky field computer program FS2TELE (Parker 1992). During data entry, relative Tele measurements are converted to user-defined units of measure and displayed for editing prior to disk storage. Sample tree data (see Table 1) included species code, relative vertical and stem TU's, and computed stem heights and diameters at breast height, stump, top, and 4 intermediate stem points.

Sample Tree Volumes

Previous studies by Max and Burkhart (1978), Matney and Sullivan (1980), and others have concluded that a segmented polynomial regression model with three quadratic submodels is superior to a single, non-segmented model for taper prediction. These complex models however are not practical for small data sets with limited diameter and height ranges. A non-segmented, third-degree polynomial of the form:

$$\left(\frac{d_i}{dbh}\right) = b_0 + b_1X_i + b_2X_i^2 + b_3X_i^3 \qquad (8)$$

where $X_i = \frac{h_i}{H}$

d_i = stem diameter at the i'th point above breast height,
h_i = height (stem length) at the ith point,
H = total or merchantable tree height, and
b_0, b_1, b_2, b_3 = regression coefficients

will do a reasonably good job on a microcomputer for describing tree form from breast height to a merchantable or total height (Hesske and Parker 1983). The model should not be used with data points below breast height. The stem section below breast height can be assumed to be a cylinder of diameter d.b.h. or any other appropriate geometric solid. The non-segmented, third-degree model can be conditioned through the top for conifers and other single-stemmed species so that at $h_i = H$ or $X_i = 1$, stem diameter $d_i = 0$ and the conditioned model becomes:

$$\left(\frac{d_i}{dbh}\right) = b_1(X_i-1) + b_2(X_i^2-1) + b_3(X_i^3-1) \qquad (9)$$

Since the dependent and independent variables in model (8) are relative measures or ratios, the resulting regression equation carries no unit of measure. After tree measurements are fitted to the model, the regression equation can be transformed to the application form:

$$d_i = dbh\,[b_1(X_i-1) + b_2(X_i^2-1) + b_3(X_i^3-1)] \qquad (10)$$

where
the unit of measure for d_i is determined by the unit of measure of d.b.h. Model (9) is a very flexible taper model that adjusts equally well to trees of the same d.b.h. but different height and trees of the same height but different d.b.h. It can be used to predict tree form for a single tree or a population.

The sample tree measurements for one tree in Table 1 were fitted to model (9) to obtain predicted stem diameters at points other than the four intermediate measurement points

Table l-Relative sample tree measurements from Tele-Relaskop and computed stem heights (feet) and diameters (inches, outside bark)

Stem position	Relative vertical	Relative horizontal	Height[a]	Diameter[b]
	----- *Percent* -----			
D.b.h.	-2.50	1.91	.0	14.3
Stump	-9.00	2.45	75.3	18.3
Top	111.87	.00		.0
Point 1	91.00	.60	82.4	4.5
Point 2	57.00	1.40	41.2	10.6
Point 3	38.00	1.55	29.3	11.6
Point 4	21.50	1.80	19.0	13.5

[a] Height (ft) = 0.6239 ft (Vertical percent, - stump percent).
[b] Diameter (in.) = 0.6239 ft (12) (Horizontal percent).

so that single tree volumes could be computed for user-defined merchantability limits and units. Computed volumes in cubic feet are shown in Table 2; however, other volume units such as board feet and cords can be computed with the predicted stem diameters. Cubic foot volume below breast height was computed with Smalian's formula using the actual Tele-Relaskop d.b.h. and stump measurements. Stem volume above breast height was computed using equation (10) to predict diameter at 4 ft intervals and Smalian's cubic foot volume formula. The volume of the last tip section (4 ft or less) was computed assuming the section was a cone.

Table 2—Calculated sample tree measurements from Tele-Relaskop data, predicted stem diameters (inches, outside bark) with a conditioned, non-segmented, third-degree polynomial equation, and computed cubic volumes of tree segments

	Tele-relaskop Measurements		Polynomial model predictions	
Stem position	Tele-diameter	Tele-height	Predicted diameter[a]	Predicted volume[b]
Top	0.0	75.3	0.0	
Point 1	4.5	82.4	4.7	0.57
Point 2	10.6	41.2	10.1	7.01
Point 3	11.8	29.3	12.1	8.07
Point 4	13.5	19.0	13.3	9.09
D.b.h.	14 3	4.1	14.3	15.89
Stump	18.3	.0	18.3	5.99
Total				48.42

[a] $d_i = dbh\,[-2.4063(X_i-1) - 7.7852(X_i^2-1) - 4.2695(X_i^3-1)]$

where $X_i = \frac{h_i}{H}$

[b] Volume (ft^3) computed with Smalian's formula using predicted diameters at 4 ft intervals between intermediate measurement points on tree bole.

To demonstrate the stability of the conditioned polynomial model relative to Bitterlich's (1978) conoid model in regards to location and number of intermediate measurement points, combinations of the four intermediate points in Table 2 taken three at a time on a single tree were selected to represent four "sample trees". The Tele-Relaskop data for each "sample tree" were fitted to model (8) and to Bitterlich's (1978) single-curve conoid function with sine curve interpolation. The results of this single, non-statistical comparison are shown in Table 3. Cubic volumes computed from predicted diameters of 4 ft segments with the non-segmented polynomial equation using three of four intermediate measurement points varied from -3.3 to +1.5 percent of the four-point tree volume (row 1). The Scribner board foot volumes computed from predicted diameters of 16 ft log segments varied from -3.4 to +1.6 percent of the four-point tree volume. The conoid cubic volumes varied from -17.7 to +10.3 percent of the four-point tree volume.

Table 3-Predicted heights and volumes from conditioned, non-segmented polynomial taper equation of Tele-Relaskop measurements and total cubic volumes from conoid function using combinations of three out of four intermediate measurement points on a single tree

Tree height (ft) for 14.3 in. d.b.h.			Polynomial taper cubic volume (o.b.)		Scribner board feet	Conoid cubic volume (o.b.)	
Total	3"-top	6"-top	Total	3"-top	6"-top	6"-top	Total
75.3	67.3	56.2	46.4	46.3	45.2	165	41.9
75.3	67.6	56.5	45.6	45.7	44.6	161	36.3
75.3	66.2	59.7	47.1	46.9	45.9	168	46.2
75.3	66.8	57.1	45.1	45.0	43.9	177	34.5

The volume differences in Table 3 demonstrate that the conoid function approach to volume computation of single trees is highly sensitive to the location of upper stem measurements. This conoid sensitivity translates to field application problems when required upper-stem measurement points are obscured from view by foliage or other stems.

The ability to calculate upper-stem diameters and sample tree volume with a minimum of non-destructive, tree measurements could be quite useful in CFI studies to compare individual tree growth and changes in tree form over successive measurement periods and in growth and yield studies within environmentally sensitive ecosystems.

Standing Tree Volume Equations

in the previous discussion, upper-stem measurements taken with the Tele-Relaskop on sample trees were used to compute single-tree volumes for user-defined merchantability standards and units of measure. Since the Tele-Relaskop measurements are relatively easy to obtain and the volume computations can be completed rather quickly on a microcomputer, single-tree volumes to anticipated or unanticipated merchantability standards could realistically be obtained for sample trees within a specific cruise area or larger geographic area. The single-tree volumes can be stored on disk and fitted to any standing tree volume model suitable for the area and species.

The combined variable model for single tree volume:

$$Vol = b_0 + b_1 (D^2H) \qquad (11)$$

where

D is tree d.b.h. and H is merchantable or total tree height, can be fitted with sample tree volumes in a microcomputer environment for various units of measure and merchantability standards. The nonlinear version of the combined variable model

$$Vol = b_0 + b_1(D^{b_2}H^{b_3}) \qquad (12)$$

is a more versatile model since the coefficients of diameter and height are not arbitrarily assumed to be 2 and **1,** respectively; however, fitting model (12) by actual nonlinear routines is not easily handled in the microcomputer environment. An approximation of the diameter and height coefficients of nonlinear model (12) can be obtained by fitting the data to a linear logarithmic transformation of the nonlinear model:

$$\ln(Vol) = \ln(b_1) + b_2(\ln D) + b_3(\ln H) \qquad (13)$$

and then using the coefficient estimates as constants in "nonlinear" model (12).

The TELE system (Parker 1983) will compute sample tree volumes from the Tele-Relaskop measurements in user-defined units of measure and to specified merchantability standards. The sample tree volumes are then fitted to the linear combined variable model, by species, to obtain 13 sets of volume equation coefficients. Table 4 is an example of the merchantability standards and equation coefficients obtained for a single species with the TELE system. The equations were derived from 50 Teie-sample trees selected on 20-0.2 ac circular plots in a 40 ac stand during a standard cruise. The equation coefficients from the linear or nonlinear combined variable model can be used directly in the **OMNITALI** Inventory Processor System (Parker 1984) to compute cruise volumes.

Species-Average Taper Equations

Tele-Relaskop measurement data for a defined geographic/physiographic area can also be used to compute species-average taper equations. Equation coefficients for model (9) are obtained by fitting all stem measurements for a species. The species-average taper coefficients are used directly in an inventory processor to compute tree volumes for user-specified merchantability standards and volume units. Unlike the single tree volume equations above, the taper coefficients allow maximum flexibility, at the time of inventory processing, for obtaining single tree volumes to user-defined limits. Since taper coefficients do not vary substantially within defined geographic/physiographic regions for a single species and model (9) is a relative variable model that is a function of tree d.b.h. and height, the equation coefficients for model (9) will "adjust" upper stem diameter predictions in response to local differences in the tree d.b.h.-height relationship. In practical applications using species-average taper coefficients for model **(8),** tree height can be subsampled so that only tree d.b.h. need be measured on inventory tally trees. A d.b.h.-height regression can be used to predict individual tree heights in the inventory data.

An example of multi-tree, species-average taper coefficients are shown in equation (14) below.

$$d_i = dbh\,[-0.7571(X_i - 1) + 0.3877(X_i^2 - 1) - 0.6703(X_i^3 - 1)]$$
$$\text{where } X_i = \frac{h_i}{H} \qquad (14)$$

Table 4-Regression equation coefficients for Tele-Relaskop sample tree volumes fitted to a combined variable model of form: $Vol = b_0 + b_1(D^{b_2}H^{b_3})$ where D is tree dbh and H is merchantable height to specified top diameter limit, outside bark, or total tree height

Equation	Volume unit	Top diameter o.b.(in.)	Height unit	b_0	b_1	b_2	b_3
1	Total cu.ft	0	Total tree height	0.363709	0.002893	1.959743	0.995882
2	Cubic ft	3	Total tree height	591795	.002300	1.987744	1.028663
3	Cubic ft	3	Merchantable ft	-.366644	.005425	1.792590	.991536
4	Cubic ft	3	No. of 16.0 ft bolts	-.366644	.084792	1.792590	.991536
5	Cords	3	Total tree height	.000882	.000033	1.908887	1.008739
6	Cords	3	Merchantable ft	-.009014	.000081	1.726497	.956625
7	Cords	3	No. of 16.0 ft bolts	-.009014	.001142	1.726497	.956625
8	Cubic ft	6	Total tree height	.716858	.001726	2.065139	1.037900
9	Cubic ft	6	Merchantable ft	-.624280	.008506	1.642746	1.019577
10	Cubic ft	6	No. of 16.0 ft logs	-.624280	.143685	1.642746	1.019577
11	Doyle bf	6	Total tree height	-1.967694	.000554	2.665839	1.220397
12	Doyle bf	6	Merchantable ft	-7.207106	.003947	2.204032	1.152211
13	Doyle bf	6	No. of 16.0 ft logs	-7.207106	.096315	2.204032	1.152211

The equation coefficients were derived from the same Tele-Relaskop measurements taken on 50 sample trees selectedon 20-0.2 ac circular plots that were used to derive the volume equation coefficients in Table 4. Species-average taper coefficients are also used in the OMNITALI Inventory Processor System (Parker 1984).

INVENTORY PROCESSING AND THE TELE-RELASKOP

The preceding discussions about single and multiple tree taper coefficients and volume equations have indicated potential uses of Tele-Relaskop measurements for biometricians and mensurationists, but what about the management and/or procurement forester? Each of the preceding examples has direct application to the processing of inventory/cruise data, which is the "bread and butter" of field foresters. Field foresters generally do not have the available technology to develop their own volume tables or to "adjust" current volume tables to their local conditions. They are totally dependent upon volume equations and/or tables developed by someone else for timber conditions and utilization standards that may not be representative of their conditions or needs. The Tele-Relaskop allows field foresters to obtain current, tree measurements without time-consuming, destructive sampling (i.e. felling sample trees) procedures and to develop their own volume equations/tables using available software that can be applicable to stand- or area-level timber conditions.

To demonstrate the utility of the Tele-Relaskop procedures, the cruise data from the 20- 0.2 ac plots taken on a 40 ac tract were processed with the OMNITALI Inventory Processor System using conventional volume tables/equations, single tree volume equation coefficients (table 4) and species-average taper coefficients (equation (14)) derived from 50 sample trees measured with the Tele-Reiaskop during the cruise. Table 5 shows the results of the cruise computations. The cruise tally contained plot-by-plot, tree-by-tree data that included measurements of tree d.b.h. (l-in. classes) and merchantable heights in feet to a 3.0-k-r. top (o.b.) for pulpwood trees and number of 16 ft logs to a 6.0-in. top (o.b.) for sawtimber trees . Single tree volumes in the inventory data were computed with:

1. conventional volume equations for Minor's form class 77 volume table (Merrifield and Foil 1967) for pulpwood and Mesavage and Girard form class 80 volume table (Mesavage and Girard 1946, Killcreas and others 1985, Parker and Matney 1995) for sawtimber using tree d.b.h. and merchantable tree height;

Table 5—Estimated timber volumes from 409 pulpwood and 167 sawtimber trees measured on 20, 0.2-ac fixed radius plots on a 40-acre tract computed with (1) conventional form class volume equations, (2) Tele-Relaskop derived volume equations, and (3) Tele-Relaskop taper coefficients from 50 sample trees

Volume computational procedure	Standard cords	Board feet Doyle	Sampling error	Coef. of variation
			----Percent----	
Form class equations (Minor's 77; M&G 80)	282	128,198	15.2	32
Tele-Relaskop single-tree volume equations	249	128,403	15.8	34
Tele-Relaskop species-average taper coefficients	325	137,905	14.4	31

2. volume equation coefficients computed from the 50 Tele-Relaskop sample tree volumes shown in Table 4 using tree d.b.h. and merchantable tree height in feet for pulpwood (equation 6) and number of 16 ft logs for sawtimber (equation 13); and

3. species-average taper coefficients computed from the 50 Tele-Relaskop sample tree measurements shown in equation (14) using tree d.b.h. and total tree height from the 50 sample trees.

With procedure 3, d.b.h. was recorded for each tree on the inventory plot and total tree height was recorded for only those trees measured with the Tele-Relaskop. Prior to processing the inventory data, the OMNITALI processor extracted those tally trees with d.b.h. and heights from the data set and computed a log height-reciprocal of d.b.h. regression. Then, during the actual inventory processing, tally trees with no recorded total height were assigned a predicted height from the regression. Volumes of pulpwood trees were computed in 4 ft bolts to a 3.0-in. top, o.b., and sawtimber trees in 16 ft logs to a 6.0-in. top, o.b. using equation (14) in an iterative procedure to predict upper stem diameters at the desired stem lengths. Pulpwood bolt volumes (o.b.) were computed with Smalian's cubic foot volume equation, summed to the tree level, and converted to standard cords using appropriate cubic foot to cord conversion factors for the tree d.b.h. Sawtimber volumes of 16 ft log segments were computed with the Doyle board foot equation where o.b. diameters were converted to i.b. scaling diameters with a bark thickness equation.

The results of the inventory processing comparisons are presented in Table 5 where sampling errors and coefficients of variation were computed on the overall mean volume estimate for combined cubic feet. Since the volume of the sample tract was not determined with a 100 percent tally and the tract was inadvertently cut during an emergency "wet period" without retention of scale tickets, the true tract volume is unknown. While the bias of each procedure relative to the true volume cannot be quantified, the taper coefficient procedure produced the smallest sampling error and coefficient of variation. Without passing judgement on the superiority of one procedure over another, it is evident that the Tele-Relaskop procedures provided realistic estimates of tract volume that are comparable to conventional volume computational procedures. The real advantages of the Tele-Relaskop procedures over conventional volume equations/tables are that single tree volumes can be derived from sample trees taken on a specific tract, are developed to reflect current merchantability standards, and are not associated with cruiser estimates of tree form.

SUMMARY

The Tele-Relaskop is a dendrometer that can be used to obtain relative, non-destructive, upper stem measurements of sample trees and these upper stem measurements can be used to develop tract-specific, single-tree volume and species-average taper equations. The measurement accuracy of the Tele-Relaskop (0.01 percent for diameter and 0.1 percent for height) is best translated into practical applications with the aid of a microcomputer and specialized software systems such as TELE and OMNITALI. Using Tele-Relaskop measurements to compute local volume and taper equation coefficients allows cruisers to compute inventory volumes to changing merchantability standards without reference to field estimates of tree form, such as form class. Changes in utilization standards can be immediately incorporated into current inventory processing procedures. The Tele-Relaskop is a useful mensurational tool for both field and research foresters, but practical applications have been limited by the sophisticated calculations required to utilize upper stem measurements for the development of tree taper and volume functions and to link these functions to traditional inventory processing procedures. Research is currently underway in the Department of Forestry at Mississippi State University to evaluate tree measurement and volume computation accuracy of the Tele-Relaskop in comparison to other dendrometers and a new laser device.

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INTENSIVE FOREST MANAGEMENT COMES OF AGE: MODELED, MANAGEMENT ACTIVITY SPECIFIC RESULTS FOR LOBLOLLY PINE PLANTATIONS'

Coleman W. Dangerfield, Jr. and David J. Moorhead[2]

Abstract-Intensive forest has progressed to the state of site- and activity-specific recommendations that provide predictable outcomes of wood-flow and financial performance across chosen rotations. Recent Georgia-based research has developed growth and yield models for intensive pine plantation management scenarios. This research indicates yield responses to sequences of intensive management cultural practices. The Georgia Pine Plantation Simulator (GaPPS) v. 4.20 was used to model intensive forest management activities for loblolly pine plantations. Interactions between site preparation intensity, hardwood release. and fertilization were examined with respect to wood-flow, financial performance and rate-of-return (ROR).

INTRODUCTION

Application of agricultural-like practices of competition control, soil tillage to increase available rooting volume, pest control, and fertilization has resulted in dramatic growth gains in loblolly pine plantations across the South (Bailey and Borders 1997). In particular, the adoption of vegetation control in site preparation and early rotation ages has consistently produced dramatic growth gains (Miller and others 1991, Pienaar and Shiver 1993). Additionally, fertilization of pines at establishment and mid-rotation ages has dramatically increased over the last decade with substantial yield increase on many sites (Gent and others 1986, Allen and Morris 1998).

The private forest landowner and professional forest managers now can choose from an ever expanding menu of cultural activities in effort to increase stand growth and yield. The challenge is to select treatments that provide cost-effective gains (Moorhead and 'others 1998). Research data from University of Georgia Warnell School of Forest Resources Consortium on Accelerated Pine Production Studies and Plantation Management Research Cooperative have been used to develop growth and yield models for specific intensive management activities (Zhou and Bailey 1997). We examined the wood-flow and financial performance of increasing management intensity on loblolly pine plantations.

METHODS

Five specific scenarios were examined to establish and manage loblolly pine on cut-over sites: 1) Base = Chop and Burn, 2) Base + release at age 14, 3) Base + Chemical site preparation, 4) Base + release + fertilizer at age 14, and 5) Base + Chemical site preparation + fertilizer at age 14. All treatments received herbaceous weed control.

Growth and yield scenarios were modeled using GaPPS 4.20 (Zhou and Bailey 1997) using the following inputs: base site index at age 25 of 65 feet, 600 trees per acre surviving at age 5 years, discount rate of 4 percent, and management charged at $2 per acre per year. Treatment costs per acre were obtained from practices applied in the Coastal Plain of Georgia by forestry consultants in 1998-1999:

Mechanical site preparation (chop and burn) - $60
Chemical site preparation - $105
Seedlings + planting - $75
Herbaceous weed control - $40
Mid-rotation woody release - $70
Mid-rotation fertilization - $60

Product prices were $25 per cord for pulpwood, and $60 per cord for chip-n-saw (Timber Mart-South 1998). Financial performance reported in uninflated dollars. Optimum rotation age was selected when bare land value (BLV)was maximized.

RESULTS AND DISCUSSION

Total costs of the five scenarios ranged from $175 to $340 per acre (table 1). Optimum rotation age varied from 25 years for the scenario 1 chop + burn, to 20 years for scenario 5 where chemical site preparation and mid-rotation fertilization was used (table 2). Scenario 5 was also the most expensive at $340 per acre. Rotations for all other scenarios optimized at 21 or 22 years. Little overall differences were found in optimized rotation total wood-flow between all but the most intensive scenario 5. However, three to four additional years of growth were required by the base scenario of chop + burn to produce an equivalent wood-flow when compared to the more intensive scenarios. The most intensive set of treatments in scenario 5 resulted in a six cord per acre volume increase five years earlier than the base scenario produced. Overall, while uninflated SEV, AEV, and IRR were similar across scenarios, the reduction in rotation age with more intensive treatments moved cash-flow forward in the investment period.

Wood-flow increments and the rate-of-return (ROR) of treatments for each scenario are presented in Table 3. Control of competition with herbicides at establishment or at mid-rotation provided the greatest increments in wood-flow. Scenario 3, chemical site preparation, yielded the greatest wood-flow change (11.19 cords) over the optimized 21 year rotation, however, the ROR of the treatment over the 21 year period was 4.87 percent. Compare that investment to scenario 2, release at age 14, which yielded a 5.5 cord increase and an 8.85 percent ROR over the eight year

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Table I-Model scenario and per acre component and total costs

Scenario	Chop +burn	Chemical site preparation	Seedlings +planting	Herbaceous weed control	Woody release	Fertilizer	Total cost
	$/acre						
1 = Chop+bum (base)	**60**	**0**	75	**40**	0	**0**	175
2 = 1 + Release	**60**	**0**	75	**40**	70	**0**	245
3 = 1 + Chemical site preparation	**60**	105	75	40	0	0	280
4 = 2 + fertilizer	**60**	0	75	40	70	**60**	305
5 = 3 + fertilizer	60	105	75	40	0	**60**	340

Table 2—Optimum rotation age, based on Bare Land Value (BLV), total volume per acre, Soil Expectation Value (SEV), Annual Equivalent Value (AEV), and Internal Rate of Return (IRR)

Scenario	Optimum BLV rotation age	Total cords per acre	SEV	AEV	IRR
	Years		$/acre		*Percent*
1 = Chop +burn (base)	**25**	44.20	272	10.86	6.48
2 = 1 + Release	**22**	42.96	288	11.52	6.60
3 = 1 + Chemical site prep.	21	46.97	306	12.25	6.19
4 = 2 + fertilize	22	45.93	282	11.28	6.47
5 = 3 + fertilize	20	51.04	380	15.22	6.63

Table 3-Total treatment cost, incremental treatment costs, wood-flow Increments and value, and rate-of-return (ROR) of incremental treatments

Scenario	Total treatment cost	Treatment cost change	Number of years for wood-flow change	Total wood-flow change from treatment	Growth change per year	Total wood-flow value change from treatment	Treatment ROR
	$/acre		*Cords/acre*	*cords*	*$/acre*	*Percent*	
1 = Chop+bum (base)	175	—	—	—	—	—	—
2 = 1 + Release	245	70	**yr 14 to 22 =** 8	5.50	0.64	**138**	**8.85**
3 = 1 + Chemical site preparation	280	105	yr **0 to 21 = 21**	11.19	0.53	280	4.78
4 = 2 + fertilizer	305	**60**	**yr 14 to 22 =** 8	2.97	0.37	74	2.66
5 = 3 + fertilizer	340	**60**	**yr 14 to 20 =** 6	4.07	0.67	102	9.25

treatment period. The addition of fertilizer following release (scenario 4) produced an additional 2.97 cords in eight years with a 2.66 percent treatment ROR. Controlling hardwood competition with the addition of fertilization can boost wood-flow while keeping the invest time at a minimum.

The intensive site preparation in scenario 5, mechanical and chemical, resulted in a 9.25 percent ROR return from the mid-rotation fertilization treatment applied at age 14. This result was from the shorter six year investment/response interval in the 20-year optimized rotation for scenario 5.

Landowners and managers can use newly developed growth and yield models such as GaPPS (Zhou and Bailey 1997), and/or other yield models along with estimates of specific treatment responses (Allen and Morris 1998) to evaluate potential yield and financial performance of selected intensive management activities. All managers should clearly define management, product, and rotation objectives in order to select the most cost effective set of silvicultural treatments. For many landowners, maximizing production through high cost treatments may not be the most feasible or desirable investment activity. Examining specific treatment responses can help to maximize the returns on capital available for investment.

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USING LIVE-CROWN RATIO TO CONTROL WOOD QUALITY: AN EXAMPLE OF QUANTITATIVE SILVICULTURE[1]

Thomas J. Dean[2]

Abstract-Quantitative silviculture is the application of biological relationships in meeting specific, quantitative management objectives. It is a two-sided approach requiring the identification and application of biological relationships. An example of quantitative silviculture is presented that uses a relationship between average-live crown ratio and relative stand density to manage wood quality objectives in loblolly pine.

INTRODUCTION

In general, quantitative silviculture quantifies basic elements of stand structure and the biological relationships that strongly influence them (Jack and Long 1996). Quantitative silviculturists use this information to meet specific management goals and objectives by translating goals and objectives into a set of structural characteristics. Management issues that have been addressed with quantitative silviculture include calculating the number of trees to plant and thinning schedule necessary to produce a stand with a given average stand diameter, determining the stand conditions necessary for specified periodic annual increments, and creating specific wildlife habitats. To expand the range of potential management issues, research in quantitative silviculture draws from a variety of fields such as population biology, production ecology, and biometrics in addition to traditional silviculture.

There are two primary aspects of quantitative silviculture: (1) identifying a relationship and (2) applying the relationship. These two aspects can be clearly seen in the density management diagram: a widely used tool for quantitative silviculture. The density management diagram was first introduced in the United States by Drew and Flewelling (1977). The basic structure of the diagram depends on the relationship between average tree size and the stand density in self-thinning stands. Drew and Flewelling (1977) applied the relationship to the management of stand density. Another example of quantitative silviculture is the application of the relationship between sapwood cross-sectional area and leaf area to distributing growing stock among size classes in uneven-aged ponderosa pine stands (O'Hara 1996).

This paper presents an example of quantitative silviculture that shows how stand structure and associated biological relationships can be used to manage wood quality. Industries that have traditionally relied on wood from old-growth forests are having to switch their raw material source to intensively managed forests. The problem that these users face is finding material that meets their quality requirements because logs from these new sources generally have more juvenile wood, a greater number of knots, and larger diameter knots (among other characteristics). These characteristics affect the visual quality and the dimensional stability of the products, which clearwood users regard as important attributes of traditional old-growth sources (Eastin and others 1996). Theoretically, pruning can produce clear lumber regardless of the density or management intensity, and foresters have long known that the width of the juvenile core and average branch diameter can be minimized with high stand densities. However, pruning the live-crown and maintenance of high densities reduce diameter growth, conflicting with most current management objectives. An acceptable compromise between these conflicting objectives can be obtained, however, with quantitative silvicultural techniques using the relationship between average-live crown ratio and relative stand density.

THE RELATIONSHIP

As stand density increases, intertree shading causes death in the lower branches of the crown and a reduction in the live-crown ratio (the ratio between the length of the green crown and total height). This interaction results in a negative relationship between average live-crown ratio and its stand density (Long 1965). For loblolly pine plantations in the West Gulf between the ages of 1 I- and 16-years old, average live-crown ratio (C,) decreases linearly with increases in relative stand density (R_d) according to the equation

$$C_r=82.74-0.67R_d \ (n=32, R^2=0.75) \qquad (1)$$

(fig. 1). Relative stand density is the ratio between SDI and 450, the species specific SDI for loblolly pine. SDI is calculated as $TPA(Dq/10)^{1.6}$, where Dq is the diameter of the tree with average basal area.

THE APPLICATION

Management Objectives

An important step in quantitative silviculture is translating objectives into structural terms: for this example, objectives will be translated to target average live-crown ratios. While a wide variety of wood quality variables exist, important variables most readily influenced through density management are the width of the juvenile core and knot size. Juvenile wood is comprised of crown-formed wood and wood formed during the transition to mature wood after the crown moves up from a particular cross section (Clark and Saucier 1989). The length of time the live crown resides at a particular stem cross section also determines knot size. Since crown structure is related to stand density, trees grown in low-density stands will have larger knots sizes and wider juvenile cores than trees grown in high-density stands because of different crown structures. Once acceptable limits or goals for wood quality are stated, density management prescriptions can be prepared.

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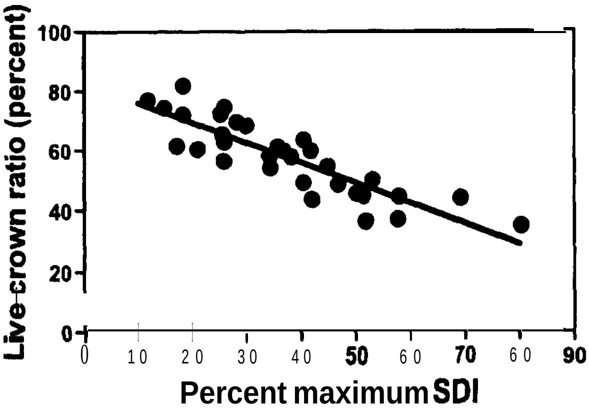

Figure l-Relationship between average live-crown ratio and relative stand density expressed as percent maximum SDI for midrotation (11 to 16-years old) loblolly pine plantations growing in the West Gulf region of the United States. Line fitted with simple linear regression: $Y=82.74-0.67X$ ($n=32$, $R^2=0.75$).

The principal approach to managing juvenile wood is to minimize its development. A seemingly semantic approach is to maximize the proportion of mature wood. This approach, however, suggests prescriptions that concentrate on diameter growth and actually results in a greater proportion of juvenile wood within the stem than the minimization approach. Simulations conducted by Maguire and others (1991) show that the amount of crown wood within the stems of Douglas-fir stems is less for trees grown under high densities than for trees grown under lower densities. Consequently, the higher the stand density, the smaller the juvenile core.

Knot size is also related to stand density. Ballard and Long (1988) showed a strong, negative exponential relationship between the mean of the five largest branches on the butt log and the number of lodgepole pine trees per acre. Simulations conducted by Maguire and others (1991) also indicated that branch size on the first log of Douglas-fir decreases with stand density. According to the grading rules published by the Southern Pine Inspection Bureau for 2-inch dimension lumber, for all other factors being equal, decreasing average branch diameter will improve lumber grade. Indeed, Clark and others (1994) found that the percentage of loblolly pine lumber graded No. 2 and better increased with decreased spacing and increased basal area after thinning.

Management Constraints

The actual minimum proportion of juvenile wood that can be achieved at a particular age is limited by practical management constraints. In this case, efforts to minimize the proportion of juvenile wood within the stem may produce trees too weak to respond to thinning quickly. As with management objectives, management constraints must also be expressed in terms of stand structure. Maintaining a tree's ability to quickly respond to thinning is usually accomplished by preventing average live-crown ratio from falling below 40 percent (Smith 1986). If the stand is to be pruned, an additional constraint may be to eliminate green pruning within the first log. This constraint may be met by setting the lower stand density such that when the stand is thinned and pruned, the base of the live crown is above some specified standard such as 18 ft. If it is not pruned, this constraint would ensure no grade reduction of the butt log after thinning due to branch persistence and growth.

Expressing these constraints in structural terms is accomplished with the relationship between average live-crown ratio and relative stand density. The relative stand density corresponding to 40 percent average live-crown ratio for West Gulf loblolly pine is 63 percent. The minimum height required for a minimum of 18 ft to the base of the live crown is calculated with equation [l] at regular intervals of stand density. The two lines representing these constraints form a wedge on the West Gulf density management diagram for loblolly pine (fig. 2). Marketing constraints are commonly set by a minimum average stand diameter, and lower growing stock limits are usually set no lower than canopy closure (Dean and Baldwin 1993).

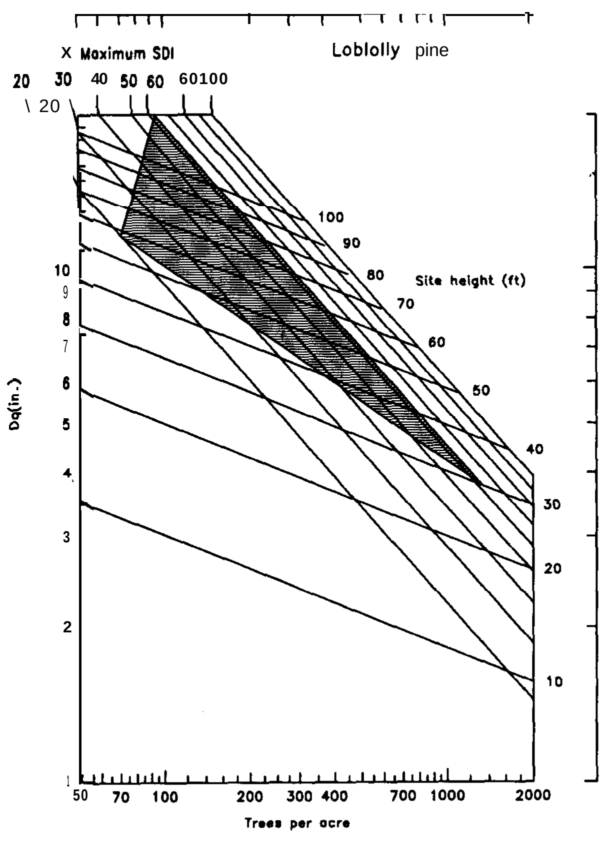

Figure P-Density management diagram showing the region where average live-crown ratio is greater that 40 percent (upper boundary of shaded area) and the height to the base of the live crown is at least 18 ft (lower boundary of shaded area). The left boundary of the shaded area is arbitrarily set..

Prescriptions

To minimize the proportion of juvenile wood and to satisfy a 5-inch diameter thinning requirement, 890 trees per acre must survive to the first thinning at age twelve, assuming a site index of 60 (base age 25 years) (fig. 3, option A). At 100 percent survival, this translates into a 7 x 7-ft spacing. Such close spacing is vulnerable to wind and ice damage after

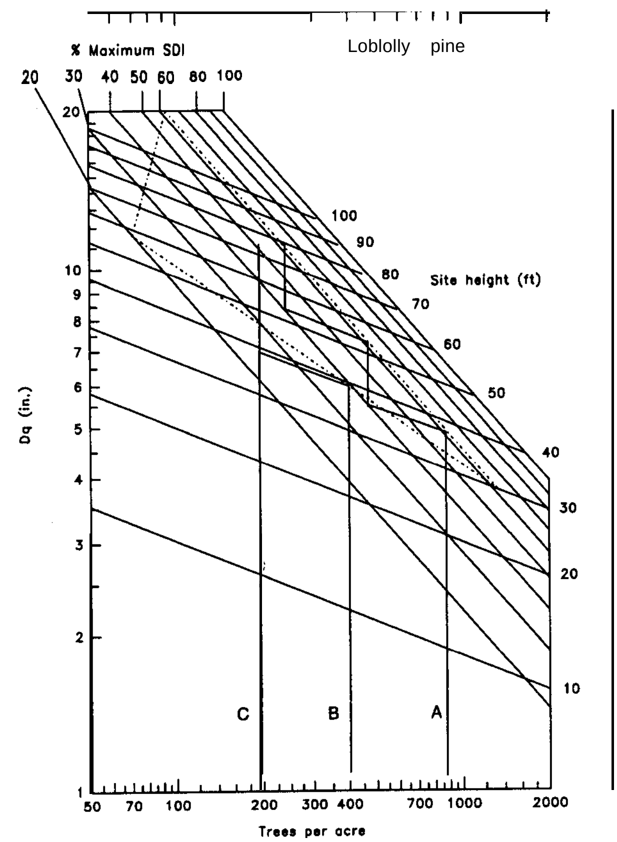

Figure 3-Density management diagram showing three alternative prescriptions for managing the quality of the butt log at rotation age. Option A results in the smallest proportion of juvenile wood. Yields for each option shown in Table 1. The wedge outlined with the dash-dot line is the shaded area shown in Figure 2.

thinning; consequently, this plan prescribes two thinnings to avoid inherent dangers with one radical thinning before harvest. At a rotation age of 47 years, the average stand diameter is projected to be 11.6 inches. For this option, the projected proportion of juvenile wood in the butt log of the average tree at rotation age is 19 percent. This prescription would yield 81 cunits/acre over a **47-year** rotation (table 1).

An alternative prescription designed to produce the same average stand diameter 7 years earlier, increases the projected proportion of juvenile wood in the butt log to 25 percent. The accelerated diameter growth is accomplished by maintaining larger values of average live-crown ratio throughout the rotation but with the constraint that the height to the base of the live crown is 18 ft when the stand is thinned at age 13 years. This plan requires that 400 TPA survive to the first thinning and includes only one thinning since the relative density when the stand is thinned should only be 39 percent (fig. 3, option B). An additional consequence of this option is lower yields from thinning and final harvest (table 1).

The effect of planting sufficient number of trees to allow for a thinning on the projected proportion of juvenile wood is illustrated by eliminating the thinning in option B (fig. 3, option C). By having 190 TPA survive to the end of the rotation, 11 .&inch trees are produced within the same 40

Table l-Yields of various options for managing the quality of the butt log in loblolly pine plantations

Option	Operation	Age	Yield[a]
			cunits/acre
A	Thinning	12	6.7
	Thinning	23	13.4
	Harvest	47	61.2
Total			81.3
B	Thinning	13	6.5
	Harvest	40	49.0
Total			55.5
C	Harvest	40	49.0

[a] Yields calculated as described by Dean and Baldwin (1993) using a growth-and-yield simulation program (COMPUTE P-LOB) to calculate volume to a 3-inch top.

years, but the proportion of juvenile wood within the butt log of the average tree increases to 37 percent. Eliminating the thinning increases the overall live-crown ratio of the trees averaged over the length of the rotation, increasing the width of the juvenile core within the first log.

Option A is the superior of the three options based on the projected proportion of juvenile wood in the butt log at the end of the rotation. A quantitative relationship between average branch size on the butt log and relative stand density does not yet exist for loblolly pine: however, based on reports for other species, option A would probably have smallest, average knot size between the three alternatives. Economics, obviously, exert a strong influence on the choice of the three alternatives. Without a premium on the value of the logs produced by option A, the spacing prescribed by this option would likely make it economically inferior to the other options, unless interest rates were extremely low. However, if a premium on logs with small knots and a preponderance of mature xylem were available, economic analyses may favor, at the very least, increased planting densities over those prescribed in options B and C.

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PROJECTING A STAND TABLE THROUGH TIME[1]

Quang V. Cao and V. Clark Baldwin, Jr.[2]

Abstract-Stand tables provide number of trees per acre for each diameter class. This paper presents a general technique to predict a future stand table, based on the current stand table and future stand summary statistics such as trees and basal area per acre, and average diameter. The stand projection technique involves (a) predicting surviving trees for each class, and (b) growing tree diameters such that the stand table at the end of the growth period produces future stand summaries identical to those mentioned above. Linear and nonlinear diameter growth models produced similar results. The stand table projection approach was as good as the parameter-recovery Weibull model for unimodal distributions, and out-performed the Weibull when diameter distributions were bimodal or irregular.

INTRODUCTION

Stand tables give number of trees per acre for each diameter class. They provide information to compute product volumes and are thus a desirable feature in growth and yield modeling. In 1980, Clutter and Jones developed a stand table projection model which was later revised by Pienaar and Harrison (1988). Nepal and Somers (1992) developed an algorithm to project a stand table so that the future stand table would result in trees and basal area per acre identical to observed values. Recently, Tang and others (1997) introduced a distribution-independent approach to project a diameter distribution through time.

The objective of this project was to develop a model to project a current stand table to a future age, such that the resulting future stand table produces stand-level variables such as trees per acre, basal area per acre, and average diameter. These variables are compatible with either actual values or those predicted from a whole stand model.

DATA

Two data sets were used in this research. The first data set consisted of planted loblolly pines (*Pinus taeda* L.) at the Hill Farm Research Station in north Louisiana. These trees were subjected to thinning and pruning treatments at ages 6 and 11 plus a control. There was a total of 35 plots. Diameter at breast height (dbh) was recorded for each tree every 3 to 8 years (table 1).

The second data set was from 63 direct-seeded longleaf pine (*Pinus palustris* Mill.) plots established in central Louisiana. Tree diameters were remeasured every 3 or 5 years (table 1). Precommercial thinning was applied to 39 plots at age 7.

Table 2 shows the distribution of observations from stands of planted loblolly pines and direct-seeded longleaf pines by stand age and basal area.

METHODS

The stand table projection system consisted of a survival equation and a diameter growth equation.

Survival Equation

For simplicity's sake, we assumed that all mortality occurred at the beginning of the growth period and surviving trees would remain at the end of the period. Number of trees for the ith diameter class after mortality can be computed from

$$n_{2i} = n_{1i} \{1 - \exp[a_1 (D_i - D_{min} + 1)]\} \qquad (1)$$

where

n_{1i} and n_{2i} = trees per acre in the ith diameter class before and after mortality, respectively,
D_i = midpoint of the ith diameter class,
D_{min} = midpoint of the minimum diameter class, and
a_1 = coefficient.

Note that the quantity $(D_i - D_{min})$ represents the distance between the ith diameter class and the minimum diameter. Equation (1) indicates that trees in a small diameter class will suffer more heavily from mortality than those from a larger diameter class. The survival function has only one coefficient, a,, which was computed such that the sum of trees over all diameter classes was equal to total trees per acre after mortality. A numerical method such as the secant method (Press and others 1996) can be used to solve for a,.

Diameter Growth Equations

In this study, we looked at a linear growth equation,

$$D_{2i} = b_1 + b_2 D_{1i}, \qquad (2)$$

and a nonlinear growth equation,

$$D_{2i} = b_1 (D_{1i})^{b_2}, \qquad (3)$$

where

D,, and D_{2i} = midpoints of the ith diameter class at times 1 and 2, respectively, and
b, and b_2 = coefficients.

Bailey (1980) showed that diameter growth was either linear or nonlinear, depending on the diameter distribution. His nonlinear equation form was slightly different from equation (3).

After diameter growth, number of trees per acre in each diameter class was recalculated using Nepal and Somers' (1992) approach which assumed that trees in each class followed a doubly-truncated Weibull distribution.

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-16, 1999.

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Table I-Distribution of 35 planted loblolly pine plots and 63 direct-seeded longleaf pine plots by measurement age

Plots	Measurement ages
No.	
Planted loblolly pines	
26	11, 16, 21, 29
9	13, 18, 21, 25, 29
Direct-seeded longleaf pines	
7	14, 17
7	14, 17, 22
1	17, 22
16	17, 20, 23, 26
8	18, 23
22	22, 27

Table 2—Distribution of observations from stands of planted loblolly and direct-seeded longleaf pines by stand age and basal area

	Stand basal area						
Age	40	80	120	180	200	240	Total
Years	*Square feet per acre*						
Planted loblolly pine							
11-13	23	3	4	5			35
14-16	6	16	4				26
17-19					8		9
20-22		14	9	3	9	1	35
23-25							9
29		4	13	9	8	1	35
All	29	37	30	21	30	2	149,
Direct-seeded longleaf pine							
14-16	14	2					14
17-19	8	19	11	3			41
20-22		7	19	21	1		48
23-25	2	5	4	14	1		26
26-28			4	34	2		40
All	22	33	38	72	4		169

The two parameters, b, and b_2, of the linear or nonlinear diameter growth equation were found such that summing up the resulting stand table produced the specified average diameter (Davg) and basal area per acre (B). Therefore b, and b_2 are solutions for the following system of 2 equations and 2 unknowns:

$$f_1 = (\Sigma n_i D_i)/N \cdot \text{Davg} = 0 \qquad (4)$$
$$f_2 = K \Sigma n_i D_i^2 - B = 0 \qquad (5)$$

where

n_i = number of trees per acre in the ith diameter class after diameter growth,

N = total trees per acre after mortality, and

K = 0.005454 = a constant to convert diameters in square inches to basal area in square feet.

The summation sign denotes the sum over all diameter classes.

The algorithm used to solve for b, and b_2 is as follows:

1. Guess starting values for b, and b,.
2. Compute diameter increment for each diameter class.
3. Compute number of trees for each diameter class (n,) after diameter growth.
4. Compute f, and f_2.
5. Compute new values for b, and b,, then go back to step 2. The loop continues until f_1 and f_2 are sufficiently close to zero (or less than a predetermined value).

NUMERICAL EXAMPLE

Table 3 shows an example demonstrating the application of the new methods to projecting a stand table from age 20 to age 23 for plot 310109 from the direct-seeded longleaf pine data set. In this example, it was assumed that the observed stand table at age 20 was available, but only stand summaries at age 23 were known (N = 613.45 trees/acre, Davg = 6.33 in., and B = 149.22 sq.ft./acre). Number of trees in each diameter class was reduced after mortality (column 4). Final stand tables were then computed after trees grew according to the linear diameter growth function (column 5) or the nonlinear function (column 6). Note that stand tables produced by these two methods were very similar.

The observed and predicted trees per acre in each diameter class are shown in Figure 1. Also shown is a stand table from a Weibull distribution, obtained using the parameter recovery method. It is obvious from the graph that the Weibull did not perform very well when the actual distribution was bimodal as in this example.

EVALUATION

The stand table projection methods based on linear and nonlinear diameter growth were evaluated against the parameter-recovery Weibull distribution approach, using growth data from planted loblolly pines and direct-seeded longleaf pines. Three criteria were employed in the evaluation:

1. The K-S statistic (Steel and Torrie 1980).
2. The Chi-square statistic (Steel and Torrie 1980).
3. A simple form of Reynolds and others' (1988) error index, which is the sum over all diameter classes of the difference between observed and predicted number of trees in each diameter class.

Table 3-A numerical example demonstrating the application of the new methods to projecting stand table from age 20 to age 23 for plot 310109 from the direct-seeded longleaf pine data set

	Observed trees/acre		Predicted trees/acre at age 23		
Diameter (1)	Age 20 (2)	Age 23 (3)	After mortality (4)	Linear D growth (5)	Nonlinear D growth (6)
Inches					
2	33.61		13.76	7.46	7.43
3	134.45	67.23	87.57	57.51	57.50
4	126.05	100.84	100.10	89.81	89.87
5	75.63	58.82	66.44	77.79	77.81
6	100.84	75.63	93.60	72.41	72.43
7	142.86	109.24	136.80	99.80	99.80
8	75.63	100.84	73.74	110.13	110.08
9	33.61	58.82	33.11	61.02	61.00
10	8.40	33.61	8.33	29.00	29.00
11		8.40		7.95	7.96
12				.56	.57
N[a]	731.09	613.45	613.45	613.45	613.45
Davg	5.40	6.33	5.73	6.33	6.33
B	132.46	149.22	122.24	149.22	149.22

[a] N is total trees per acre, Davg is average diameter in inches, and B is stand basal area in $ft.^2$ per acre.

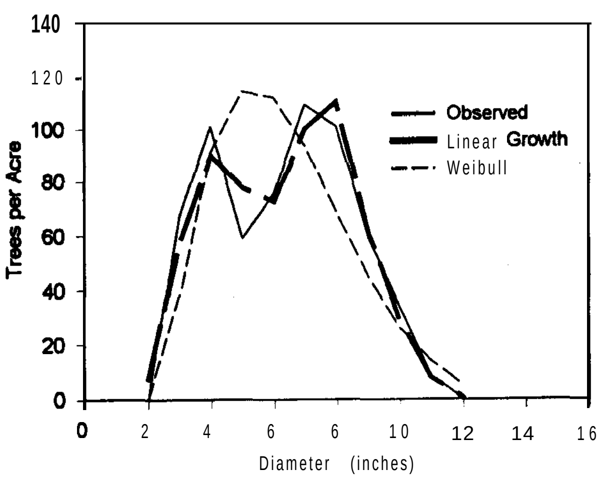

Figure l-Observed and predicted diameter distributions at age 23 for plot 310109 from the direct-seeded longleaf pine data set by the stand table projection and Weibull methods.

Results of the evaluation for both data sets are shown in Table 4.

Planted Loblolly Pines

The K-S statistics and the error indices for all three models were not different at the 5 percent level, even though values from the Weibull distribution model were always higher. Only the Chi-square statistics from the Weibull distribution were significantly different from those of the other two models. The values for the linear and nonlinear diameter growth models were very close, confirming the fact that these two models produced very similar stand tables. The relatively good performance of the Weibull model might be due to mostly unimodal diameter distributions from planted loblolly pines. These distributions could be adequately characterized by the Weibull function.

Direct-Seeded Longleaf Pines

As with planted loblolly pines, the linear and nonlinear diameter growth models produced essentially identical values for direct-seeded longleaf pines. The Weibull values, on the other hand, were significantly higher for all three criteria. The reason is likely that direct-seeded longleaf pine data contained some plots that involved bimodal or irregular diameter distributions. As shown in the previous example, the Weibull model did not perform as well as the stand table projection models in those cases.

Table 4-Means (and standard deviations) of the evaluation statistics by method and species

Method	Evaluation statistic		
	K-S	χ^2	Error index
Planted loblolly pine (n = 114)			
Linear growth	0.051[a] (0.031)	3.822[a] (3.970)	0.259[a] (0.152)
Nonlinear growth	.052[a] (0.031)	3.746[a] (3.479)	.260[a] (0.154)
Weibull	.058[a] (0.033)	5.753[b] (6.130)	.285[a] (0.156)
Direct-seeded longleaf pine (n = 106)			
Linear growth	.032[a] (0.015)	3.891[a] (3.133)	.166[a] (0.072)
Nonlinear growth	.033[a] (0.015)	3.963[a] (3.003)	.167[a] (0.072)
Weibull	.046[b] (0.022)	7.479[b] (5.597)	.221[b] (0.095)

Note: For each evaluation statistic and for each data set, means with the same letter are not significantly different at the 5 percent level (from the Duncan's multiple range test).

CONCLUSIONS

The two stand table projection models based on either linear or nonlinear diameter growth produced similar results. Therefore the simple linear growth model is recommended. Furthermore, the stand table projection models were as good as the parameter-recovery Weibull model for unimodal distributions, and may out-perform the Weibull when diameter distributions are bimodal or multimodal.

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PREDICTING DIAMETER JUMP ON EVEN-AGED STANDS[1]

Boris Zeide and Yujia Zhang[2]

Abstract-Average diameter of forest stands changes as a result of two processes: tree growth and thinning. Unlike growth, thinning changes diameter abruptly, in a jump. This component of stand dynamics was investigated using the data from permanent plots established in loblolly pine (*Pinus taeda* L.) plantations. Diameter jump is considered as an outcome of following processes: (l) competition, (2) thinning intensity, (3) stand variability, and (4) the relationship between sample size and the position of extreme deviates. Two models of the relationship between diameter jump and the ratio of removed trees were designed and tested. The selected model explains 88 percent of variability in diameter jump. The knowledge of diameter jump may contribute to a better understanding of stand dynamics and may facilitate growth modeling.

INTRODUCTION

The increase in average stand diameter has two components: continuous tree growth and discrete jump that results from the removal of trees by natural or silvicultural thinning. The aim of this study is to develop a model for predicting diameter jump from commonly available inventory information. The objectives are to evaluate the contribution of diameter jump to stand dynamics, identify processes that determine diameter jump, select predicting variables, design at least two models, and test them using permanent plot data.

DATA

The permanent plot data were collected from 1980 to 1992 in cutover, site-prepared loblolly pine plantations (*Pinus taeda* L.) originated from woods-run (unimproved) seedlings (Burkhart and others, 1985, Avila and Burkhart 1992, Hasenauer and others, 1994). The plots, maintained by the Loblolly Pine Growth and Yield Research Cooperative at Virginia Polytechnical Institute and State University, were established in 186 locations covering the entire native loblolly pine range from the Atlantic coast to eastern Texas. There are three plots at each location: control, lightly thinned (about one-third of basal area removed at each thinning), and heavily thinned (one-half of basal area removed). Plot areas varied from 0.024 to 0.113 hectare (ha). On thinned plots, the trees were cut immediately after the initial measurement. Due to various disturbances 174 out of the original 559 plots were dropped from the data set by the last measurement. Each of the remaining plots has been measured five times at a three-year (yr) interval. The total number of plot measurements is 2502. Summary statistics for the first and the fifth measurements are given in Tables 1 and 2.

CONTRIBUTION OF DIAMETER JUMP

Definitions

Diameter jump, J (centimeter (cm)), is the difference between quadratic mean diameters, Da(t) (cm) and Db(t) (cm), after and before thinning (natural or silvicultural) when the age of trees, t (yr), is the same:

$$J = Da(t) - Db(t), \qquad (1)$$

The growth, G (cm), is the difference between the average diameters of the same number of trees after a given period of growth, l. G is calculated using only the trees that survive by the next measurement:

$$G = Db(t+l) - Da(t), \qquad (2)$$

Diameter Jump

The average ratio of diameter jump to the growth (J/G) was calculated for each measurement and thinning level of the loblolly pine data set. The ratios change with the time after thinning. A reasonable period at which to compare the ratios is that when stand density (characterized by Reineke's (1933) stand density index) returns to the pre-thinning level. This happens after about 9 years for lightly thinned plots and 12 years for heavily thinned plots (table 3). At that moment the J/G ratio is about 1/3 for both lightly and heavily thinned plots. Thus, diameter jump accounts for 1/4 (=(1/3)/(1+1/3)) of the total increase of diameter.

The low values of the ratio for the control plots reflect the low intensity of natural thinning (2.3 percent per year) resulting from the lack of time since crown closure. During this time, trees increase their diameter without a substantial decline in numbers, which explains why the J/G ratio is smaller than in the thinned stands.

PROCESSES DETERMINING DIAMETER JUMP

Diameter jump is caused by several ecological and statistical processes such as competition, which determines the direction and intensity of thinning, the extent of thinning measured by the proportion of thinned trees, and stand variability. Competition among trees assures that usually phenotypically larger trees survive in the process of natural thinning, which makes diameter jump positive. The same happens as a result of silvicultural thinning from below, which often aims at anticipating and salvaging future mortality and directing resources to more valuable larger trees.

Intensity of Thinning

Intensity of competition and its duration are integrated by one variable: the ratio of removed trees, R,

$$R = Nr/Nb, \qquad (3)$$

where

Nr is the number of trees removed and Nb is the number of trees before thinning.

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

[2] Professor and Research Specialist, School of Forest Resources, University of Arkansas, Monticello, AR 71656-3468, respectively.

Table l-Basic statistics of the loblolly pine data set at the first measurement (559 plot measurements)

Variable	Statistics		
	Minimum	Mean	Maximum
Age from seed (years)	9	16	26
Plot elevation (m)	4.6	103.6	336.3
Number of trees per hectare	702.9	1,419.5	2,643.9
Arithmetic mean height (m)	4.2	14.6	22.2
Diameter (cm)	6.7	14.6	25.6
Standard deviation of diameter (cm)	1.3	3.6	6.4
Basal area (m^2/ha)	5.0	24.5	54.9
Density of pines	139.2	561.7	1,094.3
Density of hardwoods	.6	22.0	150.3

Table 2—Basic statistics of the loblolly pine data set at the fifth measurement (385 plot measurements)

Variable	Statistics		
	Minimum	Mean	Maximum
Age from seed (years)	21	26	36
Number of trees per hectare	226.3	620.6	1,927.4
Arithmetic mean height (m)	10.1	16.0	25.5
Diameter (cm)	14.7	22.2	34.2
Standard deviation of diameter (cm)	2.7	4.2	7.5
Basal area (m^2/ha)	12.1	30.1	49.0
Density of pines	256.7	621.1	1,033.2
Density of hardwoods	1.6	27.7	136.9

This ratio is a major cause of diameter jump: As more and more trees are removed from below, the diameter of the remaining trees will be increasing but at a declining rate, which will be minimal when average trees are thinned. If thinning proceeds further, this rate will pick up again, reaching another maximum when the second-largest tree is removed.

This reasoning indicates that the form of the curve relating J and R is likely to resemble the inverse of the accumulated diameter distribution. In this study, we used the distribution published by Clutter and others (1963, page 104) to test this assumption. Comparison of Figures 1 and 2 shows that the shape of the J-R relationship is indeed similar to the inverse of the accumulated diameter distribution. Both curves are concave down for the low ratios and concave up for the larger ones. Along with this qualitative agreement, there is a difference: the inverse distribution appears as the J-R relationship compressed from the left side. Raising R to some power greater than 1 can produce this compression (fig. 3) accounting for the proportion of smaller trees.

This observation suggests that the inverse of the present diameter distribution can be used to predict the future diameter jump. The driving variable should be the ratio of the removed trees, raised to some power, $r>1$.

Stand Variability

The second process determining diameter jump is diameter variability among trees. The jump cannot exceed the difference between the mean and maximum diameters. The maximum diameter is a subject of much uncertainty because

Table 3-Diameter jump (J) and tree growth (G) on loblolly pine plots. Time is number of years since first measurement, NB and NA are numbers of trees per plot before and after thinning, DQB and DQA are quadratic mean diameters before and after thinning, SDI is Reineke's stand density index before thinning, and R is the ratio of removed trees

Time	NB	NA	DQB	DQA	SDI	R	J	G	J/G
			- - - - cm - - - -				- - - - - - - cm - - - - - - -		
				Lightly thinned plots					
0	130	77	14.75	16.23	567	0.41	1.48	0.00	—[a]
3	77	75	18.17	18.22	466	.42	1.48	1.94	0.76
6	75	72	19.72	19.82	520	.45	1.53	3.50	.44
9	72	71	20.98	21.10	565	.45	1.59	4.75	.34
12	71	—[a]	22.33	—[a]	613	—[a]	1.94	6.10	.32
				Heavily thinned plots					
0	130	58	14.73	16.72	567	.55	1.98	.00	—[a]
3	56	57	16.94	18.98	360	.56	1.98	2.22	.89
6	57	56	20.78	20.85	432	.57	2.02	4.06	.50
9	56	55	22.31	22.36	480	.58	2.05	5.59	.37
12	55	—[a]	23.80	24.49	531	—[a]	2.32	7.08	.33
				Control plots					
0	62	58	14.77	15.03	580	.06	.00	.00	—[a]
3	56	54	16.51	16.88	653	.13	.25	1.48	.17
6	54	50	17.88	18.22	686	.16	.55	2.85	.19
9	50	47	18.98	19.33	719	.24	.74	3.95	.19
12	47	—[a]	20.31	20.31	742	—[a]	.96	5.2	.18

[a] no data available.

it depends on the size of the single largest tree on a plot. A more reliable approach is to define the maximum in terms of mean diameter and its standard deviation, both of which are estimated using all measured trees.

The difference between the mean and maximum diameters that sets the upper limit of the jump varies not only with stand characteristics but also with sample size. The effect of sample size on the position of the extreme deviate is largely a statistical process.

MODELING OF DIAMETER JUMP

Requirements

Any model relating diameter jump, J, and the ratio of removed trees, R, should satisfy the following requirements.

1. When no trees are removed, there is no diameter jump:

   $J(R=0)=0,$

2. Diameter jump cannot exceed the difference between the largest and mean diameters. When all trees but the largest are removed, (so that R-l), J approaches its maximum, M:

   $J(R\to 1)\to M,$

3. The first derivative of the jump with respect to R has the U-shape.

Model Forms

Many equations can satisfy the above requirements. This study develops and compares two of them.

Inverse Weibull model-The reasoning behind the J-R relationship suggests that it is the inverse of an accumulated frequency distribution. The Weibull distribution, proposed by Weibull in 1951 and introduced for forestry applications by Bailey and Dell in 1973, is one of the most popular distribution functions. Its accumulated (integral) form is:

$$y=a(1-\exp(-bx^c)), \quad (4)$$

where

a, b, and c are parameters.

Using J (instead of x of equation (4)) and R^r (instead of y) provides the following model of diameter jump:

$$J=M(-\ln(1-R^r/a))^c, \quad (5)$$

where

in terms of the parameters of equation (4), $M=(-1/b)^{(1/c)}$ and $c=1/c$.

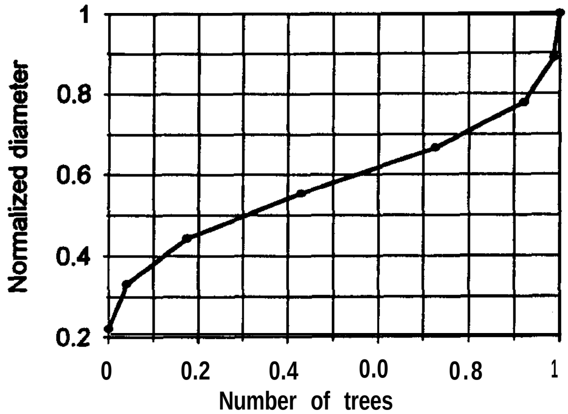

Figure I-The inverse of the diameter distribution of shortleaf pine (*Pinus echinata* Mill.) from Clutter and others (1983, page 194). To normalize diameter and number of trees per unit area, they were divided by their maximum values.

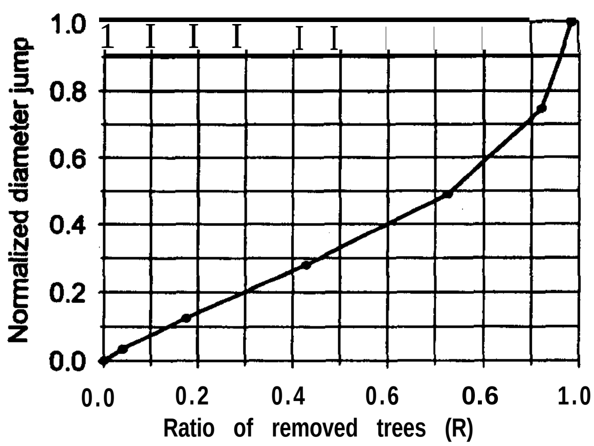

Figure 2-The relationship between diameter jump and the ratio of shortleaf pine trees removed from below for Clutter's and others (1983, page 104) diameter distribution.

Parameter a can be determined from the boundary condition specified as the second requirement: **J(R=1)=M.** If so, from equation (5) it follows that:

$$(-\ln(1-1/a))^c=1, \qquad (6)$$

and

$$a=1/(1-1/e)=e/(e-1)=(1-e^{(-1)})^{(-1)}, \qquad (7)$$

Thus, this diameter jump equation takes the following form:

$$J=M(-\ln(1-(1-e^{(-1)})R^r))^c, \qquad (8)$$

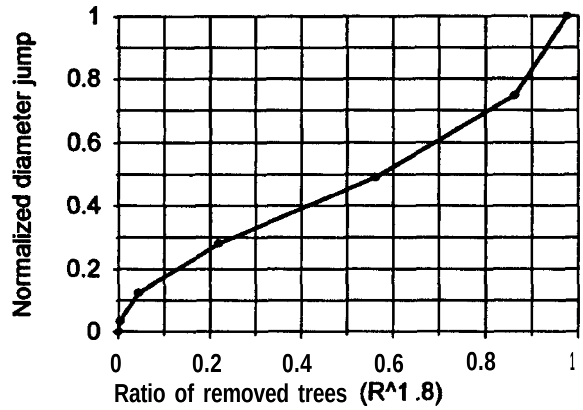

Figure 3-The relationship between diameter jump and the ratio of removed **shortleaf** pine trees raised to the power of 1.8.

Exponential model-To test its performance, the model designed above (equation (8)) should be compared with at least one alternative obtained from different considerations. We will start with designing a differential model relating the rate of change of J with respect to **R^r.** This derivative should be U-shaped (requirement 3) and can be expressed as follows:

$$dJ/dR^r=b1*\exp(-b2R^r)+c1(\exp(c2R^r)-1), \qquad (9)$$

All five parameters, bl , b2, cl, **c2,** and **r,** are expected to be positive.

Integration of equation (9) results in:

$$J=-bl/b2*\exp(-b1 \bullet R^r)+cl/c2*\exp(c2*R^r)-c1*R^r, \qquad (10)$$

Two boundary conditions (J=M when R=l and J=O when **R=0),** permit the elimination of cl and **c2:**

$$J=M(\exp(b2*R^r)-\exp(-b1*R^r)-b2*R^r)/(e^{b2}-e^{b1}-b2), \qquad (11)$$

Estimating Maximum Jump

The maximum diameter jump is likely to change with the standard deviation of diameter, stand density, number of trees per plot, and other stand characteristics. We will estimate this maximum using all available information.

Effect of sample size -The relationship between the sample size, n, and the maximum jump, M, was tested by a linear function

$$M(n)=a1+a2*\ln(n), \qquad (12)$$

and an alternative expression:

$$M(n)=a1 \bullet n^{(a2)}, \qquad (13)$$

where
al and a2 are parameters.

Effect of average diameter-Because average diameter, D (cm), is closely related to standard deviation, stand density, and number of trees per unit area, it is one of the chief predictors of the maximum jump. Naturally, the jump J = 0 when D = 0. The subsequent increase is likely to be monotonous. These considerations suggest that a power function may be promising for predicting the maximum jump:

$$M(D) \propto D^d, \quad (14)$$

where
d is a parameter.

Stand characteristics-The effect of stand characteristics such as number of trees per unit area, stand density, and composition, will be uncovered in the process of testing the model.

Testing and improving the models

comparing the models of diameter jump-The two equations (equations (8) and (11)) were compared with respect to the following criteria: (1) precision, (2) dependence on thinning level, and (3) number of model parameters. Both equations explained the same proportion of variance in J (0.78). However, the inverse Weibull did not vary with thinning level as much as the exponential model and contains fewer parameters (r and c versus b's and r). Therefore, we adopted the inverse Weibull form as the basis of the diameter jump model.

Then we tested two forms of the module describing the effect of tree number (equations (12) and (13)). Again the precision was the same. However, using number of trees/ha before thinning, N, (instead of number of trees per plot) improved the fit. The resulting model of diameter jump, J, includes three modules driven by number of trees/ha before thinning, N, quadratic mean diameter before thinning, D, and the ratio of removed trees, R:

$$J=kN^a D^d(-\ln(1-(1-e^{-1})R^r))^c, \quad (15)$$

where
a, c, d, k, and rare parameters.

Homogenizing the residuals —It appears that the residuals of equation 15 increase with the ratio of removed trees. The Goldfeld-Quandt test of heteroskedasticity (Studenmund 1992) confirms this impression. The GQ value was 23.7, which is significantly greater than the critical F-value of 2.21.

The observation that the residuals are proportional to the ratio, R, helped us to correct this deficiency: while fitting the model, we used the reciprocal of R as a weight (Neter and others, 1990) to eliminate heteroskedasticity. The fitted equation for loblolly pine, in its parameterized form, is:

$$J=6.22 \cdot 10^{-3} N^{0.48} D^{1.07}(\ln(1-(1-e^{-1}) R^{2.42}))^{0.37}, \quad (16)$$

$(R^2=0.87, SEE=0.65, n=3873)$

where
R^2 is coefficient of determination,
SEE is standard error, and
n is the number of observations.

All estimates of parameters, obtained using the SAS Proc Model, are highly significant ($P > |T| < 0.01$).

Elevation and diameter jump -To utilize the information available for the loblolly pine plots, we applied the model to each region of the data set. Analysis of residuals showed that they were strongly correlated with the region. We managed to identify the variable responsible for this variation: it was plot elevation above sea level, L (meter (m)). Plotting the model residuals over elevation indicates that diameter jump declines at higher elevations.

Several equations were designed to connect maximum jump and elevation, assuming that average elevation, L' (m), does not affect diameter jump. Among tested equations were,

$$M(L)=k-(k-1)(L/L')^l, \quad (17)$$

$$M(L)=\exp(l(L-L')) \; (l<0), \quad (18)$$

$$M(L)=(L/L')^l \; (L>0, l<0), \quad (19)$$

where
k and l are parameters.

Hardwood density and diameter jump -Besides plot elevation, analysis of residuals shows that hardwood density, H (characterized by Reineke's stand density index), is also a significant predictor of diameter jump.

Since the residuals increase with hardwood density, the effect of hardwoods widens the diameter distribution of pines and increases the maximum jump. If the module describing the effect of hardwoods on maximum jump, m(H), is a factor of the jump, then $m(H)=1$ when H=O. The following equations satisfy this requirement:

$$M(H)=1+h \cdot H, \quad (20)$$

$$M(H)=(1+H)^h, \quad (21)$$

where
h is a parameter.

Diameter Jump Prediction Model

Testing the alternatives accounting for the effects of elevation and hardwoods, it was found that equations (19) and (21) explained the highest proportion of variance in J. The model that includes the elevation and hardwood modules is slightly more precise than equation (16):

$$J=9.06 \cdot 10^{-3} N^{0.46} D^{0.98}(-\ln(1-(1-e^{-1}) R^{2.82}))^{0.32} (L/103.64)^{-5.58 \cdot 10^{-2}} (1+H)^{2.94 \cdot 10^{-2}}, \quad (22)$$

$(R^2 = 0.88, SEE = 0.63, n = 3873)$

where
J is diameter jump,
N is the number of trees/ha before thinning,
D is the quadratic mean diameter before thinning,
L is the plot elevation above sea level, and
H is hardwood density.

DISCUSSION

The separation of two components of diameter increase, diameter jump and continuous growth, opens new possibilities for modeling stand dynamics. This study documents the contribution of diameter jump, an abrupt change in average diameter that results from natural or silvicultural thinning. This neglected component of stand dynamics constitutes about **1/3** of diameter growth and accounts for **1/4** of the total diameter increase.

The model developed for predicting diameter jump is driven by the ratio of removed trees and several factors that determine the maximum jump. The readily available number of trees per hectare and their average diameter proved to be good predictors of this maximum. These variables reflect many processes that influence diameter jump. Since both variables change with age, age itself was found to be an insignificant predictor. Plot elevation above sea level and hardwood density improved significantly the prediction of diameter jump. As a result, the model developed for loblolly pine explains 88 percent of diameter jump variation. In its form and parameters, the proposed model encapsulates long-term information on the jump, which may facilitate prediction of stand dynamics.

ACKNOWLEDGMENTS

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Weibull, W. 1951. A statistical distribution function of wide applicability. Journal of Applied Mechanics. 18: 293-297. removed shortleaf pine trees raised to the power of 1.8.

ESTIMATING WHOLE CROWN NEEDLE BIOMASS WITH DOUBLE PHASE SAMPLING[1]

Hector M. De los Santos and Bruce E. Borders[2]

Abstract —It has been hypothesized that leaf area measurements will be useful in growth modeling of pine plantations. Thus there is currently a great deal of interest in estimating leaf area and leaf biomass in plantations. A strong linear relationship between total dry needle biomass (TNB) and total live branch basal area (LBBA) suggests that under a destructive sampling plan, we can direct sampling effort to measure the diameters of the live branches rather than TNB. The total LBBA can be used as an auxiliary variable in a double phase sample. This double phase sample will estimate TNB with more precision at less cost than a double phase sample which uses tree d.b.h. as the auxiliary variable. Seventy one loblolly pine trees measured in the Georgia Piedmont and the Coastal plain of South and North Carolina were used for the analysis. The proportion of the second phase sample size becomes stable around 6 percent when realizing a one kg bound on the error estimates for the mean while measuring the TNB on an average of 10 trees well distributed across the range of sizes. To meet this bound the first phase sample requires an average of 150 trees to be measured for LBBA. The slope of the relationship between TNB and LBBA is hypothesized to be site-specific depending on the nutritional and management conditions.

INTRODUCTION

The main problem associated with the use of leaf area or leaf biomass as a growth predictor variable is the inherent difficulty to accurately measure it. The demanding field and laboratory work increases dramatically for medium to large trees. Volume of fresh needle biomass from a large tree can occupy 2 m^2 (Kaufman and Troendle 1981). As a result, sample size has been limited for most studies. The appropriate selection of sampling strategy will produce reliable estimates of population parameters and narrow confidence intervals. This is not trivial for leaf area/leaf biomass studies where the high cost of the foliage collection limits sample size and thus makes models less reliable at a large regional scale.

The problem of estimating sample size for crown biomass assessments was clearly discussed by Brister and Shiver (1985). They proposed a useful double sampling strategy based on regression estimators with DBH as the auxiliary variable. They show how the use of this sampling strategy will not only produce narrow confidence intervals, but allows for the calculation of a reliable sample size for the main and auxiliary variable based on population characteristics.

MATERIALS AND METHODS

The research was conducted in a loblolly pine spacing study established at the B.F. Grant Memorial Forest near Eatonton Georgia (Pienaar and others 1997). The study was planted with genetically improved seedlings in March 1983 and consists of 24 plots each 1/10 acre (0.08 ha) with six planting densities 100, 200,400 800, 800 and 1000 trees per acre (247, 494,988,1483, 1977 and 2471 tress per hectare, respectively). The experimental design used is completely randomized with four replications of each density. In the summer of 1997 felled trees from the first thinning of the B. F. Grant spacing study were sampled to produce needle biomass estimators. Trees from all plots, except the 247 trees/ha plots, were cut to reach a residual target number of trees. Forty-three trees were selected and sampled using the methodology described by Xu (1997) to develop a two-level allometric estimation of total needle biomass: equations based on branch measurements will estimate dry needle branch biomass and in turn other equations will estimate total tree dry needle biomass. Sample trees came from four crown classes: Dominant, co-dominant, intermediate and suppressed. The variables measured for each tree include: diameter at breast height (DBH) in cm, total height from the stump (THS) in m, stump height (SH) in m, and live crown height (LCH) in m. The crown also was carefully measured and divided in five equal size sections along the stem. One branch was randomly taken in each section and the parts of the branch with foliage were collected, identified for tree and section number and bagged for further laboratory analysis. For each sample branch, length (m) and basal branch diameter (mm), at approximately 20 mm from the base of the branch, were obtained with a measuring tape and a digital caliper, respectively. The branch height (BH) and basal branch diameter (BBD) was recorded for every live branch to later estimate the total tree needle biomass. In the laboratory the foliage of each sample branch was separated from the branch fragment, identified and dried until reaching a constant weight. The needle weight was then measured with a balance to the nearest gram. Additional databases for similar studies on loblolly pine were provided by Profs. Graham H. Brister and Timothy B. Harrington to run several validation tests and to illustrate the double sampling strategy.

Relationship Between Needle Biomass and Total Live Branch Basal Area

In an attempt to increase the precision of estimation for total needle biomass the relationship between the total needle biomass and the total live branch basal area in mm^2 (LBBA) was analyzed. LBBA was defined as:

$$LBBA = \frac{\pi}{4}\sum_{i=1}^{n} BBD^2 \qquad (1)$$

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

[2] Doctoral Student in Forest Biometrics and Professor of Forest Biometrics, D.B. Wamell School of Forest Resources, University of Georgia, Athens, GA 30602-2152, respectively.

Where BBD = basal branch diameter measured at 20 mm from the base of the branch.

Figure 1 shows that this relationship is very strongly linear and stable for the trees in this study. This behavior is logical since the needle biomass per branch was estimated with an equation that uses the BBD squared and the branch relative position in the crown as independent variables (De los Santos 1998). To verify this relationship a database generated by Brister in 1977 for 28 loblolly pine trees was used (fig. 2). All trees in this database were located in the coastal plain of North and South Carolina and total needle biomass was obtained by removing and weighing all needles in each branch. Clearly the relationship between LBBA and the TNB is very similar to the relationship observed for the 43 trees in spacing study. A similar relationship was found by Whitehead (1990) in ***Pinus radiata*** for branch basal area and leaf area clustered on "branch complexes" but was never aggregated to estimate the total leaf area per tree.

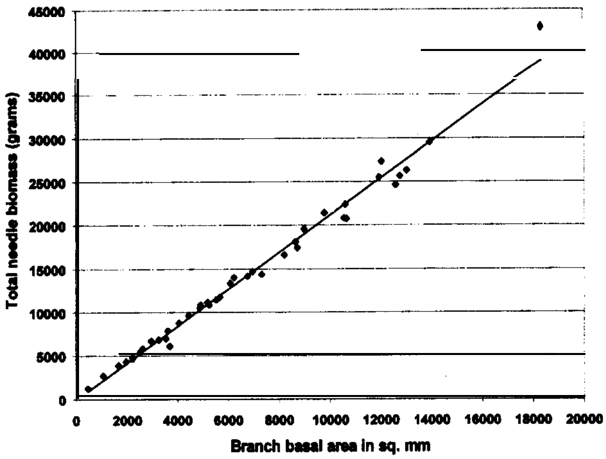

Figure l-Calculated total dry needle biomass vs total live branch basal area of loblolly pine for the B. F. Grant spacing study.

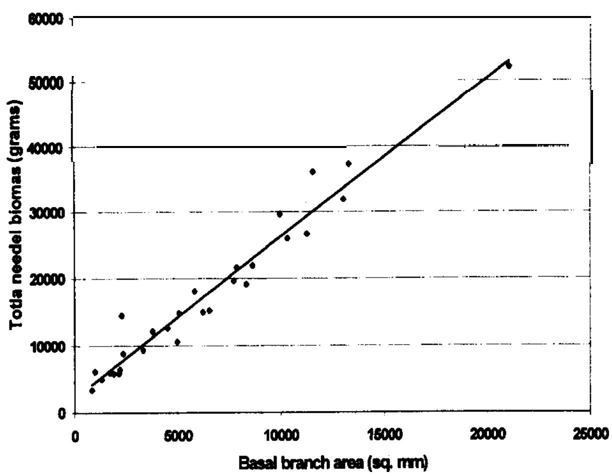

Figure 2—Observed total dry needle biomass vs total live branch basal area for loblolly pine on the coastal plain of South and North Carolina.

It is interesting to speculate about the conditions for which this relationship is true and stable. Shade intolerant species growing in relatively dense stands tend to move nutrients from the lower, less efficient branches to the highly productive upper crown. As a result self-pruning eliminates the lower, oldest branches at a rate that does not allow the formation of heartwood in branches; consequently all needle biomass is associated exclusively with branches that are 100 percent sapwood.

Linear regression analysis of both databases using LBBA as the independent variable shows a strong and stable correlation between TNB and LBBA (table 1 and 2). The slope of the regression line can be interpreted as the amount of needle biomass sustained by each unit of conductive tissue surface area attached to the stem. The differences in the slope can be attributed in part to the process of allometric estimation versus measured biomass and by differences in site quality and management at each site. Trees in the B. F. Grant spacing study sustain more needle biomass than the trees from sites in the coastal plain. This is most likely due not only to differences in nutrient availability but to the amount and types of competing vegetation.

Based on the strength of this relationship it seems reasonable that more intensive sampling of crown needle biomass can be done using total live branch basal area as an auxiliary variable for estimating total needle biomass and leaf area. Since the measurement of LBBA does not require collecting foliage, we can increase the number of trees sampled to investigate tree-to-tree and stand-to-stand variability in needle biomass and leaf area. Under this premise the use of regression estimators with a double phase sampling strategy should produce reliable estimates and relatively narrow confidence intervals for the population.

Double Sampling to Estimate Total Needle Biomass per Tree

The strong linear correlation between LBBA and TNB made these variables suitable to implement a double phase sampling strategy based on regression estimators. The regression estimator for the mean is defined by Cochran (1977) as:

$$\bar{Y}_{dr} = \bar{Y} + b(\bar{x}' - \bar{x}) \qquad (2)$$

where

$\bar{x}$ = mean of auxiliary variable from the first phase sample (LBBA),

$\bar{x}$ = mean of auxiliary variable from the second phase sample (LBBA),

$\bar{Y}$ = mean of variable of interest from the second phase sample (TNB), and b = slope of the regression line of y on x.

Table l-Analysis of variance for live branch basal area (LBBA) vs. total dry needle biomass for B.F. Grant database

Source	df	SSE	MSE	F value	Prob>F
		Analysis of variance			
Regression	1	691369020.8	691369020.8	3049.81	.0000001
Residual	40	9067698.453	226692.461		
Total	41	700436719.3			

R-square = 0.98705

	Coefficients	Standard error	t stat	P-value
Intercept	120.8546	139.7541	0.8647	0.392324
LBBA	.4638	.0084	55.2251	0.00001

Table 2—Analysis of variance for live branch basal area (LBBA) vs. total dry needle biomass for Brister database

Source	df	SSE	MSE	F value	Prob>F
		Analysis of variance			
Regression		544452712	544452712	497.139	.0000001
Residual	2:	26284127.89	1095171.995		
Total	25	570736839.8			

R-square = 0.95394

	Coefficients	Standard error	t stat	P-value
Intercept	-436.412	382.2230	-1.14177	0.264812
LBBA	0.391966	0.01758	22.2966	.0000001

In this case the LBBA is the auxiliary variable and the second phase variable or variable of interest is TNB. For the databases used in this study we have 43 trees from the B.F. Grant spacing study and 28 trees from the coastal plain of North and South Carolina. The estimates for the population were calculated assuming the databases collected the information both as dependent and independent phases. The value for ***b*** and the correlation coefficient were given from the relationship for Brister's database in table 2. The variance of the mean for each case was defined by De Vries (1986) as:

$$Var\bar{Y}_{dr}=\frac{S^2_{y.x}}{n}\left(1+\frac{1}{n}+\frac{1}{n'}\right)+b^2\frac{S^2_x}{n'} \qquad (3)$$

for independent phases, and

$$Var\bar{Y}_{dr}=\frac{S^2_{y.x}}{n}\left(1+\frac{1}{n}-\frac{1}{n'}\right)+b^2\frac{S^2_x}{n'} \qquad (4)$$

for dependent phases. Where

$$S^2_{y.x}=\frac{\sum_{i=1}^{n}(y_i-\bar{y})^2+b^2\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-2} \qquad (5)$$

$$S_x^2=\frac{\sum_{i=1}^{n'}(x_i-\bar{x})^2}{n'-1} \quad (6)$$

n'= sample size for the first phase sampling **(28),**
n= sample size for the second phase sampling (43 or **71),**
and all else is as define above. For this example we also use the generalized expression derived for large first phase sample size (De Vries 1986).

$$Var\bar{Y}_{dr}=\frac{S_y^2}{n}\left(1-\frac{n'-n}{n'}\right)\hat{\rho}^2 \quad (7)$$

where

$$S_y^2=\frac{\sum_{i=1}^{n}(y_i-\bar{y})^2}{n-1} \quad (8)$$

$\hat{\rho}$ = Estimated correlation coefficient for the second phase, and all else is as defined above.

For the double phase sample the value of the mean was adjusted making its value smaller than the estimate obtained with the standard estimated mean (table 3). Also the confidence intervals for double sampling are narrower as a result of the smaller associated variance calculated in each case. When trying to estimate needle biomass on a per acre/hectare basis the difference between these estimators will lead to a considerable difference on needle biomass per surface unit.

Sample size calculations
To estimate the sample size to meet a given bound (B) on the error estimation for a double phase sample we assume a **20:1** cost ratio between second and first phase sample units. The sample size for each phase can be calculated with the following notation (Shiver and Borders 1997).

$$n'=\frac{\sqrt{\frac{adC_n}{C_{n'}}+d}}{B^2/t^2} \quad (9)$$

$$n=\frac{\sqrt{\frac{adC_{n'}}{C_n}+a}}{B^2/t^2} \quad (10)$$

where

$$a=S_y^2(1-\hat{\rho}^2) \quad (11)$$

$$b=S_y^2(\hat{\rho}^2) \quad (12)$$

B = bound on the error of estimation for the mean, t = 2 (approximate t value for 95 percent confidence level), C_n = cost to obtaining data from sampling unit in the second phase, $C_{n'}$ = cost to obtaining data from sampling unit in the first phase, and the-ratio n/n' was calculated with:

$$f=\sqrt{\frac{C_{n'}(1-\hat{\rho}^2)}{C_n\hat{\rho}^2}} \quad (13)$$

The sample size calculations suggest that we can achieve a more narrow bound than that resulting from a traditional estimator. The threshold for which sampling becomes extremely expensive for minimal improvement in precision is evident for a bound of less than 750 grams per tree (fig. 3, table 4). To further illustrate sample size estimation for this

Table 3-Estimates for the mean, variance, and confidence intervals for TNB under the different sampling strategles proposed

Sampling strategy	Mean	Variance	Upper limit	Lower limit
	Grams			
Traditional calculations	6389.3	819891.1	8200.3	4578.4
Indepented phases	5554.7	282444.2	6617.3	4491.5
Dependet phases	5554.7	280845.3	6614.3	4494.4
Generalization for large first phase sample size	5554.7	294241.8	6639.3	4469.5

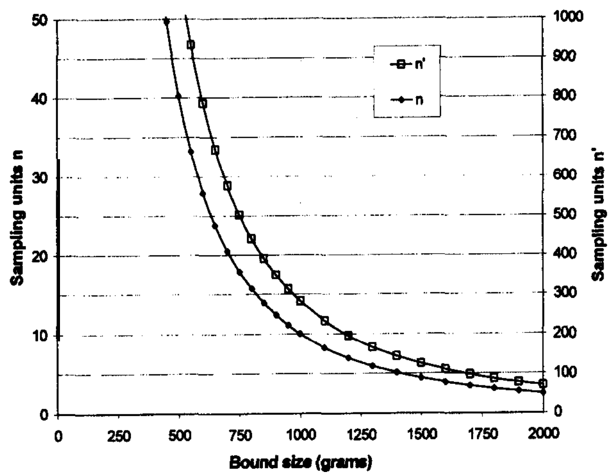

Figure 3—Sample size calculations using the Brister database with LBBA as auxiliary variable.

Table 4—Estimated sample sizes for Brister database with LBBA as auxiliary variable and TNB as second phase variable

Bound	n'	n
Grams		
50	80432	5856
150	8937	628
250	3217	226
350	1641	115
450	993	70
550	665	47
650	476	33
750	357	25
850	278	20
950	223	16
1000	201	14
1100	166	12
1200	140	10
1400	103	7
1600	79	6
1800	62	4
2000	50	4

Table 5—Sample sizes per phase, n/n' ratio, coefficient of correlation, variance, and slope for the simulations

	Simulation 1		Simulation 2		Simulation 3		Simulation 4	
ρ Ratio n/n'	0.0581		0.0591		0.019		0.061	
b	0.417	0.967	0.327	0.966	0.418	0.996	0.368	0.964
S^2_y	380757096.5		119675238.5		331257559.6		161115329.6	
Bound	n'	n	n'	n	n'	n	n'	n
Grams								
50	137109	7969	36739	2173	58468	1111	59416	3659
150	15234	885	4082	241	6496	123	6602	407
250	5484	319	1470	87	2339	44	2377	146
350	2798	163	750	44	1193	23	1213	75
450	1693	98	454	27	722	14	734	45
550	1133	66	304	18	483	9	491	30
650	811	47	217	13	346	7	352	22
750	609	35	163	10	260	5	264	16
850	474	28	127	8	202	4	206	13
950	380	22	102	6	182	3	165	10
1000	343	20	92	5	146	3	149	9
1200	238	14	64	4	102	2	103	6
1400	175	10	47	3	75	1	76	5
1600	134	8	36	2	57	1	58	4
1800	106	6	28	2	45	1	46	3
2000	86	5	23	1	37	1	37	2

situation, four simulations were carried out with an artificial second phase sample size of 10. These data were created by randomly selecting 10 trees from the 28 used in the previous analysis (table 5, figure 4 and 5). The sample size estimation averaged 182 trees (range 92 to 343) for the auxiliary variable and 9 trees (range 3 to 20) for the variable of interest with a bound on the error of 1000 grams.

The ratio n/n' for the four simulations average 4.9 percent (range 1.9 to 8.1 percent). The average and range results of the simulations suggest some possible extremes for the sample. For a second phase sampling a preliminary sample size bigger than 10 but less than 20 will produce estimates of at least 1000 grams for the error bound. In the best case 10 trees will be more than enough to obtain good estimates for the population and be used as part of preliminary sampling or calculation of sample size depending on the variation found.

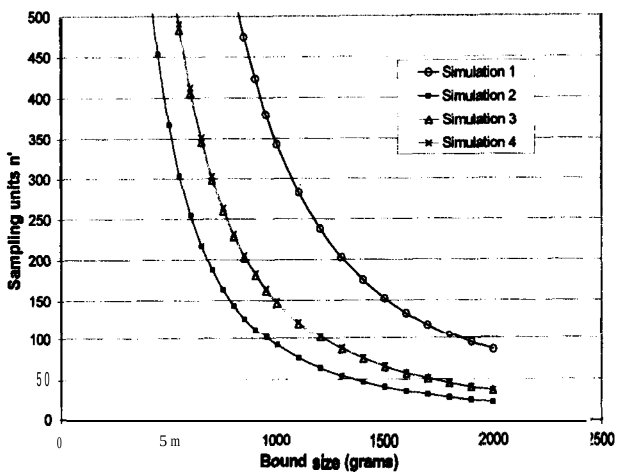

Figure 4-Simulated sample size calculation for the auxiliary van able (LBBA).

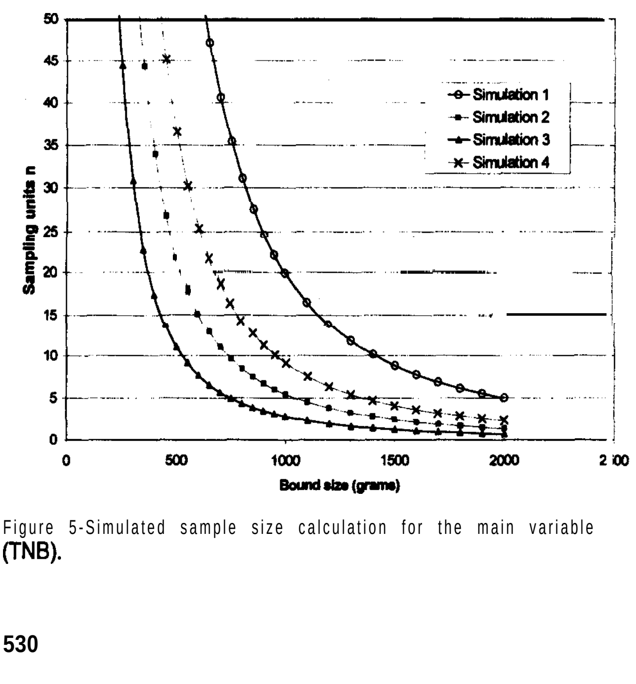

Figure 5-Simulated sample size calculation for the main variable (TNB).

CONCLUSIONS

If we consider that the TNB-DBH relationship can be described best as a non-linear function with large data dispersion, it is not a surprise that we improve the estimates for the population using LBBA as the proposed auxiliary variable. If we intend to use DBH as the auxiliary variable we should derive estimators based on this non-linear relationship that will be more complex than the regression estimators used. Furthermore the sample size required for total tree needle biomass can remain small and still produce good estimates using LBAA as the auxiliary variable.
It should be noted that the proposed sampling strategy requires destructive sampling for its implementation.

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A SURVIVAL MODEL FOR SHORTLEAF PINE TREES GROWING IN UNEVEN-AGED STANDS'

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Abstract-A survival model for shortleaf pine (*Pinus echinata* Mill.) trees growing in uneven-aged stands was developed using data from permanently established plots maintained by an industrial forestry company in western Arkansas. Parameters were fitted to a logistic regression model with a Bernoulli dependent variable in which "1" represented individual tree survival and "0" represented individual tree mortality. Predictions from the model can be interpreted as probabilities of survival. The most important independent variable for prediction of survival probability was the ratio of quadratic mean stand d.b.h. to tree d.b.h. The data were used to evaluate the performance of the model by d.b.h. classes. The model was developed for use in an individual-tree growth simulator for uneven-aged shortleaf pine forests.

INTRODUCTION

Despite the economic importance and wide distribution of shortleaf pine relatively little effort has been directed at modeling individual tree survival. Lynch and others [in press(a)] developed a model for individual tree shortleaf pine survival in even-aged forest stands. Individual tree level equations for shortleaf pine dynamics are part of Central States Twigs (Miner and others 1989) and a multipurpose forest projection system for southern forests developed by Boulton and Meldahl (1990). Apparently, no survival models have previously been developed specifically for shortleaf pine managed in uneven-aged stands, though Murphy and Shelton (1996) developed a survival model for individual trees in uneven-aged loblolly pine (*Pinus taeda* L.) stands. This paper will present results from the development of a model for survival of individual shortleaf pine trees growing in forest stands under uneven-aged management.

Shortleaf pine has a greater natural range than any of the other southern pines and is second only to loblolly in volume (Willet 1986) The species is especially important in the Ouachita mountain region of western Arkansas and eastern Oklahoma. Forecasts of stand dynamics for uneven-aged shortleaf pine stands are important on many acres of forest land managed by public agencies, non-industrial private owners, and certain forest industries in western Arkansas and eastern Oklahoma. Though the uneven-aged system produces somewhat lower merchantable volume than even-aged management it has traditionally been utilized by certain forest industries in the West-Gulf region to produce dimension lumber (Guldin and Baker 1988). Attractive features of the system include low-cost regeneration and relatively high sawtimber volume growth. These features make uneven-aged management of southern pine a viable alternative, especially on lower-quality sites (Guldin and Baker 1988, Shelton and Murphy 1994). A discussion of selection management for shortleaf pine in the Ouachita mountains has been given by Murphy and others (1991). Baker and others (1996) have elucidated the principles of uneven-aged management for loblolly and shortleaf pine.

Most of the information currently available for stand dynamics of shortleaf pine growing in naturally regenerated stands is based on data from even-aged stands. USDA Miscellaneous Publication 50 (USDA Forest Serv. 1929) includes normal yield tables for shortleaf pine which were based on data obtained from fully-stocked temporary plots. Yield tables developed by Schumacher and Coile (1960) were developed from 74 "well-stocked" temporary plots. Murphy and Beltz (1981) and Murphy (1982) developed growth and yield equations for shortleaf pine based on Forest Inventory and Analysis plots, most of which were located in unmanaged forests. Murphy (1986) gives a comprehensive account of the growth and yield information available for shortleaf pine prior to 1986. Lynch and others 1999b and Huebschmann and others (1998) describe the Shortleaf Pine Stand Simulator (SLPSS), an individual tree model for even-aged shortleaf pine stands which contains a prediction equation for probability of tree survival. This model is based on remeasured plots located in the Ozark and Ouachita National Forests and distributed over a range of ages, densities and site qualities.

Murphy and Farrar (1985) have developed equations describing the growth and yield of uneven-aged shortleaf pine stands. These equations describe growth and yield on a stand-level basis. Since the equations describe net yields, there are no explicit predictions for survival or mortality. Murphy and Farrar (1988) proposed a framework for growth and yield model development in uneven-aged loblolly-shortleaf stands which used the Weibull distribution to predict tree diameter distributions. This framework also consisted of stand-level equations.

Logistic Model

The logistic model is often used to develop prediction equations for event probabilities (Hosmer and Lemeshow 1989, Neter and others 1989). Hamilton (1974), Hamilton and Edwards (1976), and Monserud (1976) describe the use of the logistic model for development of individual-tree mortality or survival models. The model can be written as:

$$P_j = (1 + \exp[-(b_0 + b_1x_{1j} + b_2x_{2j} + \ldots + b_mx_{mj})])^{-1} \qquad (1)$$

where
P_j is the annual probability for survival of tree j,
x_{ij} is the value of independent variable x_i for tree j,
b_0 is an estimated coefficient representing the intercept, and
b_i is an estimated coefficient associated with x_{ij}.

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When regression techniques are used to estimate parameters for individual-tree survival models, the dependent variable is "1" for trees that survive the measurement period and "0" for trees that do not survive the measurement period. Remeasured plot data are usually obtained for intervals longer than one year. Since it is often desired to use these data to model annual survival probabilities, the following formulation has been suggested by Hamilton and Edwards (1976) and Monserud (1976):

$$P_j^t = (1 + \exp[-(b_0 + b_1 x_{1j} + b_2 x_{2j} + \ldots + b_m x_{mj})])^{-t} \qquad (2)$$

where
t is the number of years in the measurement period, and
P_j^t is the probability that tree j survives a t year period.

The use of iteratively re-weighted nonlinear regression is recommended for estimation of the coefficients in this model (Hamilton 1974, Hamilton and Edwards 1976, Monserud 1976). The weight used should be the inverse of $P^t(1 - P^t)$, where P^t is the probability of survival fort years predicted by the model. When this weight is used, maximum likelihood estimates are obtained. McCullagh and Nelder (1989) show that iteratively re-weighted regression provides maximum likelihood estimates for a class of models, which includes the survival model above.

DATA

Data were obtained from permanently established 0.2 acre plots located in southwestern Arkansas maintained by Dsltic Farm and Timber of El Dorado, AR. The majority of the plots were located in Arkansas south of US. Interstate Highway 40 and west of U.S. Highway 65. The first measurements were made following the 1965 growing season. Subsequent measurements were made during the dormant season at 5 or 6 year intervals. New plots have been added to the permanent plot system to replace lost plots or when new property has been acquired.

D.b.h. was measured on all living trees 5.1 inches or larger on each plot. USDA Miscellaneous Publication 50 (USDA Forest Service 1929) was used to determine site index for each plot. Though the concept of site index is usually associated with even-aged stands, researchers such as Murphy and Farrar (1985) have evaluated relative site quality using site index. Baker and others (1996) state that in uneven-aged stands of loblolly or shortleaf pine, site index is an approximation since trees currently in dominant or codominant positions have probably been in the understory at some point in the past. Trees used for determination of site index in uneven-aged stands should have ring patterns that do not show signs of suppression. Total height measurements were made at the ends of the 1988 and 1393 growing seasons. Prior to 1988, only merchantable heights were recorded.

For this analysis, all plots containing loblolly pine were discarded. Plots used in the study were allowed to contain up to 30 percent hardwood. Growth intervals for a given plot were also eliminated from the data used for analysis for: timber stand improvement or harvest during the interval, more than 20 percent of plot initial basal area per acre lost to mortality, or merchantable shortleaf pine basal area below 30 ft^2/acre or more than 90 ft^2/acre. Since adequate reproduction is required to sustain uneven-aged management, plots with growth intervals having densities in excess of 90 ft^2/acre were deemed not able to sustain uneven-aged management.

In order to eliminate autocorrelation problems in parameter estimation due to time dependencies, only one growth period was retained for each plot. Some growth periods were eliminated to avoid over representation of some site and basal area classes. Table 1 gives summary statistics for the 152 plots used in the analysis. Equation 1 is designed to predict probability of survival on an individual-tree basis. Therefore, data from individual shortleaf pine trees were used to estimate coefficients in equation 2. A summary of the data from 3,722 shortleaf pine trees located on 152 remeasured plots in uneven-aged shortleaf pine stands is given in table 2.

ANALYSIS

Estimation of Coefficients

Several variables potentially related to individual tree survival in uneven-aged shortleaf stands were examined. These included shortleaf basal area per acre, hardwood basal area per acre, total basal area per acre (shortleaf plus hardwood basal area), site index, d.b.h. of the subject tree, and ratio of plot quadratic mean d.b.h. to individual tree d.b.h. PROC LOGISTIC (SAS Institute 1989) was used to screen variables using a model similar to equation 1; the dependent variable was 1 for trees surviving the measurement period and 0 for trees not surviving the plot measurement period. Within PROC LOGISTIC a stepwise procedure is available which uses the adjusted chi-square statistic and the 0.05 significance level. According to this procedure, neither site index nor basal area per acre were significantly related to individual shortleaf pine tree survival in these uneven-aged forests. Murphy and Shelton (1998) found that site index was significantly related to individual-tree survival in uneven-aged loblolly stands. However, basal are per acre was not significantly related to survival for the loblolly pine data examined by Murphy and Shelton (1998). Lynch and others [in press(a)] developed a survival model for even-aged shortleaf pine stands in which stand basal area was significantly related to individual-tree survival. This model is used in a distance-independent individual tree simulator for even-aged shortleaf pine stands (Lynch and others [in press(b)], Huebschmann and others 1998). Levels of basal area per acre for the data of Lynch and others [in press(a)] ranged from about 30 square feet per acre to approximately 170 square feet per acre. It may be that the wider range of basal areas occurring in the even-aged data allowed the effect of basal area per acre on survival to show significance. Uneven-aged management of the southern pines maintains stands under a much narrower range of densities than even-aged management.

After data screening the following final model form resulted:

$$P_j^t = (1 + \exp[-(b_0 + b_1 R_j)])^{-t} \qquad (3)$$

where
$R_j = D_q/D_j$
D_q = quadratic mean d.b.h. (inches) for the stand containing tree j, and
D_j = d.b.h. (inches) for tree j.

Although useful to determine model form, PROC LOGISTIC cannot be used to estimate coefficients in equation 3 because remeasurement period lengths for the data

Table I-Data summary for 152 remeasured plots in uneven-aged stands in southwest Arkansas

Variable	Average	Standard deviation	Minimum	Maximum
Trees per acre				
Shortleaf pine				
Initial	122.4	48.5	40	265
Mid-period	139.2	57.7	40	305
Final	137.1	58.1	40	300
Hardwoods				
Initial	17.4	16.1	0	65
Mid-period	25.4	22.1	0	125
Final	24.5	21.4	0	125
Basal area (ff per acre)				
Merchantable shortleaf pine (d.b.h. 5.1 in. or greater)				
Initial	55.0	15.3	30.1	90.0
Mid-period	60.9	16.2	32.7	95.2
Final	66.9	17.8	32.6	102.0
Shortleaf pine sawtimber (d.b.h. 9.1 in. or greater)				
Initial	30.4	14.1	2.6	75.2
Final	42.1	15.0	5.7	77.2
Hardwoods (d.b.h. 5.1 in. or greater)				
Initial	6.5	6.4	0	30.1
Mid-period	7.6	6.7	0	30.6
Final	8.6	7.3	0	35.1
Shortleaf site index (ft, base age 50 yr)	56.3	7.3	35	74

Table P-Summary of data obtained from 152 remeasured plots in uneven-aged shottieaf pine stands containing 3,722 shortleaf pine trees in southwest Arkansas, used for estimation of coefficients in model for probability of survival

Variable	Average	Standard deviation	Minimum	Maximum
Stand-level				
Periodic shortleaf mortality (trees/ac)	2.2	3.9	0	20
Plot or stand quadratic mean diameter (in.)	9.0	1.2	6.6	13.2
Tree-level				
Tree d.b.h. (in.)	8.7	2.5	5.1	19.4
Ratio of plot or stand quadratic mean diameter to tree d.b.h.	1.10	.27	.43	2.36

analyzed in this study were 5 or 6 years. Therefore PROC NLIN (SAS Institute 1989) was used to estimate param eters in equation 3 with iteratively re-weighted regression as described above in the description of the logistic equation.

The final parameter fitting process resulted in:

$$P_j^t = (l+\exp[-(7.31384 \ -1.42814 \ R_j)])^{-t} \qquad (4)$$
$$(0.5303) \quad (0.4284)$$

Standard errors for coefficient estimates appear in parentheses beneath the estimated values in equation (4). Values of students t-statistic obtained by using the standard errors in equation 4 indicate that the estimates are significantly different from zero at the 0.05 significance level. When used in an individual-tree growth simulator with annual time steps, the exponent representing the length of the survival period will be set to t=l.

Model Evaluation

Hamilton and Edwards (1976) used a chi-square test to evaluate logistic models for individual-tree survival. Hosmer and Lemeshow (1989) and Neter and others (1989) describe procedures for evaluation of logistic models using the chi-square test. Their recommendations applied to evaluation of a tree survival model using d.b.h. classes would result in the following test statistic:

$$X^2 = \Sigma\, [(O_{j0}-E_{j0})^2/E_{j0} + (O_{j1}-E_{j1})^2/E_{j1}] \qquad (5)$$

where

X^2 is the chi-square statistic,

E_{j0} is the expected number of trees in d.b.h. class j dying,

O_{j0} is the observed number of trees in d.b.h. class j dying,

E_{j1} is the expected number of trees in d.b.h. class j surviving,

O_{j1} is the observed number of trees in d.b.h. class j surviving, and

Σ represents summation over all d.b.h. classes.

Expected versus observed survival and mortality by d.b.h. classes are given in table 3 together with chi-square contributions. The contribution to chi-square from mortality is much higher than for survival. In these managed stands, most trees survive during the measurement interval. Thus the chi-square denominator is much higher for survival than for mortality. As a result the chi-square contribution of observed vs. expected survival is much lower than that for mortality. The total chi-square statistic is 12.75 (0.17 + 12.57).

The hypothesis to be tested is that the logistic model fits the observed survival and mortality data. Simulation studies by Hosmer and Lemeshow (1980) indicated that two degrees of freedom should be subtracted from the number of categories when chi-square computations are based on the same data used to estimate model coefficients. Thus, table 3 indicates that the appropriate number of degrees of freedom is **15-2=13.** A chi-square statistic of X^2 = 12.75 and 13 degrees of freedom yields a p-value of 0.47. Since p-value = 0.47 > 0.05 = significance level, we fail to reject the hypothesis that the logistic equation 4 fits the observed survival and mortality data. Since the p-value is much greater than the significance level, we accept equation 4 as an adequate survival model for shortleaf pine trees in the uneven-aged stands used for this analysis. Because some plots were measured on a 5 year interval and others were measured on a 6 year interval, it is difficult to compute an exact over-all annual mortality rate from table 3. However, the table indicates that the annual rate is probably somewhere between 0.4 and 0.3 percent.

Table 3—Survival and mortality expected from a logistic survival model versus observed survival and mortality by d.b.h. classes for the plot remeasurement period with chi-square contributions

	Number of survivors			Mortality		
D.b.h. (in.)	Observed	Expected	Chi-square	Observed	Expected	Chi-square
5						
6	665144	665.365 141.521	0.0.0002	19 2	18.635 4.479	1.3.0072
8	606	604.828	.0023	12	13.172	.1043
9	501546	499.415 546.242	..0001	10 6	9.758 7.585	.0060
IO	383	385.785	.0201	8	5.215	1.4874
11	281	284.481	.0426	7	3.519	3.4446
12	215	214.530	.0010	2	2.470	.0895
13	122	120.692	.0142	0	1.308	1.3078
14	102	101.994	3.5×10^{-7}	1	1.006	3.6×10^{-5}
15	55	54.468	.0052	0	.532	.5318
16	19	19.821	.0340	1	.179	3.7739
17	8	7.933	.0006	0	.067	.0668
18	4	3.968	.0003	0	.032	.0321
19	3	2.975	.0002	0	.025	.0247
Total	3654	3654.019	.1692	68	67.981	12.5793

SUMMARY AND CONCLUSIONS

Data from remeasured plots located in uneven-aged shortleaf pine stands were used to estimate coefficients in a logistic model, which can be used to predict the probability of individual shortleaf pine tree survival. The model uses the ratio of quadratic mean stand d.b.h. to individual tree d.b.h. to predict the probability of individual tree survival. A chi-square test indicated that the model fits the data in an acceptable manner.

This logistic model can be used to predict annual survival probabilities for individual shortleaf pine trees growing in uneven-aged stands. This survival model is being used as part of a distance-independent individual-tree growth model for uneven-aged shortleaf pine stands which is currently under development. Foresters who apply uneven-aged management concepts to shortleaf pine stands should find the model to be useful for management planning.

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A MATRIX TRANSITION MODEL FOR AN UNEVEN-AGED, OAK-HICKORY FOREST IN THE MISSOURI OZARK HIGHLANDS[1]

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Abstract-We present a matrix growth model for an uneven-aged, oak-hickory forest in the Ozark Highlands of Missouri. The model was developed to predict ingrowth, growth of surviving trees, and mortality by diameter class for a five-year period. Tree removal from management activities is accounted for in the model. We evaluated a progression of models from a static, fixed-parameter to a dynamic, function form. The model was based on data from 366 0.2-acre permanent plots, measured over seven five-year periods from 1957 to 1992. Variables used in development of the dynamic model included basal area of larger trees (an index of competition) and number of trees per acre. Models were evaluated using 92 reserved plots by comparing predicted and actual diameter-distributions over five- and thirty-five-year periods. Application of this matrix model requires only a DBH distribution in trees per acre.

INTRODUCTION

In recent years, there has been renewed interest in uneven-aged forest management (Guldin 1996, Stout 1998). To effectively manage our forests with uneven-aged systems, quantitative tools, such as growth models, are needed. In the state of Missouri, the most widely used forest growth model is TWIGS, an individual-tree, distance-independent model (Miner and others 1988). While the Central States version of TWIGS has been shown to produce reliable results on a region-wide basis (Indiana, Illinois, and Missouri), (Kowalski and Gertner 1987, Miner and others 1988) there has been much interest in developing a growth model specifically designed for application in uneven-aged forests in the Missouri Ozark Highlands. Compared to traditional, single-tree, distance-independent models, whole-stand solutions have been suggested as more appropriate for use in the application of uneven-aged management (Moser, 1972, Hann and Bare 1979). Matrix transition models have advantages over other whole-stand methods because they are conceptually simple and relatively easy to develop (Harrison and Michie 1985). Matrix-transition models have been developed for uneven-aged forests in many other regions of the United States (Buongiomo and Michie 1980, Solomon and Hosmer 1986, Michie and McCandless 1986, Lin and Buongiorno 1997, Lin and others 1998). This paper presents a whole-stand, matrix growth model developed for a large, privately owned forest under uneven-aged management in Southeast Missouri.

DATA

Beginning in the early 1950's, a system of continuous forest inventory (CFI) plots were installed on the Pioneer Forest, a 160,000-acre privately owned forest located in the Ozark Highlands of Missouri. By 1957, permanent, fifth-acre, circular plots had been laid out, at a density of approximately one plot for every 320 acres on the forest. Plots were remeasured on a five-year schedule; only trees five-inches and larger in diameter at breast height (DBH) were included in the inventory. Trees were permanently numbered and information was recorded on a number of variables including species and DBH. At subsequent inventories, mortality and harvest removals since the last inventory were also recorded. Ingrowth trees received a new, permanent number once they crossed the threshold diameter of 5 inches[3].

During the period 1957-1992, there were 366 plots that were consistently remeasured. These plots comprised the database for model fitting and validation. Twenty-five percent of the plots were randomly selected and resewed to validate the final version of the model. The remaining plots were used to parameterize the models. As the plots were remeasured at five-year intervals, one five-year period from each plot was selected at random for model development. This was done to insure independence.

For every plot in the modeling data set, basal area per acre (BA), number of trees per acre (TPA), and basal area of conifers per acre (BAC) were calculated. Basal area of conifers was the only species-specific variable used to develop the model. BAC was included to account for the differential growing space requirements of shortleaf pine (*Pinus echinata* Mill.) and upland hardwoods. To illustrate, in 1992 the quadratic mean diameter (QMD) on the Pioneer Forest was 8.72 inches (Loewenstein and others 1995). For upland hardwood stands with a QMD of nine inches, 100 percent stocking occurs at approximately 112 ft^2 of basal area per acre (Gingrich 1967). In comparison, a pine stand with the same QMD reaches 100 percent stocking at 150 ft^2 of BA (Rogers 1983). A similar relationship exists across all levels of stocking.

For each tree in the modeling data set, a binary variable was used to indicate if the tree survived or died over the selected five-year period. For each surviving tree, an additional binary variable was coded to specify whether it remained in the same two-inch diameter class over the five-year period, or grew into a larger diameter class. An indicator of competition, basal area of larger trees (BAL) was calculated for each tree. BAL is the sum of the BA for all trees with a larger diameter than the subject tree. This value is a

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[3] Loewenstein. 1996. An analysis of the size- and age-structure of a managed unevenaged oak forest. Unpublished Ph.D. Diss., University of Missouri. 167 p.

surrogate for social position of the subject tree and estimates the volume of growing space available.

METHODS

Static Model

The simple, fixed parameter model was developed first. For each two-inch diameter class, probabilities for survival and growth were calculated. The transition matrix is given in Table 1. Probabilities are listed for a tree moving from the DBH class indicated by the column label, to the DBH class indicated by the row label. For example, the probability that a tree in the 1 P-inch DBH class would move to the 14-inch class is 0.2562 and its probability for remaining in the 12-inch class is 0.6860. The probability of mortality is derived by subtracting the sum of each column from one. Ingrowth was estimated on a grand average of stems crossing the threshold diameter during the five-year period.

Table I-Probabilities obtained from the fixed-parameter model

D.b.h.	6	8	IO	12	14	16	18	20	22+
6	.7093	0	0	0	0	0	0	0	0
8	.2581	.6975	0	0	0	0	0		0
10	0	.2765	.7052	0	0	0	0	0	0
12	0	0	.2712	.6860	0	0	0	0	0
14	0	0	0	.2562	.7111	0	0	0	0
16	0	0	0	0	.2089	.6640	0	0	0
18	0	0	0	0	0	.2800	.6071	0	0
20	0	0	0	0	0	0	.3393	.5000	0
22+	0	0	0	0	0	0	0	.4000	.9444

Dynamic Model

The variable-parameter model was fit with a two-step, logistic regression model.

Mortality Model

The first model predicted tree mortality. Separate models were fit for each two-inch diameter class using the glm function in S-PLUS (Venables and Ripley 1997). Independent variables considered were basal area per acre, conifer basal area per acre, number of trees per acre, and basal area of larger trees. The most significant independent variables were determined to be basal area of larger trees and trees per acre. The model form is shown by equation 1, where in this instance "Y" is mortality.

$$E(Y|BAL,TPA)=\frac{EXP(b_0+b_1(BAL)+b_2(TPA))}{(1+EXP(b_0+b_1(BAL)+b_2(TPA)))} \qquad (1)$$

Growth Model

The second model predicted five-year diameter growth. Specifically the model predicted if a tree would move to the larger, adjacent diameter class, or remain in the same two-inch diameter class. Using trees that survived the five-year time step, the models were fit by diameter. Again, the same variables were considered as in the mortality model, and the same variables were used, BAL and TPA. The model form is shown by equation 1, where "Y" in this case is movement to the larger diameter class. Ingrowth for this model also used the grand average of stems crossing the threshold diameter during the five-year period.

Probability

After parameterization, probabilities obtained from the mortality and growth models were compared to the actual outcomes of mortality and growth.

RESULTS AND DISCUSSION

There was no statistically significant correlation between the actual mortality and growth values and the predicted values. Thus it was impossible to assign a critical probability for mortality or growth. The low correlation values, along with the minimal removal of error by the model suggested that there would be little improvement in using the variable-parameter model.

From this point on, we will examine the performance of the static, fixed parameter model. Using the transition probabilities obtained from the fixed-parameter analysis, the reserved validation plots were "grown" for periods of five and 35 years. In the event of a harvesting activity, the appropriate number of trees was removed from the diameter distributions, and harvesting activity was assumed to occur immediately prior to the inventory. CFI data from the 1957 inventory was utilized for this evaluation. Corresponding CFI data was used to compare the output of the model projections. The CFI data for a specific plot in 1962 was compared to the five-year model predictions for that plot, and the same procedure was repeated for the 35-year period using the 1992 data.

Model Evaluation

Five-year results-Output was evaluated using a chi-square goodness of fit test. Diameter distributions of the CFI data were compared to the modeled diameter distributions. Of the 92 validation plots, 87 (95 percent) of the plots were found to be statistically similar to the CFI data at an alpha level of 0.05. This suggests that for short periods of time, such as a five-year period, the model predicts diameter structure well.

Thirty-five-year results-After seven periods of simulation, (35 years), when modeled output was compared to the 1992 CFI data, only 11 of the plots did not differ from the CFI data (alpha = 0.05). The area of greatest divergence occurred in the smallest diameter classes, the six- and eight-inch classes. This was likely due to changing levels of recruitment, or ingrowth into the six-inch class over time (Loewenstein 1996).

CONCLUSIONS

Conditions on the Pioneer Forest were not static for the period of 1957-l 992. Average number of trees and stocking increased while the average diameter of trees went down (Loewenstein 1996). The parameters for this model were based on averages across this time period. However, these averages apparently do not explain all of the variation in stand dynamics on the forest. Another event that may have caused problems in prediction occurred in the early-1980's. The Ozark region of Missouri suffered extreme drought in 1980 and again in 1983 (Law and Gott 1987). Mortality from these drought events and subsequent oak decline (Dwyer and others 1995) dramatically affected trees on the forest and thus, the representative inventory. The model does not have a mechanism to account for such catastrophic mortality.

For short periods of time, specifically five years, the model performs well. However, when time periods are lengthened, the model's predictive ability declines. While the model predicts fairly well in larger diameter classes, those above the 14-inch class, it does not fair as well in the smaller diameter classes. This may be attributed to the lack information available for small diameter trees. It is difficult to predict recruitment into the threshold diameter class, especially with a relatively large threshold diameter of five inches DBH (Shifley and others 1993). With additional information on the dynamics of small diameter trees, and an improved methodology for ingrovvth prediction, overall model prediction should improve.

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A QUANTITATIVE ASSESSMENT OF SLASH PINE CROWN STRUCTURE IN TREES MARKED FOR GAP CREATION'

Daniel J. McConville, Steven B. Jack, and Robert J. Mitchell'

Poster Summary

INTRODUCTION

Ecosystem management can in part be viewed as an approach in which natural disturbances, and the resulting patterns and processes, guide the implementation of managed disturbances in the landscape. Longleaf pine (*Pinus palustris* Mill.) forests dominated the coastal plain landscape prior to European settlement, and were described as open-canopied, monotypic pine woodlands with even-aged cohorts of longleaf regenerating within an all-aged forest matrix (Wahlenberg 1946). The natural disturbance regime of these forests consisted primarily of frequent, low intensity disturbances such as lightning and windthrow that would kill one or small groups of adult pines. In an ecosystem management context one silvicultural system that closely emulates the natural disturbance regime of the longleaf pine overstory is the "Stoddard-Neel" (SN) method practiced in south Georgia and north Florida.

The SN silvicultural approach can be best illustrated by the results from more than 45 years of management on several shooting plantations in the Thomasville, GA area that share a common set of desirable characteristics. These results were accomplished through selective cutting guided by a number of criteria. The importance of any of these criteria depends on the landscape context of the stand in question and the landowner's objectives; nevertheless, they can be hierarchically ranked in the following manner: 1) Only a portion of the stand growth is harvested at each cutting cycle; 2) diversity of size classes and ages is maintained or enhanced; 3) wildlife values and understory diversity are promoted; and 4) vigor of the stand and the quality of residual timber are improved.

Assessment of the growth potential of trees is largely done through visual assessment of crown structure and foliage color. Considerable work has documented that pine growth is controlled by the amount of foliage and its spatial arrangement in crowns (e.g., Gower and others 1994; Stenberg and others 1994). Yet, little work has documented the variation in these characteristics in southern pine stands and the precision by which visual assessment can predict future growth.

The SN method was implemented at Ichauway, in southwest Georgia, to convert a 200-acre mature (63-year-old) slash pine (*Pinus elliottii* Engelm.) stand to a multi-cohort longleaf pine forest. During the Spring of 1998 approximately 150,000 board feet of timber was marked for removal in one-half to two acre groups and as single trees between group openings. Single trees were marked for removal if they appeared to have stem defects, poor crown structure, or discolored foliage, or to achieve desired spatial conditions.

The objective of this study was to evaluate if observed, visual differences in crown condition can be quantified and correlated with recent stemwood growth patterns.

PROCEDURES

During the summer of 1998, 31 marked trees located between groups were paired with 31 nearby (within 25 m) unmarked trees of approximately the same diameter at breast height (DBH-1.3 m). Sample trees were cored at breast height and annual radial and basal area increment were determined for the 5-year period 1993-I 997 using WinDendro®. Marked and unmarked trees were compared for differences in DBH and stemwood radial and basal area increment using a paired t-test.

Each of the sample trees was photographed using a stereo-photography system that consisted of two Nikon 35-mm cameras mounted on an aluminum base approximately 70 cm apart. The system also included an Impulse 200® laser rangefinder mounted between the cameras for determining angle of inclination and horizontal distance from camera unit to tree stem. The distance of the camera to tree stem, angle of inclination of stereo unit, azimuth, height above ground, and lens focal length (50, 85, or 105 mm) were recorded.

Stereo images for tree crowns were analyzed to determine 3-dimensional coordinates of the crown base and top and a random sample of shoots (approximately 30 percent by crown area), using SigmaScan Pro@ image analysis software and standard close-range photogrametrical methods. Estimates of shoot density and distribution for each tree pair were determined and compared.

RESULTSANDDISCUSSION

When selecting sample tree pairs an effort was made to choose unmarked trees that were the same size as their corresponding marked pairs. Results from a paired t-test (table 1) demonstrate that tree pairs did not differ significantly in DBH. Although tree pairs were not different in size, paired t-tests show that unmarked trees had significantly higher 5-year diameter and basal area increment than their marked pairs (table 1). Mean cumulative basal area was greater for the marked trees in 1993 but by 1997 differences were not significant. For all five years mean basal area increment was greater for unmarked trees (fig. 1).

As expected the unmarked trees, which were selected to continue growth through the next cutting cycle, had significantly higher shoot densities than those trees marked for removal. Figure 2 illustrates that the higher shoot density extends over a greater percentage of the live crown in

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Table l-Results from paired t-tests showing differences in mean d.b.h., 5-year diameter increment and 5-year basal area increment

Variables	Marked trees	Unmarked trees	P (T< = t)
Mean d.b.h. (cm)	35.6	35.5	0.44
Mean 5-yr diameter increment (cm)	.75	.94	.02
Mean 5-yr basal area increment (cm^2)	36.6	46.6	.04

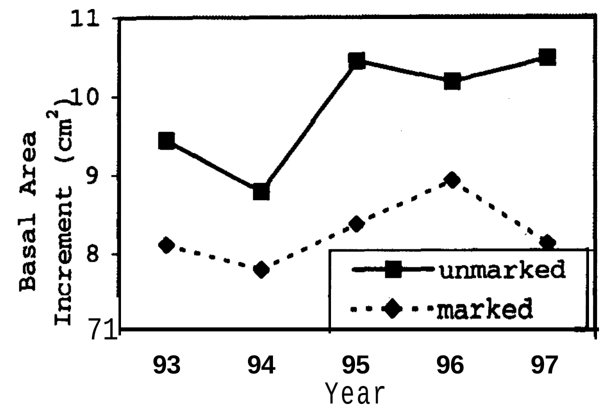

Figure l-Mean basal area increment over a 5-year period for marked and unmarked trees.

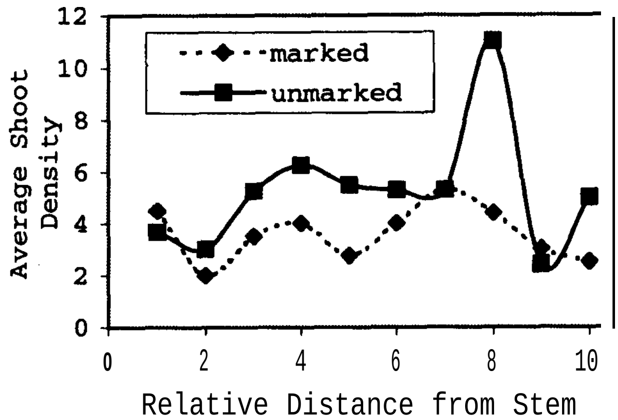

Figure 3—Horizontal distribution of shoot density for marked and unmarked trees.

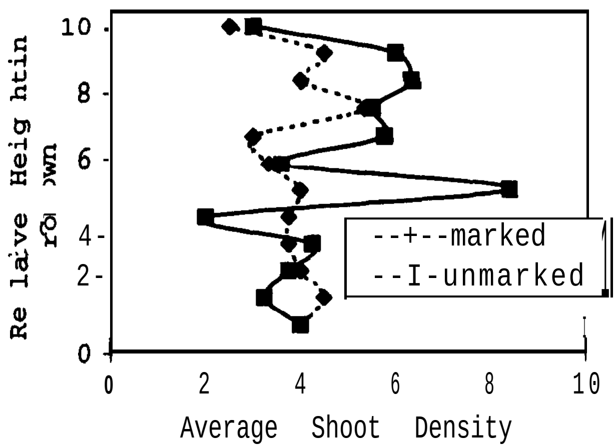

Figure 2—Vertical distribution of shoot density for marked and unmarked trees.

unmarked trees compared to marked trees; i.e., the distribution of shoot density is shifted to the upper crown third in marked trees. What was not expected was the similarity in horizontal distributions of shoot density illustrated in Figure 3. This example comparison shows that, while unmarked trees have higher shoot densities, the horizontal distribution of foliage clusters is similar for marked trees. This similarity may be due to the very open crown structure of these mature slash pine trees that allows light to reach the inner crown region.

While these are preliminary results, it is apparent that the trees selected for removal had slower growth in recent years, thus average tree growth will be increased following harvest. This result implies that the visual crown characteristics are, on average, indicative of future growth potential. On the other hand, results comparing foliage distribution in the crowns of marked and unmarked trees are less clear. While unmarked trees have higher shoot densities, the vertical and horizontal distributions of shoots did not vary as much as expected. Some of this discrepancy may be attributed to the variety of factors considered in selecting individual trees for removal when applying the SN method. In most cases the general adage of “cut the worst, leave the best” is applied and trees with chlorotic foliage, low foliage density, or other obvious stem deformities are marked for removal. In other cases, however, trees with apparently healthy crowns may be marked and trees with less desirable crown characteristics left in the stand due less desirable crown characteristics left in the stand due either to spatial considerations or for other amenity values such as wildlife habitat. This variability in individual tree selection makes it more difficult to **find** measurable differences in crown characteristics when comparing marked and unmarked trees. Further analyses are needed to clarify the comparisons in light of the variable tree selection criteria.

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AN UPDATED SITE INDEX EQUATION FOR NATURALLY REGENERATED LONGLEAF PINE STANDS[1]

Jyoti N. Rayamajhi, John S. Kush, and Ralph S. Meldahl[2]

Abstract-From 1964 to 1967, the U.S. Forest Service established the Regional Longleaf Growth Study (RLGS) in the Gulf States with the objective of obtaining a database for the development of prediction systems for naturally regenerated, even-aged, longleaf pine stands. The database has been used for numerous quantitative studies. One of these efforts was a site index equation for naturally regenerated longleaf pine stands using data from the first and second re-measurements. The equation performed well except for younger stands less than 20 years in age and was more suited to the East Gulf area than the previously available curves. The sixth re-measurement (30-year) of the RLGS was completed recently and it covers a broader range of longleaf pine stands and longer observation periods. Preliminary results in the development of an updated site index equation using data through the sixth re-measurement are discussed and its performance statistically evaluated.

INTRODUCTION

From 1964 to 1967, Dr. Robert M. Farrar, Jr., and the US. Forest Service established the Regional Longleaf Pine Growth Study (RLGS) in the Gulf States (Farrar 1978). The objective was to obtain a database for the development of prediction systems for naturally regenerated, even-aged, longleaf pine stands. During a re-measurement of the RLGS, it was discovered that the two available site index curves did not give comparable estimates of plot site index at the start and end of the five-year growth period (Farrar 1981). Using data from the first and second re-measurement of the RLGS, Farrar developed a site index equation that was published in the Southern Journal of Applied Forestry in 1981. The site index equation (base age 50) is:

$$S=(H)10^{\left[-29.468\left[\frac{1}{50}-\frac{1}{A}\right]+938.97\left[\left(\frac{1}{50}\right)^2-\left(\frac{1}{A}\right)^2\right]-16102\left[\left(\frac{1}{50}\right)^3-\left(\frac{1}{A}\right)^3\right]+88775\left[\left(\frac{1}{50}\right)^4-\left(\frac{1}{A}\right)^4\right]\right]} \quad (1)$$

where
S = height at age 50 (site index) in feet,
H = mean dominant height in feet, and
A = age (ring count at 4 feet plus 7 years).

Farrar's equation is based on a fourth degree polynomial and was weighted by a variable $1/(Age)^2$. The equation predicted minimal changes (< 5 feet) in site index over time for most of the plots. Due to this model form, the equation exhibits some illogical trends at ages below 15 years, producing unrealistic predicted site index values.

Rayamajhi (1996) and other efforts conducted at Auburn University using Farrar's equation for predicting growth and yield of longleaf pine found predicted site index values did not follow the height development pattern in some plots. Because of this and Farrar's equation being a fourth degree polynomial, efforts were initiated to produce an updated site index equation.

METHODS

Data came from 1598 observations on 300 permanent 0.1 - or 0.2 - acre plots in even-aged, naturally regenerated longleaf stands. Kush and others (1987) provide details of the study design. Several site index construction techniques were examined. For the purposes of this study, three commonly used models were examined. The 1598 observations of mean dominant height and age were fitted with the following models: 1. Farrar's fourth degree polynomial model fitted to examine the parameters; 2. modified Farrar's model where third and fourth order variables were dropped; and 3. Chapman-Richards non-linear model (Carmean 1972).

The parameters of the models were estimated by using standard linear and non-linear estimation techniques. Using the estimated parameters, site index was estimated for each plot and each re-measurement. The estimated site index for each model was evaluated. Table 1 presents the observations by age and site index based on Farrar's equation (1981).

RESULTS

Farrar Model Updated

Farrar's 1981 model was re-fit with the entire RLGS data set. The site-index equation is:

$$S=(H)10^{\left[14.6755\left[\frac{1}{50}-\frac{1}{A}\right]-1005.4336\left[\left(\frac{1}{50}\right)^2-\left(\frac{1}{A}\right)^2\right]+17194\left[\left(\frac{1}{50}\right)^3-\left(\frac{1}{A}\right)^3\right]-103876\left[\left(\frac{1}{50}\right)^4-\left(\frac{1}{A}\right)^4\right]\right]} \quad (2)$$

The model is still valid with all its parameters significant (p <.05). The magnitude of the estimated parameters β_0, β_1, β_2, β_3, and β_4 in equation [2] are very close to the parameters in equation [I] that were estimated by Farrar. However, weighting by $1/(Age)^2$ produced non-significant parameters. This may be due to reduced variability with the addition of more data, representing a broader range of sites. The estimates of the parameters and its related statistics are given in table 2. The coefficient of determination (R^2) was 78 percent.

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Table l-Number of observations by age class and site index class for the RLGS data set

Age class	Site index class 50	60	70	60	90	Total
20	23	53	105	a5	9	275
30	48	37	86	79	4	254
40	a	34	47	111	23	223
50	17	25	31	74	36	183
60	21	27	37	68	23	176
70	21	30	58	60	17	186
60	15	23	61	33	10	142
90	12	18	49	a	2	a9
100	9	13	35	—	—	57
110	2	7	4	—	—	13
Total	176	267	513	518	124	I ,598

Table 2-Parameter estimates and related statistics for the un-weighted Farrar site index model (equation) utilizing the entire RLGS data set

Parameter	Estimate	Standard error	Prob > |T|
β_0	1.85661	0.03694	0.0001
β_1	14.67550	5.54674	.0082
β_2			
β_4	-103876 17194 -1 005.43358	39588.83331 5653.79557 278.92019	.0(0024 .00aa
β_4			

The model used is the following:

$$S=(H)10^{\left[\beta_1\left[\frac{1}{50}-\frac{1}{A}\right]+\beta_2\left[\left(\frac{1}{50}\right)^2-\left(\frac{1}{A}\right)^2\right]+\beta_3\left[\left(\frac{1}{50}\right)^3-\left(\frac{1}{A}\right)^3\right]+\beta_4\left[\left(\frac{1}{50}\right)^4-\left(\frac{1}{A}\right)^4\right]\right]}$$

Modified Farrar Model

The parameter estimates using data through the sixth re-measurement of the RLGS did not produce estimates, which were very different from those of Farrar (1961). Efforts to produce a model with fewer parameters were undertaken. Farrar's model was reduced to an un-weighted second-degree polynomial. The following site index equation was obtained:

$$S=(H)10^{\left[-6.7463\left[\frac{1}{50}-\frac{1}{A}\right]+35.9519\left[\left(\frac{1}{50}\right)^2-\left(\frac{1}{A}\right)^2\right]\right]} \qquad (3)$$

The estimates of the parameters and its related statistics are given in table 3. The R^2 estimated is 76 percent and its parameters were highly significant ($p < 0.0001$).

Non-Linear Model

Several site index models have employed non-linear techniques to estimate parameters. Utilizing the Chapman-Richards function (Carmean 1972), the RLGS data produced the following site index equation:

$$S=H\left[\frac{1-\exp(-0.0568896A_0)}{1-\exp(-0.0568896A)}\right]^{\frac{1}{(1-2.095444)}} \qquad (4)$$

where

A_0 is index age.

The estimates of the parameters and its related statistics are given in table 4.

Table 3-Parameter estimates and related statistics for the modified Farrar site index model (equation) utilizing the entire RLGS data set

Parameter	Estimate	Standard error	Prob > |T|
β_1	-6.74634 2.00795	0.(.55669	0.(.0001
β_2	-35.95195	8.32733	.0001

The model used is the following:

$$S=(H)10^{\left[-\beta_1\left[\frac{1}{50}-\frac{1}{A}\right]+\beta_2\left[\left(\frac{1}{50}\right)^2-\left(\frac{1}{A}\right)^2\right]\right]}$$

parameters were significant when it was refitted without the weight (model above). Farrar's modified model was fit with only one linear and one quadratic term, since it was flexible enough to account for the variation. In addition, this modified model is more parsimonious and far less complex to use.

Farrar (1981) compared his model to that of Miscellaneous Publication 50 (1976) and Schumacher and Coile (1960) by comparing the standard deviations of difference at the start and end of a 5-year re-measurement period for **20-year** age classes. For purposes of this study, RLGS plots were divided into IO-year age classes and the standard deviation of site index from the modified model was compared to the updated model.

Table 4—Parameter estimates and related statistics for the non-linear site Index model (equatlon) utilizing the entire RLGS data set

Parameter	Estimate	Asymptotic standard error	Asymptotic 95 percent confidence interval: Lower	Asymptotic 95 percent confidence interval: Upper
β_0				
β_2	84.73(.05694	.0(13644	83.47(.0515432	85.99(.0622507
β_2				

The model used is the following:

$$S=H\left[\frac{1-\exp(-\beta_1 A_0)}{1-\exp(-\beta_1 A)}\right]^{\frac{1}{(1-\beta_2)}}$$

where A_0 is index age.

DISCUSSION

The non-linear model did not perform well in fitting the height development patterns of the RLGS data, especially in the younger and older age classes. The mean square error (MSE) was very high compared to the updated and modified Farrar models. The model seems to contain some specification error producing larger residuals, The specification error in the non-linear model needs to be handled properly. One possibility is considering the effects climate, and possibly changes in climate, may have on the model.

Farrar (1981) used a weighted fourth degree polynomial to fit the re-measured RLGS data (360 observations) available during the study. The data set was much smaller and contained more variability as compared to the current data set. However, the non-parsimonious fourth degree polynomial was flexible enough to fit the data. Farrar's model was reconstructed with the current RLGS data (1598 observations), the third and fourth degree parameters were non-significant with the weight **($1/Age^2$)** in the model. The

Using an analysis of variance procedure **(ANOVA)** and estimating the contrast between the updated and modified model, it was observed that the two models were significantly different at lower (< 40 years old) and higher (> 70 years old) age classes (table 5). Around index age (50 years), the models did not differ statistically. The reason for the similarity around the base age was due to the constraint enforced to pass the site index equation at the base age (50 years). The models were also significantly different in overall comparison ($p < 0.0001$). However, when comparing the models for 1 O-year age classes, the modified model had a lower standard deviation for 84 percent of the observations. It is also observed that the estimated site index did not change much around the base age (50 years). The number of plots is given by N (table 2) and the absolute difference of site index was higher in higher age class, which might be due to fewer numbers of plots.

A family of site index curves produced by the modified equation is shown in figure **1.** The curves have an index age of 50 years.

Table 5—Estimates of absolute differences between the site indices, p-values, and standard errors of estimates by age class comparing Farrar's original site index model with the modified Farrar site index model

Age class	Estimated difference	Prob. > |T|	Standard error	N
20	2.64	0.0013	0.814	550
30	3.08	.0034	1.048	508
40	.70	.4488	.919	446
50	.05	.9662	1.199	336
60	.65	.6076	1.258	353
70	1.71	.1305	1.131	372
80	2.96	.0134	1.189	284
90	4.08	.0023	1.319	178
100	5.26	.0001	1.308	114
110	6.05	.0252	2.534	26

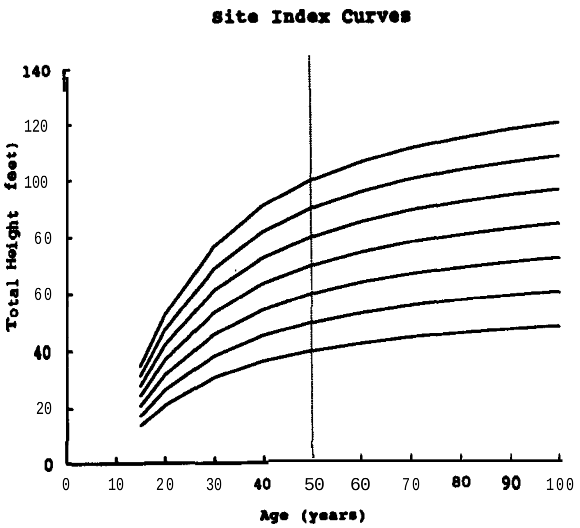

Figure l-Site-index curves for naturally regenerated longleaf pine in the east Gulf area, index age 50 (from modified Farrar's equation).

SUMMARY

Modified sites index equation for naturally regenerated, even-aged, iongieaf stands using Farrar's (1981) site index model was produced by using the current RLGS data set. The modified equation performed as well as the existing equation with only two parameters instead of four. A non-linear model did not fit the observed height development pattern. Another variable, such as climate may be needed in the model that will account for large residuals. Residuals will be examined and efforts will continue for a more precise and flexible model. Site index may be changing (personal communication, Dr. William Boyer, USDA Forest Service, Southern Research Station, Devaii Dr., Auburn, AL 36849) and efforts are underway to answer to this question.

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BIOMASS AND OIL CONTENT OF EASTERN REDCEDAR (*JUNIPERUS VIRGINIANA*)[1]

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Abstract-Management of eastern redcedar, especially open-grown trees invading pastures and rangelands is a significant problem in Oklahoma and adjacent states. Information on biomass and potential oil yields is needed to develop new uses, improve utilization, and provide alternatives for land managers. Oil extracted from *Juniperus* species has been used in the flavor and fragrance industry and has been shown to have insecticidal and antimicrobial activity. Closed-grown and open-grown eastern redcedar sample trees, representing a range of dbh classes from 5 to 19 inches, were collected for estimation of biomass and oil contents. Age of sample trees ranged from 22 to 82 years. Relationships between biomass components (foliage, branches, sapwood, heartwood, bark) on a green and oven-dry basis and tree dimensions (dbh. height, crown size) were evaluated and regression equations developed to estimate biomass of tree components from the more easily measured variables. Concentrations of oil in the heartwood averaged 2.43 percent (±1 .25) of the green weight and 2.94 percent (fl.53) on an oven-dry weight basis. Sapwood oil concentrations were about one-tenth of those found in heartwood. Due to differences in the proportion of heartwood and sapwood, closed-grown trees contained 4-5 times as much oil in the bolewood as open-grown trees of the same diameter (24 vs. 6 pounds for a 14-inch tree).

INTRODUCTION

Eastern redcedar (*Juniperus virginiana* L.) is the most widely distributed conifer in the eastern United States (Lawson 1990). Although not considered an important commercial species, it has been used in a variety of wood products. Perhaps the oldest use is for fence posts because of its resistance to insect damage and decay. Even before European settlement, Native Americans used cedar for baskets and perhaps for medicinal purposes. Historically, another important use was in the manufacture of lead pencils (Nichols 1946). Other products of eastern redcedar include furniture, novelty items, closet linings, and wood shavings, which are used for pet bedding. The heartwood is especially prized for its red to purple color, spicy aroma, and durability. Since heartwood is more durable than sapwood it is preferred for the manufacture of many products. However, a mixture of heartwood and lighter colored sapwood is preferred in products where color and visual qualities are more important than durability.

The acreage of eastern redcedar continues to increase because (1) the seeds are widely dispersed by birds and other wildlife, (2) the species is able to adapt to a wide range of site conditions, and (3) of increased suppression of wildfires that would have destroyed seedlings and small trees. Eastern redcedar aggressively regenerates over a wide range of site conditions and competes with valuable forage species. Various mechanical and herbicide control measures can be expensive and/or ineffective. A recent estimate found 5.9 to 7.9 million acres of eastern redcedar in Oklahoma (Bidwell and Stritzke 1989). Examination of forest inventory data for Illinois, Indiana, Iowa, and Missouri showed increases in the area of forest land and eastern redcedar was a primary species involved in this expansion (Schmidt and Leatherberry 1995). The majority of the increase was on land previously classed as pasture. Eastern redcedar contains oils that are extracted commercially from the bolewood. These oils are used widely in the manufacturing of perfumes, shampoo, medicines, cosmetic cremes, furniture polishes, soaps, and detergents (Poucher 1974). The oil contained in eastern redcedar wood is also used as an environmentally safe and natural insecticide (Adams and others 1988). Higher oil yields are obtained from old trees containing a higher proportion of heartwood (Runeberg 1960). Adams (1987) studied oil concentrations in foliage, sapwood, and heartwood for ten *Juniperus* species native to the United States. Yields, obtained by steam distillation of heartwood samples, ranged from 0.18 percent (J. *pinchotii*) to 3.8 percent (J. *ashei*) on a green-weight basis. Oil concentrations in J. *virginiana* were 2.6 percent on a green-weight basis and 3.2 percent on a dry-weight basis. While there are data describing the concentrations of oil in eastern redcedar, information linking total tree biomass and oil concentrations to estimate oil contents of whole trees is lacking.

Development of new products that increase use of eastern redcedar would benefit landowners and could transform a management problem into a profitable resource. A sustainable eastern redcedar industry would reduce the costs of control programs for farmers and ranchers. Identification of uses for branch and foliage components which comprise a major portion of the total biomass of the open-grown trees found in fields, pastures, and rangelands would be especially beneficial to achieving increased utilization. Because the relative amounts of heartwood and sapwood can affect product value, the industry needs easy, cost-effective ways to evaluate the heartwood and sapwood composition of standing trees.

OBJECTIVES

The purpose of this study is to provide information about eastern redcedar biomass and oil contents to aid in the development of a sustainable eastern redcedar industry. Standard volume measurements of logs and standing trees are suitable for conventional solid-wood products (Anderson

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and Hopper 1994). However, measurement of biomass, by component part, is more suitable or even necessary when products such as wood shavings or oils recovered from foliage, branches, or bolewood residues are contemplated. Methods to estimate biomass of trees and entire stands from more easily measured variables are needed. Estimated green weights (field condition) are important to persons harvesting and transporting trees. However, since green weights are influenced by seasonal and even daily variations in moisture contents, the scientific literature commonly reports biomass data on an oven-dry basis (150 °F). Limited information for estimating eastern redcedar biomass currently exists. A previous biomass study of eastern redcedar in Tennessee studied closed-grown trees (Schnell 1976). The most common method of estimating tree biomass uses regression equations developed by weighing tree components and relating weight to easily measured tree dimensions such as dbh and height (Crow and Schlaegel 1988).

The specific objectives of this study were to (1) develop reliable regression equations for estimation of eastern redcedar biomass by component part from more easily measured tree variables, (2) determine the effect that stand density and tree size class have on the biomass of various tree components, (3) determine the proportion of heartwood, sapwood, and bark in relation to the entire bole, and (4) determine oil content of the bolewood. Biomass estimation equations will be useful in conjunction with existing tree inventory data based on traditional measures of tree dimensions (bole diameter and height, crown size). Estimation of the relative quantities of component parts used in various products can be used to assess potential sustainability of the resource.

METHODS

The study plan specified selection of a tree from each 2-inch dbh class between 5 and 19 inches, the size classes common in Oklahoma (5 inch class=4.0-5.9, 7 inch class=6.0-7.9, etc). Influence of stand density on distribution of total biomass among various above-ground tree components was examined by selecting trees that were either open- or closed-grown. Open-grown trees were found in fields and pastures free of competition from other trees on all sides. Closed-grown trees were surrounded by trees of similar size and age and showed evidence of natural pruning with small dead branches, < 1 inches diameter, on the lower portion of the tree bole.

Field Measurements

Once a tree was selected for sampling, dbh and crown diameter were measured. Crown diameter was determined by using the average of two measurements taken at right angles about the tree. The tree was then felled by cutting at ground level and live crown length was measured. Ten live sample branches at least 1 inch in diameter at the base were selected evenly throughout the crown based on live crown length. Using calipers, each sample branch was divided into three segments, by diameter class: (1) < ¼ inch, (2) ¼-1 inch, and (3) > 1 inch. Branches < ¼ inch contained mostly leaves and were therefore considered to be foliage. The division at 1 inch was selected since preliminary study showed this to be the point where heartwood begins to appear. The green weight was recorded for each category of branches. The samples were then placed in paper bags and returned to the laboratory for drying. Foliage samples were placed in cold storage until drying to prevent any weight loss due to respiration or decomposition. The remaining live branches were removed from the tree and weighed. A subsample of dead branches was randomly selected from the tree, weighed, and returned to the laboratory for drying. The remaining dead branches were removed from the tree and their weights determined.

After all branches were removed from the tree, total tree height and height to a 3-inch diameter top were measured and recorded.

The bole of each tree was divided into five sections with each representing 20 percent of the bole length. A sample disk about 1 to 3 inches long was cut from the base of each section. The disks were labeled, weighed, placed in polyethylene sample bags, and returned to the laboratory where they were placed in cold storage. A sample section of the bole, approximately l-foot long was cut from the base of the bole, to be used for study of oil contents and constituents (Payne and others 1998). Total weight of this sample section and the remainder of the bole were determined in the field.

Laboratory

Biomass-The samples of dead branches, live branches, and foliage were dried to a constant moisture at 150 °F until there was no further weight loss and the weights recorded. The total age of each tree was determined from the basal sample disk using caution to avoid counting the many false rings that are found in eastern redcedar (Kuo and McGinness 1973). The heartwood, sapwood, and bark were separated for each sample disk, using wood chisels, and the green weights of each component recorded. The samples were then dried to constant moisture content at 150 °F and the weights recorded. These data were used to determine the percentage of heartwood, sapwood, and bark in the bole by green weight and dry weight.

Oil contents-Samples for oil analysis were taken from the basal section of the bole and prepared by separating heartwood and sapwood and grinding in a Wiley Mill to pass a 0.8 mm sieve. A modified Abderhalden drying apparatus was used to collect volatilized oil components. Trapped oil was analyzed qualitatively and quantitatively, by gas chromatography. Payne and others (1998) have reported further details on methodology and oil concentrations in heartwood samples of each tree sampled for biomass estimates in this study. Preliminary analysis of sapwood samples indicated oil content of this component was about one-tenth of the heartwood content (Payne 1997). Biomass data obtained in our study and oil concentration data reported by Payne (1997) and Payne and others (1998) were used to estimate total oil content of heartwood for the sample trees described in this paper.

Analysis

The components evaluated for each tree were foliage, ¼-1 inch branches, > 1 inch branches, dead branches, heartwood, sapwood and bark. Data obtained from drying the branch and disk samples were used in conjunction with the green weight of each tree, to determine total dry weights for each of the tree components. Green and dry weights of open- and closed-grown tree components were then subjected to regression analyses, using various independent variables, in order to develop equations that provided the best biomass estimates for each component part.

Natural log transformations of both dependent and independent variables were used. Since variables were transformed, it was necessary to compute a Fit Index (FI) for each equation to make valid evaluations and compare equations (Payandeh 1981, Schlaegel 1982). The FI statistic is calculated from residuals in measured units, such as pounds, not the transformed units **[ln(pounds)].** Predictions in logarithmic units were converted back to measured units and FI calculated from residuals in measured units.

RESULTS

Sample Tree Data

A total of 14 sample trees were selected for intensive sampling and analysis (table 1). Eight open-grown sample trees, one representing each 2-inch dbh class from 5 to 19 inches, were studied. Sample trees in the 17- and 19-inch dbh classes in the closed-grown category could not be located and only 6 trees were sampled. As would be expected forest-grown trees were considerably older than open-grown trees for a similar range of diameters by an average of about 20 years. While the entire length of open-grown trees supported live branches, the live crown length for forest-grown trees was between 35 and 50 percent of the total height. For open-grown trees, the crown diameter was approximately equal to the total length or height of the trees.

Foliage and branches of open-grown trees comprised approximately 70 percent of the total above ground biomass and bole components of sapwood, heartwood, and bark, comprised approximately 30 percent. The relative distribution of crown and bole components was nearly reversed for closed-grown trees. Crown components were approximately 35 percent and bole components approximately 65 percent of the total aboveground biomass for closed-grown trees.

Biomass Estimation

Independent variables and parameter estimates significant at the $P > 0.1$ level are included in the biomass estimation equations reported herein (tables 2 and 3). Equations for estimates, by component part, on a green or oven-dry basis for forest- and open-grown trees are reported. As with most studies of biomass for forest tree species, diameter at breast height (dbh) or dbh^2 were the mostcommon independent variables selected (Crow and Schaegell988). However, for foliage or branch components, particularly for open-grown trees, crown dimensions were sometimes the significant independent variable selected for estimation of biomass.

Equations for estimation of oven-dry biomass usually tit the data more closely than equations for estimation of green weights. For example, equations for estimating green weight of large branches on open-grown trees explained 56 percent of the variation while for oven-dry weight the Fit Index was 87 percent (tables 2 and 3). Sample trees were collected at different times over a 12 month period and seasonal differences in moisture conditions contributed to additional variation in green weight of biomass components. Fit indices for major biomass components (foliage, large branches, sapwood, bolewood) were 0.65 or greater for estimates on a dry-weight basis.

Schnell's (1976) study of forest-grown eastern redcedar in the Tennessee Valley provides an opportunity for some comparisons with our work. His results consisted of weight tables for various biomass components by l-inch dbh classes, rather than equations for estimation, and the separation of biomass components varied from our methods. Using our equations for estimation of dry-weight of biomass of forest-grown trees (table 3) yielded the following estimates for a 14-inch dbh tree:

Table l--Mean and range for open-grown and forest-grown sample tree characteristics

Characteristics	Open-grown	Forest-grown
Number sample trees	8	6
Age (years)		
Mean	42	65
Range	22 - 61	45 - 82
D.b.h. (inches)		
Mean	12.4	10.0
Range	5.7 - 19.8	5.2 - 14.7
Total height (feet)		
Mean	30.2	41.7
Range	18.7 - 37.7	28.2 - 59.0
Crown length (feet)		
Mean	30.2	22.6
Range	18.7 - 37.7	9.8 - 29.5
Crown diameter (feet)		
Mean	26.9	14.8
Range	15.7 - 38.1	8.2 - 21.6
Foliage biomass[a]		
Mean	365	67
Range	150 - 480	11 - 132
Large branch biomass'		
Mean	383	59
Range	50 - 872	1 - 126
Small branch biomass'		
Mean	162	37
Range	68 - 277	8 - 80
Dead branch biomass'		
Mean	18	65
Range	<1 - 56	12 - 149
Bark biomass[a]		
Mean	22	24
Range	7 - 42	3 - 68
Sapwood biomass[a]		
Mean	143	121
Range	40 - 265	23 - 213
Heartwood biomass[a]		
Mean	174	223
Range	21 - 405	35 - 564

[a] Biomass is in pounds, oven-dry weight.

foliage-	123	bark (bolewood)-	46
large branches-	144	sapwood (bolewood)-	225
small branches-	55	heartwood (bolewood)-	439
dead branches-	114	TOTAL TREE	1,146 lbs.

Note: Estimation of some components required crown length and total height (table 3). Regression analysis of these variables for the forest-grown sample trees yielded an estimated crown length of 30 feet and total height of 55 feet for a 14-inch tree.

Schnell's estimated oven-dry weight for a 14-inch dbh tree was 1,090 pounds, approximately 5 percent lower than our

Table 2 -Equations for estimating green weight of biomass components for forest- and open-grown eastern redcedar

Component/stand (W_i)	b_o	b_1 ln d.b.h.	b_1 in D^2	b_1 in HT	b_1 in CL	b_1 ln CD	FI
Foliage							
Forest-grown	-0.3678	—	1.0999	—	—	—	0.82
Open-grown	1.7740	—	—	1.3703	—	—	.54
Large branches (>1 inch diameter)							
Forest-grown	-5.1445	—	2.0262	—	—	—	.56
Open-grown	1.4283	—	.9803	—	—	—	.80
Small branches (<1 inch diameter)							
Forest-grown	-.9069	.9418	—	—	0.8895	—	.92
Open-grown	3.4692	.8539	—	—	—	—	.51
Dead branches							
Forest-grown	-1.3317	2.3450	—	—	—		.66
Open-grown	-19.2722	—	—	2.5304	—	3.9453	.91
Bark							
Forest-grown	-8.8627	—	—	2.8726	—	.5302	.99
Open-grown	.5465	—	1.0780	—	—	-.7686	.96
Sapwood							
Forest-grown	.2619	2.2579	—	—	—	—	.90
Open-grown	-3.8641	—	—	2.8138	—	—	.76
Heartwood							
Forest-grown	-4.0690	—	.7666	1.5986	—	—	.99
Open-grown	-.4891	2.2789	—	—	—	—	.99

$\ln W_i = b_o + b_1(\ln X_i)$

W_i = biomass of component (pounds)

D.b.h. = diameter of tree, at breast height (inches)

$D^2 = (DBH)^2$

CL = crown length of tree, (feet)

CD = crown diameter of tree, (feet)

HT = total height of tree, (feet)

$$FI = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y})^2}$$

$\hat{y}$ = predicted value of y in "actual" units

estimate. Schneii's dry-weight samples were dried at 220 °F while ours were based on drying at 150 °F and this could partially explain the difference in the two estimates. Our estimate of total boiewood weight (sapwood and heartwood) totaled 664 pounds, while Schneli's estimate of merchantable (> 3 inches diameter) plus unmerchantable stem totaled 671 pounds, for a negligible difference. Fit indices for heartwood, sapwood, and large branches of open-grown trees exceeded 75 percent. Although our study is based on a limited number of sample trees, these comparisons suggest reliable estimates of biomass for major components are possible with the equations reported here.

Oil Contents

Concentrations of oil in heartwood of the sample trees ranged from 0.60 to 5.88 percent and averaged 2.94 on a dry-weight basis (Payne and others 1998). Most open-grown trees exhibited concentrations below the mean and forest-grown trees had concentrations of 3.3 percent or greater. The differences in concentrations coupled with the greater proportion of hearlwood in forest-grown trees (table 1) resulted in greater total oil content in forest-grown trees in comparison with open-grown trees of comparable diameter classes (table 4).

An inventory of trees in 44 central and western Oklahoma counties found about 36 percent of the total eastern redcedar volume of 21.2 million cubic feet to be in trees greater than 11 inches dbh (Rosson 1995). About 445 thousand trees greater than 11 inches were found among the estimated 31 million eastern redcedar. We estimate a 12-inch dbh, forest-grown tree, to contain 17 pounds of oil. Eastern redcedar oil sold for $4.90 in 1992 (Chemical Reporter 1992) and $6.90 in 1999 (Chemical Market Reporter 1999). This represents an average annual increase of about 5 percent suggesting a steady demand for the commodity. At current prices, oil contents of a 12-inch dbh forest-grown tree would be valued at about $117.

Table 3—Equations for estimating ovendtyweight of biomass components for forest- and opengrown eastern redcedar

		b_1					
Component/stand (W_i)	b_0	ln d.b.h.	ln D^2	ln HT	ln CL	ln CD	FI
Foliage							
Forest-grown	-0.9451	2.1832	—		—	—	0.96
Open-grown	.6429	—	—	1.5359	—	—	.65
Large branches (>1 inch diameter)							
Forest-grown	-7.7431	2.0764	—	—	2.1264	—	.87
Open-grown	.6587	—	1.0221	—	—	—	.85
Small branches (<1 inch diameter)							
Forest-grown	-2.0139	—	—	—	1.7696	—	.75
Open-grown	.2043	—	—	—	—	1.4706	.66
Dead branches							
Forest-grown	-1.5431	—	1.1897	—	—	—	.71
Open-grown	-20.4515	—	—	2.6210	—	4.1592	.92
Bark							
Forest-grown	-9.9873	—	—	2.6132	.9818	—	.92
Open-grown	.4808	—	1.1068	—	—	-.9228	.96
Sapwood							
Forest-grown	-.5804	—	1.1363		—		.94
Open-grown	-4.3999	—	—	2.7190	—	❑	.78
Heartwood							
Forest-grown	-4.6641	1.4706	—	1.7136	—	—	.99
Open-grown	-1.0283	2.3748	—	—	—	—	.99

$\ln W_i = b_0 + b_1(\ln X_i)$

W_i = biomass of component (pounds)

D.b.h. = diameter of tree, at breast height (inches)

$D^2 = (DBH)^2$

CL = crown length of tree, (feet)

CD = crown diameter of tree, (feet)

HT = total height of tree, (feet)

$$FI = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y})^2}$$

$\hat{y}$ = predicted value of y in "actual" units

An 12-inch dbh tree with two eight-foot logs would contain an estimated 45 board feet (Anderson and Hopper 1994). Prices for manufactured eastern redcedar lumber at wholesale are difficult to determine due to limited trading of the commodity; current prices for western redcedar fence boards range widely with $500 per thousand board feet appearing to be somewhat above average. At this price, a 12-inch tree would yield lumber valued at about $22 compared with the possible oil yield valued at $117. An important unknown in this comparison is the substantial cost in equipment and operation of the steam distillation processing facility required to extract the oil. A 1 2-inch open-grown tree would only yield about 4 pounds of oil valued at $28, but also potentially lower returns from lumber because of the high proportion of sapwood.

CONCLUSIONS

Estimates of oil contained in eastern redcedar trees, a species often considered of limited commercial importance, suggest a potentially useful resource. Recent laboratory experiments conducted by Payne and others (1999) suggests that collection of oil on an industrial scale patterned after an Abderhalden drying apparatus is feasible. This apparatus passes heated air or nitrogen through a chamber containing wood particles into a cold trap chilled with ice water and charged with ether to collect moisture and the volatile oil swept from the drying apparatus. Potential cost savings are possible with this process because of the significant energy required to generate steam for the conventional distillation process,

The greater value of potential products from closed-grown, forest trees, also has important implications for forest inventory-what percentage are open-grown trees in fields and pastures versus the percentage of forest-grown trees? There are implications for landowners as well. implementation of management practices to promote tree growth under closed-stand conditions is an option.

Table **4—Estimated** content of oil in boiewood of forest- and open-grown eastern **redcedar** tree by **d.b.h.** class

D.b.h.	Forest-grown	Open-grown
	____ . ... pounds-----------	
6	1.2	—
7	3.1	0.2
6	5.2	1.0
9	7.7	2.6
10	10.4	2.6
11	13.4	3.4
12	16.6	4.2
13	20.4	4.9
14	24.2	5.7
15	26.4	6.5
16	—	7.3
17	—	6.1
16	—	**8.9**
19	—	**9.7**

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Insects and Diseases

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SILVICULTURAL PRACTICES IN FORESTS OF THE SOUTHERN UNITED STATES: INSECT AND DISEASE CONSIDERATIONS'

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Abstract-The relationship between silvicultural practices, e.g. thinning, and pest organisms (insects and diseases) has been investigated extensively in pine species but to a lesser degree in hardwoods. Of critical interest is the potential negative impact to the residual stand resulting from insect damage and diseases that develop as a consequence of silvicultural practices. This is especially true with the increasing economic opportunities in southern forests. Our intent is to report the positive and negative impacts of silvicultural practices for hardwoods in the southern United States that relate to insects and diseases. Emphasis will be placed on stand modification practices. The impact of these practices on current or potential pest problems will be discussed with respect to cursnt and past research concerning insects and disease. Management approaches will be suggested that will help minimize loses from insects and diseases.

INTRODUCTION

The management of forests in the southern United States is intensifying in some areas as economic opportunities increase. At the same time, management activities are becoming less intense in other areas as societal values are being considered. There are increasing interests in conservation, wetland preservation, ecosystem preservation, ecosystem management, forest health, and restoration. There is also considerable interest in the sustainability of these forests for purposes of producing fuel, fiber, lumber products, and chemicals. As a result of these latter interests, and in connection with broader ecological interests, the impact from harvesting, periodic flooding (including green tree reservoirs), and fire are of concern (Nebeker and others 1998). In each case, insects and disease-causing organisms have increasingly greater or increasingly fewer opportunities to impact a residual stand as various physiological stresses are added to or removed from the system. Consequently, there is a growing demand to understand these, sometimes complex, relationships.

Our objective is to describe a study the results of which will provide an understanding of the positive and negative aspects of thinning southern bottomland hardwood stands in relation to insect and pathogen populations.

METHODS

Study Area

The study area was located in the Delta National Forest (DNF), Sharkey County, near Rolling Fork, MS during 1997. Campsite 69 served as the principle point of reference within Compartment 38 where treatment areas were established.

Plot design followed the recommendations for standard plots for silvicultural research, set forth by the USDA Forest Service's Northeastern Forest Experiment Station (Marquis and others 1990 - in Meadows and Goelz 1998).

Two 2.4 acre treatment areas were established in Compartment 38. Four measurement plots were set up in each treatment area. Each measurement plot measured 4 by 6 chains. Corners were permanently marked with PVC pipe driven into the ground. Treatments consisted of an unthinned control and a commercial thinning.

Each measurement plot was 0.6 acres, 2 x 3 chains. Each measurement plot was divided into six sectors, each sector was 0.1 acres in size (1 x 1 chain, or 66 x 66 feet). Corners of all sectors and of the measurement plot itself were permanently marked with PVC pipe driven into the ground.

In total there were twenty-four 0.1 acre sector plots utilized in the control group. Likewise, there were twenty-four 0.1 acre sector plots established in the thinned area. All 48 sectors were established and inventoried prior to the commercial thinning.

Pre-thinning inventory determined species composition, initial stand density, insect activity and numbers of diseases. The following variables were measured on all trees greater than, or equal to, 5.5 inches dbh: species, dbh, crown class, tree class, vigor classes, number of epicormic branches, length and grade of sawlogs, and number of insect and disease signs and symptoms. The locations of sample trees within their respective plots were recorded using an x-y coordinate system. An individual number was painted on each tree at about breast height (bh), and a tag was nailed to the base of each tree. A dot was also painted on each tree at bh to assure consistency in measuring dbh. Primary tree species in the area are: sweetgum (*Liquidambar styraciflua*), willow oak (*Quercus phellos*), Nuttall oak (Q. *nuttallii*), sugarberry (*Celtis laevigata),* and various elms (*Ulmus* spp.).

Commonly encountered insect signs and symptoms consisted of: insects themselves in various life stages, frass, bore holes, boring dust, scarring (resulting from callus tissue growing over entrance or exit holes), and galleries. Disease signs and symptoms commonly seen included: slime flux (weeping or oozing indicative of bacterial wetwood), stained wood, fruiting bodies such as conks and mushrooms, cankers, and fungal mats.

Post-thinning inventory was conducted in the same manner as the pre-thinning inventory except that additional data

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were collected concerning thinning related wounding to the canopy, upper-bole (above bh), lower-bole (below bh but above the root collar zone), root collar and roots.

The treated plot was thinned in fall 1997 by professional contractors using chain saws, a mechanical feller, and grapple skidders. The thinned and unthinned plots are surrounded by a 165-acre thinning within two payment units that make up the lower two-thirds of Compartment 38. The thinning was done "from below" to remove poorly formed and otherwise unmerchantable trees and favor well-formed sweetgums and red oaks to improve the quality of the residual stand. Thinning guidelines were developed as prescribed and mandated by the U. S. Forest Service.

Additional Insect Sampling

Trapping was conducted, after the thinning had been completed, using both Malaise traps and black light traps. Insect trapping was conducted from 20 August 1997 to 9 October 1997 within Compartment 38. A Townes-style Malaise trap was installed in the control area, with another Townes-style Malaise trap placed in the thinned area. Trapped insects were collected at one or two week intervals in each area. Black light traps were operated one night a week in each treatment area for approximately eight weelts. Trapped insects were stored in 70 percent ethanol. Wood-boring insects from the families Cerambycidae, Scolytidae, and Platypodidae were sorted and removed from the samples and identified to species. All others remain stored in ethanol awaiting further sorting by species of specific interest.

Diversity indices were calculated to characterize the groups of wood-boring insects collected from the unthinned and thinned areas. Indices applied were the Shannon-Weiner index (designated as H'; Magurran, 1988) and evenness index (designated as J'; Pielou, 1966). Statistical differences between the two treatments in terms of the diversity indices were tested following Hutcheson (1970) and procedures from Zar (1996). Host preferences were determined for the collected wood-boring species according to Yanega (1996), Solomon (1995), and Wood (1982).

RESULTS

Pre-Thinning

The survey of the study area prior to thinning revealed no significant differences in total numbers of trees, insect signs and symptoms, or disease signs and symptoms between the thinned and unthinned areas. A total of 469 trees were inventoried and numbered. Sweetgum, willow oak and Nuttall oak were the primary species in the study area (table 1). Insect signs and symptoms totaled 742 evenly distributed between the two treatments. Disease signs and symptoms totaled 69 with 59 percent being associated with the trees in the control treatment. The majority of the insect and disease activity was associated with willow and Nuttall oaks (table 1). Of the insect activity, primarily borers, 88 percent of the total occurred on willow and Nuttall oaks.

Post-Thinning

Wounding- Wounding to the residual trees may occur with any entry into a stand. Generally, this occurs when a harvested tree falls into a residual tree, or when logging equipment causes damage to the residual stems. The scraping and removal of bark exposing xylem is typical of logging damage. A "turn tree", a residual tree around the base of which a log is dragged, is a good example of typical basal wounding. The wounds provide places for insects to enter and serve as infection courts for pathogens.

Table l-Percentages of total numbers of trees, insect borer wounds, and disease indicators (signs and symptoms) by tree species resulting from the summer 1997 pre-treatment survey of the unthinned plot and the plot designated to be thinned in Compartment 38 of the Delta National Forest

Tree species	Percent of total trees	Percent of total borer wounds	Percent of total disease indicators
Unthinned plot			
Sweetgum	51.4	1.3	24.4
Willow oak	28.2	59.9	46.3
Nuttall oak	9.1	28.3	14.6
Sugarberry	5.4	0	9.8
Other	5.4	10.4	4.9
Plot designated to be thinned			
Sweetgum	47.4	8.7	10.7
Willow oak	29.4	39.1	71.4
Nuttall oak	6.6	39.4	7.1
Sugarberry	5.4	0	0
Other	11.4	12.8	10.7

There was a great deal of wounding that occurred in Compartment 38 as a result of the thinning operation. In the thinned plots, 84 percent of the residual stems were damaged in some way. Of the total wounds, 53 percent were on the lower-bole (basal wounding), followed by root damage (28 percent), root collar wounding (16 percent), upper-bole wounding (2 percent), and branch wounding or breakage (1 percent). Wounding of the roots, root collar, and lower bole was generally caused by logging equipment or was the result of tree removal (e.g., "turn trees"). Wounding to the upper-boles and branches occurred as cut trees fell into residual trees. During subsequent surveys of these study sites, the wounds will be monitored for additional insect and disease activity.

Insect and Disease Survey

All numbered trees in the thinned and unthinned plots were examined in November 1998 for signs of insects and diseases. One year after the thinning, logging wounds on some trees showed evidence of incipient pathogen activity (table 2), and some had entrance holes caused by wood borers, most notably by ambrosia beetles (Platypus spp.). Eleven nascent infections caused by Ganoderma *lucidum, Inonotus* spp., *Schizophyllum commune, Stereum gausapatum, Stereum hirsutum,* and *Trichaptum biforme* all occurred on one-year-old logging wounds. Two well developed butt rots and a bacterial wetwood infection were in the stand prior to thinning.

Table 2-Comparison of pathogens evident 1 year after thinning in unthinned and thinned stands in Compartment 38 of the Delta National Forest

Disease type and species	Unthinned	Thinned
Canker decay and heartwood decay		
Inonotus hispidus	2	0
Root and butt decay		
Ganoderma lucidum	0	1
Inonotus spp.	0	1
Unidentified pathogen	5	2
Heartwood decay		
Schizophyllum commune	0	2
Stereum gausapatum	0	2
Dead wood decay		
Trichaptum biforme	0	1
Stereum hirsutum	0	4
Wetwood		
Various anaerobic bacteria	4	1
Total number disease types	3	8
Total number individuals	11	14

Of the 25 pathogens or disease indicators recorded in unthinned and thinned plots, all but six occurred on willow or Nuttaii oaks (table 2). A similar finding was noted in the pre-treatment data (table 1). The ratio of disease indicators per total number of sample trees is 4.6 percent (1 1/239) on the unthinned plot and is 15.7 percent (14/89) on the thinned plot. The new infections accounted for the difference in the number of disease types between the unthinned (3) and thinned (8) plots, as well as the difference in numbers of individual disease indicators between plot types. it is anticipated that these initial decays will be more advanced when examined during the 1999 survey, and that more new infections will have occurred on other logging wounds in the thinned plot.

Of the 434 bore holes caused by insects, 319 were recorded on 87 trees in the unthinned plot and 115 were noted on 27 trees in the thinned plot. Even though the number of total borer holes was less in the thinned plot, the number of borer holes per sample tree increased from 3.7 in the unthinned plot to 4.3 in the thinned plot. This is an indication of the number of new insect borer attacks on logging wounds. Bacterial wetwood in oaks can often be diagnosed because of the slime flux oozing from wood borer attacks. in both plots prior to thinning, oaks had the greatest proportion of borer holes compared to other species (table 1). There were fewer wetwood infections detected in thinned than unthinned plots because roughly one-half of ail oaks were removed from the thinned plot. New borer attacks are either not of the type usually associated with wetwood, or have not advanced to the point where the infections begin to ooze out of the holes.

insect Trapping

A total of 1,371 individuals representing 21 species were collected from the thinned stand and a total of 172 individuals representing 14 species were collected from the unthinned area. Wood-boring insects identified to species belonged to the families Cerambycidae, Scolytidae, and Platypodidae. The majority of cerambycids were taken with Malaise traps, whereas the black light traps captured all scoiytids and platypodids. Eight species were trapped in the thinned stand that were not present in the unthinned area, whereas only one species was unique to the unthinned area (table 3). In the thinned stand, five of those eight species were cerambycids.

Table 3—Comparison of wood-boring insects collected from August to October 1997 in unthinned and thinned stands in Compartment 38 of the Delta National Forest

Family and species	Unthinned	Thinned
Cerambycidae		
Afaxia cyrpta (Say)	0	1
Distenia undafa (Fabricius)	1	4
Ecyrus dasycerus (Say)	1	7
Elaphidion mucronatum (Say)	0	6
Enaphalodes atomarius (Say)	0	12
Leptostylus asperatus (Haldeman)	0	8
L. transversus (Gyllenhal)	0	6
Leptura emarginafa (Fabricius)	1	0
Neoclytus acuminatus (Fabricius)	12	27
N. mucronatus (Fabricius)	1	28
N. *scutellaris* (Oiivier)	2	22
Styloleptus biustis (LeConte)	1	9
Urographis fasciatus (DeGeer)	2	35
Xylotrechus co/onus (Fabricius)	8	55
Scoiytidae		
Dryocotes betulae (Hopkins)	11	97
Hylocurus binodatus (Wood)	0	8
Monartum mali (Fitch)	4	34
Xyleborus ferrugineus (Fabricius)	47	353
Xylosandrus crassiusculus (Motschulsky)	21	36
Piatypodidae		
Platypus compositus (Say)	60	821
P. flavicornis (Fabricius)	0	1
P. quadridentatus (Oiivier)	0	1
Total number species	14	21
Total number individuals	172	1371

In both areas, in terms of numbers of species, most insects taken were cerambycids. However, the most abundant wood-borer collected in the two stands was a platypodid *Platypus compositus,* which accounted for 35 percent of the total catch in the unthinned area and 45 percent of the total catch in the thinned area. Overall, more species were collected from the thinned stand (table 3).

Even though there were more species of wood borers in the thinned area than in the unthinned area, there was no significant difference in species diversity (H' = 1.99 and 1.83, respectively) between the two areas. Evenness was slightly higher for the unthinned stand (J' = 0.69) than the thinned stand (J' = 0.64), reflecting a more equitable distribution of numbers among collected species (Nebeker and others, in press). This is understandable as nearly half of the insects trapped in the thinned stand were of a single platypodid species, *P. compositus.* As for abundance, much larger numbers of species from all three families were taken in the thinned stand than in the unthinned stand.

All but one of the wood-boring insects collected were species that had host preferences for hardwood tree and shrub species. No one species was collected that was primarily a pest of healthy hardwoods, instead the majority of species were ones that attack weakened, stressed, freshly-felled, or dead and decaying hardwoods. For example, *P. compositus,* the most frequently trapped insect wood-borer, rarely attacks vigorous hardwoods, but instead prefers oak, hickory, maple, and other hardwood species that are severely weakened, are dying, or that have been freshly-felled (Solomon, 1995).

DISCUSSION

The magnitude of logging damage is due to the following principal variables: 1) silvicultural system used, 2) type of equipment and configuration, 3) tree species, 4) spacing (density), 5) size class (age), 6) season of harvest (soil moisture conditions), and 7) operator carelessness (Nebeker and others 1998). The types of damage encountered include limb breakage and wounding: bole wounding, upper and lower bole; root wounding; and root breakage.

Other reports, most of which were through personal communications, also indicate considerable logging damage as was observed in this study. Meadows (1993) found logging wounds on 62 percent of the residual stems following a thinning operation in a riverfront hardwood stand in Mississippi. The most common types of damage included: 1) branches being broken in the residual canopy; 2) upper and lower bole wounding; and 3) exposure and breakage of roots. Such wounding serves as infection courts for disease organisms and attraction points for various insects that can lead to degrade and potential mortality of the residual steins. In addition, disease propagules such as fungal spores, bacteria, and viruses may be introduced into trees through wounds created by insects, birds, or mammals. The subsequent reduced vigor of individual trees may also reduce the overall health of the residual stand making it susceptible to further attacks by insects and pathogens.

With the results presented above, it is too early to really determine what the impact will be from insects and diseases. Hence it will be necessary to monitor this stand for a number of years to document the changes which take place. This will be the subject of some of our ongoing investigations.

It is our intent to produce a guide similar to one produced by Nebeker and others (1985). They state that although the principal goal of thinning is improving the growth and value of stands, other benefits are obtained, such as hazard reduction for insect infestations, disease epidemics, and damage due to abiotic agents. The mechanics by which thinning reduces these hazards is not completely understood. However, observations indicate that thinning can result in positive and/or negative effects, depending on how, where, when, and why it is conducted. The presence of more than one kind of hazard (e.g., insects and diseases) in a particular area at a given time poses some problems in designing an optimal thinning strategy. Other factors that complicate the situation are the forest type (species composition), stage of stand development, site quality, growth rate, live crown ratio, equipment used, machine operator experience, anticipated direct damage to residual stems, and ultimately the cost effectiveness of the operation. Soil compaction, soil improvement, water quality issues, wildlife habitat enhancement, weed problems, aesthetics, and the like, cannot be ignored if all aspects of thinning are to be taken into account. This is certainly true of the bottomland hardwood landscape.

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REASSESSMENT OF LOBLOLLY PINE DECLINE ON THE OAKMULGEE RANGER DISTRICT, TALLADEGA NATIONAL FOREST, ALABAMA[1]

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Abstract-Loblolly pine (*Pinus taeda* L.) decline has been a management concern on the Oakmuigee Ranger District since the 1960's. The symptoms include sparse crowns, reduced radial growth, deterioration of fine roots, decline, and mortality of loblolly pine by age 50. Reassessment of the decline sites began in May of 1996 in order to evaluate the cause of the decline/mortality complex and to re-evaluate management options. Fifteen variable radius plots were established on four compartments, representing five declining stands. Three dominant/co-dominant symptomatic trees were selected from each plot for root sampling and data collection. Two primary lateral roots were excavated from each sample tree and the fine roots examined and sampled. Root samples were placed on selective media for isolation of *Heterobasidion* annosum, *Phytophthore cinnamomi, Pythium* spp. and *Leptographium* species. *Pythium* spp. and *Phytophthora cinnamomi* were recovered from the fine root samples of all *15* plots. *Leptographium* spp. were recovered from the primary lateral root samples of 7 of the 15 plots, No *H. annosum* was found in any of the root samples. Liffleleaf disease appears to be the primary cause of the loblolly decline symptoms and mortality. Management options on these sites include managing for loblolly pine on shorter rotations of 50 years, or accelerating harvest of damaged stands with conversion to longleaf pine type and fertilization to mitigate root disease.

INTRODUCTION

The Oakmulgee Ranger District is part of the Talladega National Forest. It is located in portions of six west-central Alabama counties with the district office at Centreville, 35 miles south of Tuscaloosa, AL. The Ranger District consists of 158,000 acres, of which approximately 99,000 acres are pine forest type. The dominant forest type in the presettlement era was longleaf pine (*Pinus palustris* Mill.), which was extensively cut over and the land cultivated prior to establishment of the Talladega National Forest (Johnson 1947). During the 1930's forest practice emphasized watershed protection and much of this area was regenerated to loblolly pine (*Pinus taeda* L.).

The Oakmulgee Ranger District falls within the Upper Gulf Coastal Plain province and during the 1940's and 50's, surveys found extensive damage to shortleaf pine (*Pinus echinata* Mill.) stands caused by littleleaf disease. The disease is associated with *Phytophthora cinnamomi* Rancls and soils with poor internal drainage (Campbell and Copeland 1954, Roth 1954). The first reports of declining loblolly pine on the Talladega National Forest were in 1959. Symptoms included short, chlorotic needles, sparse crowns, and reduced radial growth in the 40 to 50 year age class. Mortality occurred 2 to 3 years after symptom expression.

In 1966, a 5-year study was established on twenty-four 1/4-acre plots on the Oakmulgee Ranger District to determine the cause, rate of decline, and degree of the mortality of loblolly pine stands (Brown and McDowell 1968). Further evaluations of the 24 plots were concluded in 1976. Results of these studies did not confirm a specific pathogen as the causal agent; however, several important observations were mace. Decline symptoms appeared at approximately age 50, but lateral and fine root deterioration preceded the presence of foliage symptoms of decline. *Heterobasidion annosum* (Fr.) Bref. and *P. cinnamomi* were recovered from some of the plots but annosum root disease and littleleaf disease were not implicated as the primary cause of the decline. The conclusions from the evaluation and follow-up study indicated reductions in growth of loblolly pine by age 50 and that site conditions and a combination of other interactions caused the decline and mortality. Recommendations were to reduce rotation age of loblolly pine from 70 to 60 years on these sites, maintain a basal area of 60 to 70 ft^2 per acre, and convert these stands to longleaf pine (Loomis 1976).

For the past 15 years, the Oakmulgee Ranger District has converted an average of 1,000 acres per year of these sites to longleaf pine, but there are approximately 40,000 acres of loblolly pine decline/dieback sites remaining. These sites have an estimated loss of 12 mmbf per year due to mortality and reduced growth. There are an additional 10,000 to 20,000 acres of similar sites and conditions on the Shoal Creek and Talladega Ranger Districts.

The National Forests in Alabama have recognized that the complexity of managing these sites within the scope of ecosystem management, wildlife habitat needs, and enhanced regulatory compliance has greatly affected their ability to restore the desired future conditions consistent with sustainable ecosystems. Forest Health Protection, Alexandria Field Office: Southern Research Station, Tree Root Biology Unit in Athens, GA, and National Forests in Alabama implemented a field evaluation of four compartments on the Oakmulgee Ranger District in May 1998. This paper presents the results of the field evaluation and discusses biological limitations present on these decline sites.

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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METHODS

Oakmulgee Ranger District personnel selected four compartments that included five stands representing a range of loblolly decline/dieback symptoms. The five stands represented 135 acres on which 15 randomly placed 1 0-factor prism plots were established. The three dominant/co-dominant symptomatic trees nearest plot center were selected for root sampling and data collection. Two primary lateral roots were excavated from each tree for fine root and lateral root samples. Root samples were put in plastic baggies and placed in an ice chest for transport to laboratories for isolation of pathogenic fungi. Additional root samples were collected from two stands by pushing over six trees with a dozer. Random samples were taken from the whole root mass of these trees.

Data were collected in each plot and included tree measurements, site information, and soil profiles. Species, diameter at breast height (d.b.h.), age, 5- and IO-year growth increments were collected from each of the root-sampled trees. Site descriptions included pine basal area and total basal area (IO-factor prism), and a soil profile description.

Pythiaceous Fungal Assay

Isolations and identifications of pythiaceous fungi were conducted at Louisiana State University Agriculture Center. Portions of the 225 pine feeder root samples were cut into 1-cm pieces, surface sterilized in a 10 percent commercial bleach, 10 percent 95 percent ETOH and 80 percent H_2O for 1 minute, and rinsed with distilled water. Ten l-cm root pieces per plot sample were plated on the following selective media: PARPH medium (Pimaricin 5 mg; Sodium Ampicillin 250 mg; Rifampicin 10 mg in 1 ml DMSO; PCNB 25 mg in 5 ml of 95 percent ETOH; Hymexazol 50 mg of 70 percent WP), which is selective'for *P. cinnamomi,* and PV medium (Vancomycin 300 mg/1; Pimaricin 0.4 mls of 2.5 percent SOLN/1 ; PCNB 25 mg in 5 ml 95 percent ETOH), which is selective for *Pythium* species.

Leptographium and *H.* annosum Isolations

The primary lateral root samples were transported to the Tree Root Biology Laboratory in Athens, GA to determine the presence of *H. annosum* and *Leptographium* species.

Lateral woody root samples from each plot ranged from 2 to 6 cm in diameter. The root samples were cut into IO-cm long segments and surface sterilized by dipping in 95 percent ethanol followed by brief flaming. The outer bark was then removed and pieces of root wood from each sample were plated onto 1.25 percent malt extract agar (12.5 g malt extract broth and 17 g agar per L of distilled water) or 1.25 percent malt extract agar amended with 200 ppm cycloheximide. The latter medium is selective for Ophiostomoid fungi. Plates were left to incubate on a laboratory bench at 22 °C for approximately 10 days or until fungal growth was observed. Ophiostomoid fungal presence was recorded after viewing cultures growing on either medium under a stereomicroscope.

Soil Profile

A soil profile was described at the center of each of the 15 plots (Art Goddard, Soil Scientist for the NF's in Alabama). The profiles were established by coring with a 3-in. diameter bucket auger down to 60 in. (National Cooperative Soil Sampling Standards). Soil color description were compared to the Munsell color charts.

Soil Analysis

One-pt soil samples were collected from the top 12 in. of each profile core from the 15 plots. Air dried and screened (4-mm mesh), soil samples were then sent to a commercial soil testing laboratory (A&L Analytical Laboratories in Memphis, TN) for nutrient analysis.

Histology of Fine Root Pieces

Random samples of unwashed fine roots were taken from each plot and placed in formalin/acetic acid/alcohol fixative (FAA) and left for 14 days (Sass 1951). Fixed root specimens were cut to 1 to 3 mm, dehydrated in an alcohol series, embedded in paraffin, and sliced into 7- to-10 μm transverse sections. Slides were stained with a variety of schedules, including Papanicolaou's hemotoxylin-eosin or an acid-Schiff procedure (Hass 1980). Stained sections were then observed under a compound microscope and evaluated for signs of abnormalities.

RESULTS

The average range of (d.b.h.) for the trees sampled were 9.1 to 14.3 in. (table 1). The stand age for the four compartments ranged from 43 to 56 years. Stand density ranged from 37 to 55 ft^2. for pine and total basal area ranged from 40 to 57 ft^2. The average 5-year growth increment for these sites ranged from 8 to 10 mm and 10 year growth was 16 to 20 mm.

Table l-Range of growth and age

Stand data/averaged by compartments	Average d.b.h.	Age	Growth increment 5 years	Growth increment 10 years	Basal area (10 factor)	Basal area Total
	---- Inches ----		------ mm ------		----- Sq. ft. -----	
C-20, stands 29 & 25	9.1	43	10	19	55	55
C-l 37, stand 6	13.2	58	8	16	43	50
C-125, stand 10	13.1	51	9	19	45	45
C-l 26, stand 28	14.3	53	10	20	37	40

Table 2-Recovery of pathogenic fungi from root samples by plot and soil series

Comp/plot #	Soil series	*Pythium* spp.	P. cinnamomi	*Leptographium* Yes	*Leptographium* No
		- - - - - - - - - *Percent*	- - - - - - - - -		
C-20/plot 1	Smithdale, fine sandy loam	70	10		X
C-20/plot 2	Smithdale, fine sandy loam	40	10		X
C-20/plot 3	Saffell, gravelly sandy loam	85	40		X
C-20/plot 4	Maubila, sandy loam	55	35		X
C-l 37/plot 1	Smithdale, fine sandy loam	50	20	X	
C-l 37/plot 2	Smithdale, fine sandy loam	45	30	X	
C-l 37/plot 3	Smithdale, fine sandy loam	70	25	X	
C-l 25/plot 1	Suffolk, fine sandy loam	50	25	X	
C-l 25/plot 2	Troup, loamy sand	10	20	X	
C-l 25/plot 3	Troup, loamy sand	30	10	X	
C-l 25/plot 4	Saffell, gravelly sandy loam	20	40		X
C-l 26/Plot 1	Maubila, sandy loam	60	50	X	
C-l 26/plot 2	Luverne, fine sandy loam	60	10		X
C-l 26/plot 3	Smithdale, fine sandy loam	70	40		X
C-l 26/plot 4	Luveme, fine sandy loam	90	20		X

Pythium species were isolated from 54 percent of root samples (range 10 to 90 percent). ***Phytophthora cinnamomi*** was recovered from 10 to 50 percent of the root samples with an average of 26 percent. ***Pythium*** spp. and *P. cinnamomi* were recovered from root samples in all plots (table 2).

Leptographium spp. were recovered from 7 of the 15 plot:;, or 47 percent. No evidence of *H.* ***annosum*** was found in any of the root samples, nor were any fruiting bodies of the fungus found during the **field** survey.

The soil profile descriptions identified six soil series with Smithdale fine sandy loam comprising 40 percent of the plots. The other soil series identified on the plots were Maubila sandy loam, Troup loamy sand, Saffell gravelly sandy loam, and Luverne fine sandy loam. Each of these soil series comprised 13 percent of the plots, with the Suffolk fine sandy loam found on one plot (table 2).

Smithdale, Maubila, Luverne, and Suffolk are described a!; well-drained to moderately well-drained soils with moderaie to slow permeability, with clay loam or sandy clay loam within 10 to 20 in. of the surface. Troup and Saffell are excessively drained to well-drained soils with moderate permeability. 1 hey are deep loamy sands or gravelly sandy loams without a clay component near the surface.

Compared to agricultural soils, the soil analysis revealed that 73 percent of the plots were very low in potassium (K), calcium (Ca), and sodium (Na). All plots except for those vrith the Troup loamy sand were low in Ca. Some of the plots were also low in manganese (Mn) and zinc (Zn). All of these val Jes were within the expected range for forest soils of these types. The **pH** ranged from 4.6 to 5.2.

The histology of the 95 fine roots that were sectioned found that 13 were dead and 12 had large necrotic zones. Six root samples had one or more dead resin ducts. The range in root mortality observed among plots was 0 to 30 percent.

DISCUSSION

This study confirmed the conditions found in the evaluations during the 1960's and 70's. The sparse crowns, reduced radial growth, deterioration of fine roots, decline, and mortality by age 50 are conditions that have prevailed on these sites. These symptoms are most commonly associated with littleleaf disease of shortleaf pine. Littleleaf has been reported to affect **loblolly** pine (Campbell and **Copeland** 1954, **Lorio** 1966, Oak and Tainter 1988). Loblolly pine affected with littleleaf symptoms are found most frequently on sites where the disease has been particularly severe on shortleaf (Campbell and **Copeland** 1954). Littleleaf was first detected in central Alabama in the early 1900's and by 1940 littleleaf occurrence was widespread in Alabama, South Carolina, and Georgia and was causing serious limitations to sustained management of shortleaf pine in the upper Coastal Plain of Alabama (Tainter and Baker **1996),** including the Oakmulgee Ranger District (Johnson 1947).

Littleleaf disease symptoms result from nitrogen deficiency in the trees and are characterized by the death of new root tips and fine roots. Although *P. cinnamomi* is considered the primary pathogen, other factors, such as poor aeration, low fertility, and periodic moisture stress, are also damaging to fine roots. Zoospores of *Phytophthora cinnamomi* are the putative agents of infection and are produced only under conditions of abundant moisture. High soil moisture associated with poor internal soil drainage is common on littleleaf sites. *Phytophthora cinnamomi* is pathogenic to many plants other than pine and is commonly found in the absence of pine. It can also be present in pine stands without causing littleleaf disease. *Phytophthora cinnamomi* is more commonly associated with eroded lands, and severity of littleleaf disease increases as the internal drainage and site index decreases. Cultivation of soils has been shown to hasten the decline of littleleaf disease trees. However, the development of littleleaf disease symptoms in healthy trees has been delayed, and improvement in the conditions of trees in the early stages of the disease has been obtained with soil applications of inorganic nitrogen (Campbell and Copeland 1954).

Pythium spp. have also been reported to be associated with littleleaf disease sites (Otrosina and Marx 1975) and with loblolly pine decline (Lorio 1966). *Pythium* spp. have a life cycle similar to *Phytophthora* spp. and are most commonly associated with damping-off (Tainter 1997).

In determining whether littleleaf disease is a primary consideration in the decline of loblolly pine on the Oakmulgee Ranger District, two site factors are important. These are the internal drainage of soils and the isolation factors of *P. cinnamomi/Pythium* spp. from the fine roots.

The Oakmulgee Ranger District soils having clay loam close to the surface horizon and exhibiting slow to moderate permeability generally maintain high moisture content and would favor *Pythium/Phytophthora* fungal populations (table 3). The Troup and Saffell soils are described as deep, well-drained loamy soils without a clay component and moderate permeability. However, the absence of an A horizon, low soil fertility, and evidence of a plow layer on some sites indicate that these areas were heavily farmed prior to planting of pines. The Oakmulgee Ranger District soils are located in the upper Gulf Coastal Plain province and the soil series descriptions do not generally indicate high risk sites for littleleaf disease; however, the agricultural history and it's effect on soil nutrients and permeability may explain the occurrence of littleleaf disease.

Isolations and detection procedures for pythiaceous fungi have become more efficient since the early surveys of the Oakmulgee Ranger District sites in the 60's and 70's. Quantitative methods of soil dilutions for propagule counts and soil population assays have been developed. The use of selective media to isolate *P. cinnamomi* and *Pythium* spp. from necrotic root tips more accurately relates fine root mortality associated with the pathogens (Tainter and Baker 1996). The isolations of *Pythium* spp. and *P. cinnamomi* from the survey (table 2) in general show a greater concentration of *Pythium* spp. than of *P. cinnamomi* in the fine roots. *Phytophthora cinnamomi* is considered the primary pathogen, as the fungus attacks and quickly kills only the succulent root tips of the pine host.

Leptographium species have been associated with conifer mortality, primarily as associates of root-feeding bark beetles (Scolytidae) and weevils (Curculionidae) that attack living trees. Some of the *Leptographium* species are weak pathogens and further damage roots already damaged by insects. Pines respond to this damage by producing resin, and *Leptographium* spp. are most often recovered from these resin-soaked tissues and may exacerbate the damage by inducing further resin production (Harrington and Wingfield 1997). Because of these characteristics, these fungi may serve as indicators of site stress and predispose infected trees to attack by southern pine beetle (*Dendroctonus frontalis*, Zimmerman) and other agents (Otrosina and others 1997).

Histology studies indicate that a high proportion of loblolly pine roots are in poor condition or are dead. Death of resin canals is unusual in loblolly pine roots but can indicate root damage.

CONCLUSIONS

Phytophthora cinnamomi and *Pythium* spp. appear to be the primary pathogens associated with the deterioration of loblolly fine root systems. This, coupled with the restricted internal drainage of the soils as a result of past agricultural practices within the historical range of littleleaf disease and the extensive planting of loblolly pine to recover these sites indicate that littleleaf disease is the primary cause of the loblolly decline symptom and mortality on the Oakmulgee Ranger District. Bulk density test of the soils and foliar analysis of symptomatic trees for nitrogen deficiency would be helpful to confirm this diagnosis.

Table 3—Soil series descriptions relative to recovery of root pathogens

Soil series	Range of *Pythium*	Range of *Phytophthora*	*Leptographium* spp. Yes	No
	------- Percent -------			
Smithdale FSL	40-70	10-40	X	
Suffolk FSL	50	25	X	
Maubila SL	55-60	35-50	X	
Luverne	60-90	10-20		X
Saffell GSL	20-85	40		X
Troup LS	10-30	10-20	X	

The *Leptographium* spp. recovered from the larger root systems exacerbate the decline of the loblolly stands. Declining stands can be more susceptible to southern pine beetle attacks.

MANAGEMENT OPTIONS

Maintain Loblolly as a Short Rotation Crop

- Age 50 is the recommended rotation age on the decline sites.
- Use periodic salvage/sanitation cuts of symptomatic trees until stands reach rotation age.
- Convert to longleaf pine management type upon final harvest at age 50.

Accelerate Conversion of Loblolly to Longleaf Management Within IO-15 Year Planning Cycle

- Convert 7 to 10 percent per year of loblolly decline sites to longleaf pine management.
- Select most severely damaged stands as a priority for conversion.

Disease Abatement/Conversion by Condition Class

Inventory the remaining 40,000 acres of decline sites and classify by age class and condition class.

Schedule harvest and conversion based on stand age a id condition class.

Stands in age classes 40 and older with a condition class of sparse, damaged, or diseased are high risk sites and should be given first priority for management conversion to longleaf pine.

Second priority should be poletimber stands of age classes 25 to 40 having some symptomatic trees. Most of these stands will already have some fine root damage due to littleleaf disease but may not be showing advanced symptoms or mortality. Use a fertilization program to reduce disease impact and extend rotation age beyond age 50 for RCW habitat management.

Stands in age classes 15-25, use standard silvicultural practices of prescribed burning and thinnings to maintain stand vigor.

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INFLUENCE OF HARVEST DATE AND SILVICULTURAL PRACTICES ON THE ABUNDANCE AND IMPACT OF PINE REPRODUCTION WEEVILS IN WESTERN GULF LOBLOLLY PINE PLANTATIONS[1]

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Abstract-Populations of the pales weevil (*Hylobius pales* Herbst)) and pitch-eating weevil (*Pachylobius picivorus* (Germar)) and/or weevil-caused pine seedling mortality were monitored in the Western Gulf Region on 36 loblolly pine (*Pinus taeda* L.) plantation sites in 1997 and 26 sites in 1993. Data also were collected for 15 site parameters on each site. Pales weevils generally emerged first and numbers peaked in late March, whereas pitch-eating weevil numbers peaked later in mid-April. Weevil-caused pine seedling mortality averaged 9.5 percent in 1997 and 17.9 percent in 1998. Only pales weevil numbers in March showed significant correlations with subsequent weevil-caused seedling mortality in both 1997 and 1998. Of the 15 site parameters evaluated, harvest to April 1 interval and site preparation intensity appeared to have the most influence on the extent of weevil-caused seedling mortality. Seedling mortality from weevils increased dramatically on sites harvested after October of the previous year, but decreased with increasing site preparation intensity.

INTRODUCTION

Pine reproduction weevils, primarily pales weevil, *Hylobius pales* (Herbst), and pitch-eating weevil, *Pachylobius picivorus* (Germar), are important pests of pine seedlings in the southern United States (Peirson 1921). Adult weevils, attracted to recently-harvested pine sites, feed on the bark and phloem of newly-planted pines, often completely girdling the seedlings. These weevils are capable of reducing first-year pine seedling survival by 40-90 percent (Thatcher 1960, Walstad and Nord 1975).

With increased cutting and replanting of pines in the South, concern has resurfaced over the accompanying increase in seedling losses due to reproduction weevils. Weevil-caused pine seedling mortality has been reported to be dependent on the period of the year that a site is harvested (Cade and others 1981, Doggett and others 1977). Damage can be reduced if planting is delayed for 8-12 months after cutting (Doggett and others 1977, Thatcher 1960). However, for economic reasons, delayed replanting is not acceptable to forest managers who generally observe a policy of promptly replanting after cutting.

There is wide variation in the occurrence of weevil activity on different sites. Foresters representing the Texas Forest Service and several forest industries with land holdings in the Western Gulf Region indicate that seedling mortality due to weevil feeding has been exceptionally light in Texas and Louisiana (personal communications with D.M.G.). However, the fact that survival of spring-planted seedlings is frequently not checked until late fall suggests that the actual seedling mortality due to weevil feeding in Texas and Louisiana may not be fully recognized. Seedlings which die early (spring or early summer) often shed their bark by fall, obscuring any signs of weevil damage. As a result, seedling mortality may be attributed to other factors, such as disease or drought.

In 1996, a study was conducted having the following objectives: 1) to determine the abundance and impact, if any, of reproduction weevils on pine seedling survival in the Western Gulf Region: 2) to determine if a correlation exists between numbers of weevils captured in pit traps and subsequent pine seedling mortality: and 3) to determine the extent to which different site parameters influence the impact of pine reproduction weevils on seedling survival.

SITES

The study was conducted in east Texas, west Louisiana, and southwest Arkansas. In 1996, 18 pine plantations, harvested between June and December, 1995, were selected in Harrison, Nacogdoches, Jasper, and Newton Counties, TX to monitor weevil populations. In 1997 and 1998, 36 pine plantations and 26 plantations, respectively, were selected to monitor weevil populations and/or evaluate the impact of weevils and other mortality factors on first-year pine seedling survival. Sites selected in 1997 were harvested between January, 1996 and March, 1997 and had been treated prior to planting with one of five commonly used site preparation methods (no site preparation (IO), burn only (4), shear only (IO), shear and bed (8), and 4 • shear and subsoil (4)). Plantations selected in 1998 were located in east Texas (north to Upshur Co., south to Hardin Co., east to Newton Co., and west to Walker Co.) and harvested between June, 1997 and March, 1998. Site preparations on these sites included 15 with no site preparation, 4 raked and piled, 2 sheared only, and 5 sheared and burned.

PROCEDURES

Three pit traps, as described by Rieske and Raffa (1991), were set up in each of 18 (in 1996), 10 (in 1997) and 9 (in 1998) plantation sites, all in east Texas, between January and March of a given year. A distance of at least two chains (132 ft) separated each trap. All traps contained fresh pine bolts and an insecticide strip and were baited with a 5:1 mix of ethanol and turpentine. Traps were reset every 2-8 weeks and captured weevils were collected and identified after 1 week.

Once each site was planted in 1997 and 1998, a survey of 100 marked pine seedlings (10 evenly spaced plots, each containing 10 flagged seedlings) was conducted monthly

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(March through November) in 1997 and three times (May, July, and November) in 1998 to determine the percent mortality attributed to weevils and other causes.

Data on various site parameters were collected for each site in 1997 and 1998 and included: 1) pine species composition prior to harvest, 2) pine basal area prior to harvest, 3) hardwood basal area prior to harvest, 4) harvest dates (or interval), 5) acres harvested, 6) acres clear cut or thinned within a 1 mile radius of the site, 7) site index at 25 years, 8) soil type, 9) volume of pine timber harvested per acre, 10) site preparation intensity (no site preparation, low, medium, or high), 11) site preparation date, 12) planting date, 13) duration of seedling storage, 14) type of planting (hand vs. machine), 15) stocking level of replant. Regression analysis was used to determine if a relationships existed between site parameters and weevil-caused pine seedling mortality and weevil trap catch and weevil-caused pine seedling mortality.

RESULTS AND DISCUSSION

Weevil Abundance

The seasonal abundance of pales weevil and pitch-eating weevil on sampled sites in the Western Gulf Region is shown in Figure IA and 1B, respectively. Peak trap catch for both species was somewhat variable depending on the year. Generally, pales weevils emerged first in January, peaked between early and late March, and became scarce by June or July. In contrast, pitch-eating weevils began emerging in February, peaked in April or May, but then remained fairly abundant through August. The species ratio of total trap catch numbers was near 1:1 in 1996. However, by 1998, pales weevil numbers had more than doubled to about 15 weevils per trap per day and the species ratio had shifted to 2:1 in favor of pales. The progressively higher numbers of pales weevil captured in 1997 and 1998 may be attributed in part to two consecutive warm winters (1996197 and 1997/98), which may have increased pales weevil larvae and adult survival compared to that of pitch-eating weevil.

Relation Between Weevil Abundance and Weevil-caused Seedling Mortality

Significant relationships were discovered in both March 1997 and March 1998 between the number of pales weevils captured in pit traps and the final percentage of weevil-caused seedling mortality on replanted sites (table 1). Other significant relationships also were discovered for pales and pitch-eating weevils in April, May and/or June. Unfortunately, no significant relationships were found in February when a trap-based monitoring tool would be most useful operationally to predict weevil damage later in the year.

Weevil Impact

In 1997, total pine seedling mortality on the 36 sites averaged 23.9 percent with a range of 0 to 71 percent. Weevils and improper planting were the major causes. Losses to weevils averaged 9.5 percent (range: 0 to 45 percent) while improper planting accounted for average losses of 5.4 percent (range: 0 to 41 percent) (fig. 2). One. fourth of the monitored sites had >20 percent weevil-caused pine seedling mortality. Other causes (combination of drought, flood, and unknown) accounted for an average loss of 8.9 percent. First-year loblolly pine seedling mortality in 1998 was considerably higher than in 1997. Total mortality on the 28 monitored sites averaged 71 .1 percent with a range of 5 to 92 percent. Drought and weevils were the major causes of mortality, accounting for 33.1 percent (range: 2 to 83 percent) and 21.6 percent (range: 0 to 65 percent), respectively (fig. 2). Forty-two percent of the sites had >20 percent weevil-caused pine seedling mortality. Other causes (combination of improper planting, disease, and unknown) accounted for an average loss of 14.1 percent.

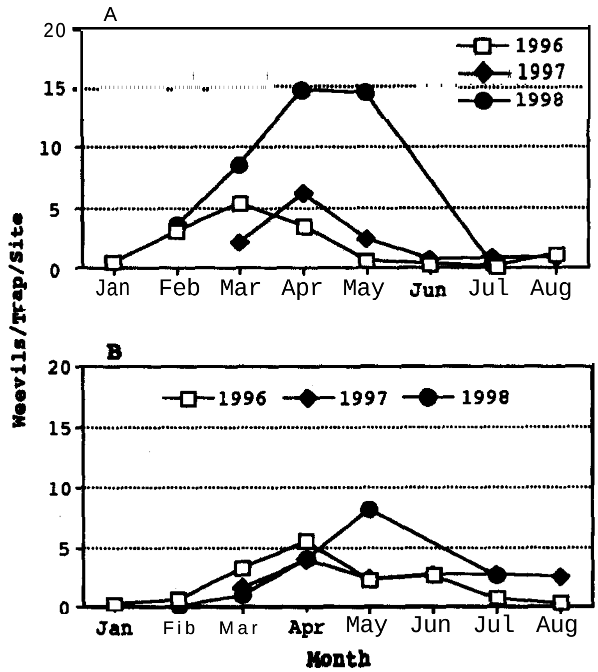

Figure I-Seasonal abundance of A) pales and B) pitch-eating weevils captured in baited pit traps from 1996 through 1996.

Table I-Relationships between the number of pales and pitchsatlng weevils captured in pit traps and percent weevil-caused pine seedling mortality

	Pales		Pitch-eating	
Month	1997	1998	1997	1998
February	—	NS	—	—
March	*a	•	NS	NS
April	NS	*	NS	NS
May	NS	•	*•	•
June	NS	—	*	—
July	NS	NS	NS	NS
August	NS	—	NS	—

NS = not significant.
a = significant relation at the 5 percent level.

Influence of Site Parameters on Impact of Weevils

Regression analysis revealed that only two site parameters (harvest to April 1 interval and site preparation intensity) that significantly influenced the extent of weevil-caused pine

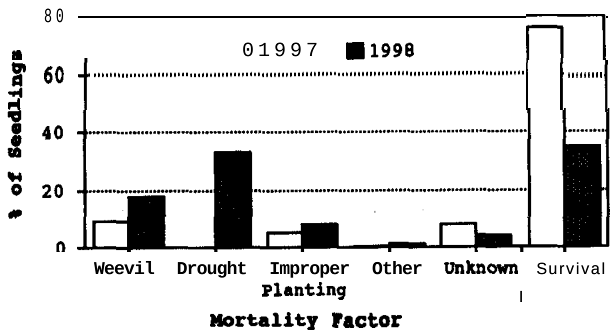

Figure P-First-year **loblolly** pine mortality and survival on plantation sites in 1997 (N = 36) and 1998 (N = 26). Percent mortality by all factors plus survival equals 100 percent.

seedling mortality in the Western Gulf Region in both 1997 and 1998 (table 2). Both parameters appeared to equally influence weevil impact in a given year. However, each parameter explained less of the variability in weevil-caused seedling mortality in 1998 compared to 1997. The occurrence of a severe drought in 1998 may have reduced the influence of these two parameters on weevil-caused pine seedling mortality.

CONCLUSIONS

This study showed that pine reproduction weevils are abundant in the Western Gulf Region and can have a significant impact on first-year pine seedling survival. Nearly one-third of all sites monitored in 1997 and 1998 experienced >20 percent weevil-caused pine seedling mortality. Of 15 site parameters evaluated, harvest to April 1 interval and site preparation intensity appeared to most influence the level of weevil-caused pine seedling mortality. Based on the results of this study, graphs illustrating potential risk of weevil damage were developed (fig. 3A and 3B). Moderate to high seedling mortality (20 - 65 percent) due to weevils alone is likely on planted sites harvested the previous November through January and having no site preparation. Low to moderate mortality (0 - 30 percent) can be expected on sites harvested between August and October of the previous year, harvested in February and March of the replanting year, and having low to moderate intensity site preparation, i.e., rake, windrow, bum, or shear. Sites harvested between April and July of the previous year are at low risk (0 - 10 percent) to weevil damage. Essentially no damage is expected on sites harvested prior to April of the previous year or having high intensity site preparation, i.e., bedding or subsoil methods. (fig. 3B). However, caution needs to be taken when assessing the risk on sites harvested in February and March of the replanting year as only 3 sites were monitored in this study. Additional sites (not just those harvested in February or March) need to be monitored to strengthen the risk rating system for the Western Gulf Region.

The significant correlation between the number of pales weevil captured in pit traps in March and the percentage of weevil-caused pine seedling mortality suggests the possibility that monitoring weevil populations early in the spring may allow prediction of weevil damage later in the year. Additional trapping studies conducted in the fall of the previous year and early the following year (January - March) are needed to develop such a predictive tool.

Table 2—Relationships between 15 slte parameters and percent weevil-caused pine seedling mortality in 1997 and 1998

	1997		1998	
Site parameter	r^2	P value	r^2	P value
Pine spp. composition prior to harvest	0.027	0.3388	0.014	0.5614
Pine basal area prior to harvest	.019	.4272	.027	.4363
Hardwood basal area prior to harvest	.170	.0125	.147	.0589
Harvest - April 1 interval	.368	.0001	.186	.0280
Acres harvested within site	.114	.0437	.000	.9184
Acres clear cut or thinned within 1 mile of site	.017	.4551	.174	.0959
Site index at 25 years	.008	.6124	.102	.1117
Soil type	.116	.0417	.013	.5738
Volume of pine harvested per acre	.099	.0616	.179	.0352
Site preparation intensity	.391	.0001	.218	.0161
Site preparation - April 1 interval	.312	.0004	.094	.1271
Planting date	.017	.4544	.000	.9332
Duration of seedling storage	.008	.6013	.005	.7680
Planting method (hand or machine)	.001	.8857	.143	.0566
Stocking level of replant	,003	.7491	.117	.0870

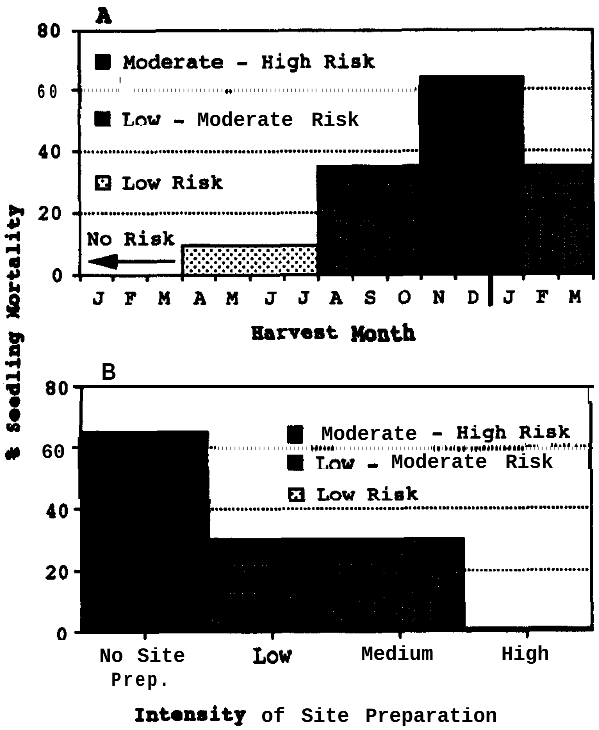

Figure 3—Risk of weevil-caused pine seedling mortality based on A) harvest date and B) site preparation intensity.

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SOUTHERN CONE RUST: A GROWING PROBLEM IN NEED OF ATTENTION?[1]

E.L. Barnard and T. Miller[2]

Abstract-Southern cone rust, caused by the fungus *Cronartium strobilinum* (Arth) Hedgc. & Hahn causes hypertrophy and abortion of first-year female strobili on slash (*Pinus elliottii* Engelm.), south Florida slash (*P. elliottii* var. *densa* Little and Dorman), and longleaf (*P. Palustris* Mill.) pines in the Atlantic and Gulf Coastal Plains of the deep southern United States. Occurrence of this disease has been historically errs tic and unpredictable and typically characterized by several years of zero to negligible infections punctuated by occasional, single years of abundant infections. For the past six years, southern cone rust has occurred at or above near epidemic levels in parts of Florida, presumably due in part to local climatic conditions. Cone and seed losses in slash pine seed orchards in Florida, southern Alabama, and southern Georgia have been estimated to exceed 50 percent in recent years. Control, if attempted, is currently based on outdated fungicide protocols that are of questionable efficacy. What is being done? What can be done? How does this disease respond to climate change? Are tree improvement programs taking into account genetic variation in susceptibility to this often overlooked disease? Do seed orchard managers need more information . . . new tools?

INTRODUCTION: THE DISEASE AND THE DAMAGE IT CAUSES

Southern cone rust, caused by the fungus *Cronartium strobilinum* (Arth) Hedgc. & Hahn sporadically causes serious losses of first-year female strobili on slash (*Pinus elliottii* Engelm.), south Florida slash (*P. elliottii* var. *densa* Little and Dorman), and longleaf (P. *Palustris* Mill.) pines in the Atlantic and Gulf Coastal Plains of the deep southern United States. Infected conelets (i.e., fertilized first-year cones) typically swell rapidly, abort, and drop from trees by mid to late summer, but some hypertrophied red-brown to brown, somewhat shriveled "mummies" may cling to trees for longer periods (Goolsby and others 1972, Hedgcock and Hahn 1922, Hepting and Matthews 1970, Maloy and Matthews 1960, Matthews 1964, Miller 1987). C. *strobilinum* is a macrocyclic, heteroecious rust fungus (Hawksworth and others 1995) and has a complex, two-host life cycle (fig. 1) analogous to that of the fusiform rust fungus, C. *quercuum* (Berk.) Miyabe ex Shirai f. sp. fusiforme (Hedgc. and N. Hunt) Bundsall and G. Snow.

Historical estimates of cone (and subsequently seed) losses directly attributable to southern cone rust infections have ranged from 20 to nearly 100 percent in certain areas (Goolsby and others 1972, Hedgecock and Hahn 1922, Hepting and Matthews 1970, Maloy and Matthews 1960). Actual losses of about 24 percent were observed in a slash pine seed orchard in north Florida in 1980 (Fatzinger and others, 1992). Losses in another slash pine seed orchard in north central Florida were very high in 1993, 1994, and 1995 (estimated > 75 percent in 1995 by Barnard and others, unpublished field observations). Barnard and others (1996) reported actual losses of approximately 20 percent in this same seed orchard in 1996, with individual clonal losses varying from about 9 percent to nearly 46 percent. This clonal variation parallels that recorded by Fatzinger and others (personal communication) in a 1980 outbreak of cone rust in a slash pine seed orchard in north Florida (i.e., 3.5 to 36.2 percent) and could be of considerable importance to forest and seed orchard managers.

Losses attributable to southern cone rust infections may not be restricted to those directly resulting from conelet infections. Merkel (1958), Miller (1987), and Dixon and others (1991) have noted that pine coneworms (*Dioryctria* spp.), especially the south coastal coneworm (D. *ebeli* Matuura and Monroe), often preferentially infest infected conelets. If unchecked, these cone/seed-damaging insects can build up populations on rust-infected conelets, with subsequent generations attacking uninfected first- and second-year cones, thus causing even greater losses.

SEED ORCHARD QUESTIONNAIRE

In 1995, a southern cone rust survey questionnaire was circulated to member slash pine seed orchard managers within the University of Florida's Cooperative Forest Genetics Research Program. This questionnaire included the following queries.

-Are you aware of the occurrence of cone rust in your orchard this year?

☐ YES ☐ NO

-The level (incidence) of cone rust in my orchard is:

☐ Non-existent ☐ Worrisome(substantial but not severe)

☐ Incidental (insignificant) ☐ Problematic(serious)

-I would estimate my infection level (percent of conelets infected) at:

☐ < 10 percent ☐ 10-50 percent ☐ > 50 percent

-If possible, from memory or records, please check the years in which you observed or know of higher than normal cone rust infections in your orchard.

☐ 1975 ... ☐ 1995

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-16, 1999.

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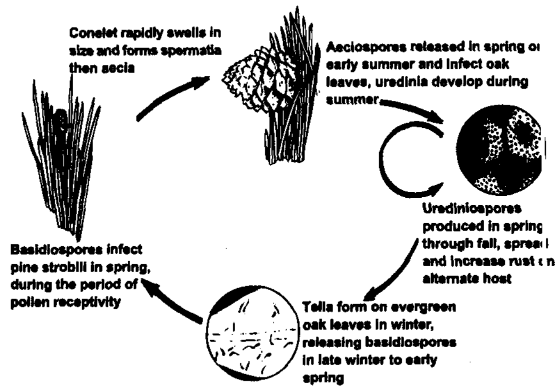

Figure I-Simplified life cycle of *Cronartium strobilinum*, the southern cone rust fungus; from Miller (1987).

A total of eleven responses to the survey was received representing twelve slash pine seed orchards in Florida, southern Georgia, and southern Alabama (fig. 2). All twelve of these seed orchards were reported to have some level of southern cone rust activity in 1995. Three of the responding seed orchard managers described their level of rust infections as worrisome and five described theirs as problematic. None of the seed orchard managers reported any cone rust prior to 1992, and only two managers reported rust activity in 1992. Rust was noted with much greater frequency in 1993 and 1994, and by 1995 eight of twelve seed orchards were reported as having more than 50 percent infection (table 1).

Depending upon the particular management paradigm(s), seed values, etc., pertinent to any given seed orchard, such numbers could certainly be construed as indicative of a problem. It is important to note, however, that estimates of infection obtained through the questionnaire represent crude, from the ground ocular estimates, much like most

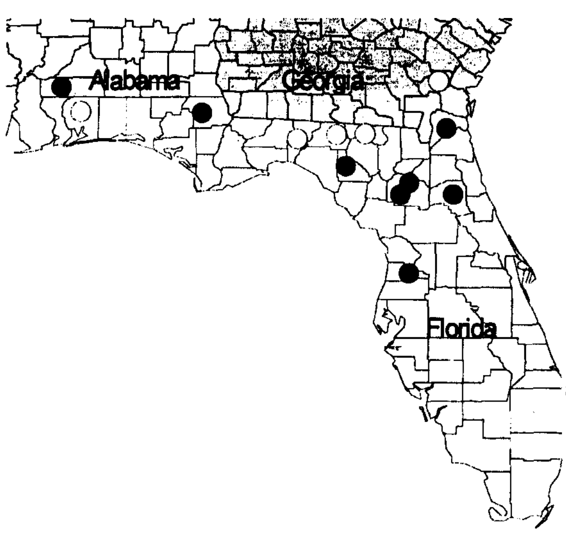

Figure P-Location of slash pine seed orchards reporting via the 1995 southern cone rust survey questionnaire. Orchards indicated by darkened circles reported estimated losses of ≥ 50 percent in 1995.

early literature reports (Goolsby and others 1972, Hedgcock and Hahn 1922, Hepting and Matthews 1970, Maloy and Matthews 1960), not actual percentages based on systematic sampling as provided by Fatzinger and others (1992) and Barnard and others (1996). It is of interest that the latter two infection assessments, 24 percent and 20 percent respectively, are a good deal more conservative than those generally provided by "eyeballing." Indeed, the difficulty of actually seeing small uninfected conelets on large trees from the ground and the distinct prominence of infected conelets (which may mask healthy conelets) renders overestimation of cone rust infection(s) a real possibility.

PERSISTENCE OF THE DISEASE AND WEATHER EXPLANATION(S)?

For reasons quite unknown, southern cone rust has persisted in recent years at what appear to be "above normal" levels, at least in much of north central Florida; a phenomenon possibly reflected in the responses of seed orchard managers to our 1995 questionnaire (table 1.). By persistence we refer to its annual or nearly annual occurrence throughout much of the area as opposed to its putatively sporadic occurrence historically. (Actually records here are scarce to non-existent. These observations capture a good deal of our collective memories). Should these observations be an accurate reflection of reality, the question looms as to why? Well, untested as it is, the second author (Miller) has a theory which is worthy of investigation. He has observed that live oak (*Quercus virginiana* Mill.) leaves infected with C. *strobilinum* are selectively shed when subjected to "hard freezes," therefore putatively breaking the disease cycle (fig. 1) before infection of pine female strobili can occur in the spring. Further field observations could verify the phenomenon and well designed research could provide validation of the theory. Examination of local weather records from north central Florida, over the past two decades provides evidence of warmer temperatures and fewer freezes in the 1990's as opposed to the 1980's (fig. 3). These data together with what we think we know about the recent abundance of cone rust infections are compatible, so far, with the "Miller theory." Again, these relationships are researchable and, if verified, might provide useful prediction models for seed orchard managers interested in controlling or managing the disease.

CONTROLOFSOUTHERNCONERUST

Control of southern cone rust has been reported with appropriately timed spray applications of ferbam fungicides (Hepting and Matthews 1979, Lightle 1959, Maloy and Matthews 1960, Matthews 1964), and some seed orchard managers routinely apply ferbam sprays for control of the disease. Unfortunately, it is difficult to nearly impossible to comment with certainty regarding the efficacy of the handful of current operational spray programs. Most fungicide applications are made to entire seed orchards and no controls (i.e., unsprayed areas) are left for comparison. Further, due to the non-systemic, prophylactic mode of action of ferbam, effective control requires repeated applications, perhaps at 5-day intervals for a period of some 25-30 days, commencing as soon as female strobili emerge from their bud scales and continuing until pollination has ended. This is apparently not the common practice of seed orchard managers who actually employ a preventive spray program. Instead, these managers typically rely upon a limited number of applications deployed often in tank mixes

Table 1-Responses to 1995 Southern Cone Rust Questionnaire[a]

Seed orchard location	Awareness (√)[b c] 1992	1993	1994	Estimated cone losses 1995
				Percent
Southern Alabama	–	–	–	>50
Southern Georgia		–	–	<10
Central Florida		√	√	>50
Western Florida	?	?		>50
Western Florida	√	√	3	10-50
Northern Florida				10-50
Northern Florida		√	√	>50
Northern Florida		√	√	>50
Northern Florida	–	√	√	>50
Northern Florida	√	√	–	10-50
Northern Florida		√	√	>50
Northern Florida		√	√	>50

[a] All reports on slash pine.
[b] Observed or know of higher than normal occurrences.
[c] Nothing reported prior to 1992.

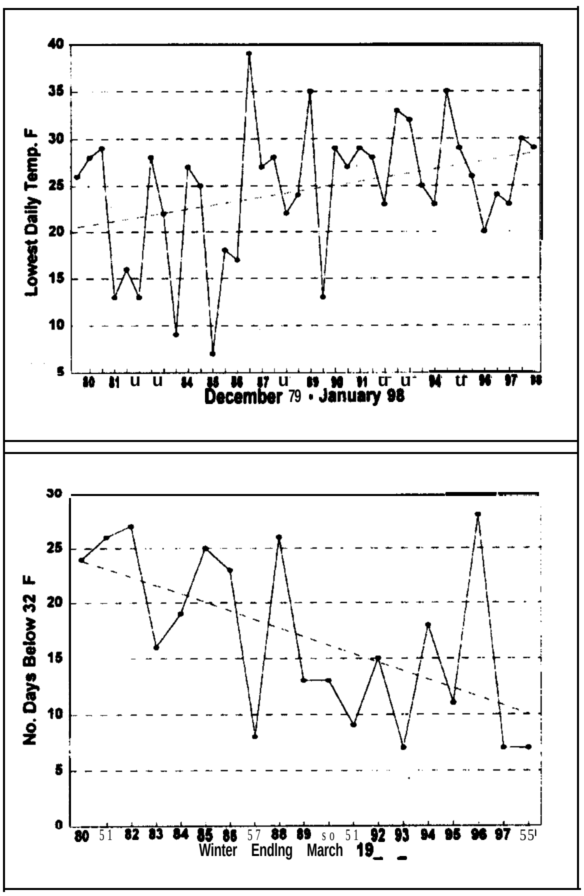

Figure 3-Lowest daily temperatures and numbers of days with temperatures falling below 32°F for winter months from 1980 to 1998 in Lake City, FL. (Source: NOAA)

with certain insecticides to reduce application costs. While these kinds of applications may reduce cone rust infections in certain situations, the overall efficacy of such protection programs is subject to question. Adequate protection with fungicides such as ferbam may require so many applications as to become cost prohibitive.

Since the early 1980's, triadimefon fungicide (Bayleton®, Bayer Corporation) has become the industry standard for controlling fusiform rust, a close relative of southern cone rust, in southern pine nurseries (Carey and Kelley 1993; Kelley 1985; Kelley and Runion 1991; Powers 1984; Rowan 1982; Snow and others 1979). Triadimefon's mode of action is systemic, and to some extent eradicant, as opposed to preventive only; triadimefon controls or eradicates some preexistent infections and prevents new infections. In addition, single low rate applications (for example, 280 grams ai/hectare or 4 ounce ai/ac) of triadimefon provide effective control of fusiform rust in pine seedlings for up to three to four weeks.

In 1996, Barnard and others conducted field trials with aerially applied triadimefon for control of cone rust infections in four north Florida seed orchards (Barnard and others 1996). Results were encouraging, but of limited value due to the non-replicated nature of the trials (three of four seed orchards in which the trial was installed produced no cone rust the year of the trial). There is reason to be optimistic about the possibilities of controlling cone rust in high value seed orchards using triadimefon. Efforts to develop effective fungicide-based controls are justifiable and may become increasingly important in future forest management paradigms.

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DEATH OF ROOT TISSUES IN STANDING [LIVE] AND FELLED LOBLOLLY PINES[1]

Charles H. Walkinshaw[2]

Abstract-Recycling tree root components is important in sustaining the productivity of southern pine forests. Death of outer cortical tissues and mortality of short roots is ubiquitous in conifers. Affected tissues lose their starch grains and accumulate secondary products, such as tannins. In this study, IO-year-old loblolly pine trees were cut at the soil surface and sequential samples of roots were collected, fixed, embedded, and sectioned for light microscopy at monthly intervals. Observations showed roots of felled trees were similar to those of standing controls for approximately 5 months. Indicators of cell and tissue death were the disappearance of starch grains, increased tannin accumulation, and decreased staining of nuclei. This pattern of changes was remarkably similar to that of dying cortical cells. The long period (5 months) afler felling and before the roots die probably has a significant effect on root microflora and the distribution of nutrients from the decomposition of surface woody debris and root systems.

INTRODUCTION

Loss of biomass from the crowns of loblolly pines (*Pinus taeda* L.) is easy to measure (Kozlowski and others 1991; Sampson and others 1998); loss of below-ground biomass can be harder to sample and measure (Kozlowski 1971, Ruark 1993). Death and rate of root decay are important on many reforestation sites where nutrient supply is marginal for seedling establishment and early tree growth. Nutrient cycling is influenced by how quickly root turnover occurs. Death of root cells was reviewed by Coulter as early as 1900 (Eames and MacDaniels 1947). I used ease of peeling the root cortex to assess the condition of primary roots. Smith (1935), Eames and MacDaniels (1947) and Esau (1953) detailed the function of the root cortex and its relationship to secondary growth. Those anatomical descriptions emphasize the complexity of below-ground biomass loss. Moreover, they suggest that microscopical examination is essential for classifying cortical cells as dead. Medical investigators routinely use a number of cellular traits to determine cell death (Ellis and others 1991, Robbins 1987). Emphasis is placed on the condition of the nucleus when standardized stain schedules are applied to sections of tissue. I applied such schedules to pine root tissues.

My objective was to devise quantitative measurements of cell traits that would precisely define root cell death. After accomplishing this, ceil death was induced by tree felling and studied in detail. These two approaches provided a quantitative method for studying below-ground biomass in loblolly pine roots.

SITES

Observations to select methods and cellular traits were made on roots from young (5 to 10 years) loblolly pine stands in the Palustris Experimental Forest (Louisiana), the Homochitto National Forest (Mississippi), and in a Forest Service planting near Laurinburg, NC. A total of 5,478 roots were sectioned and stained for light microscopy.

Experiments to induce root-cell death were conducted in the Palustris Experimental Forest. Treatments imposed in a IO-year-old loblolly pine study area included: (1) a control (no treatment), (2) felling in February and May 1994, (3) girdling at breast height, and (4) pruning lower limbs (leaving the top 1/3 of crown). Root anatomy of 10 trees each of the control and those that were felled in February and May (treatment 2) was evaluated each month for 8 months. Treatments 3 and 4 were applied in May and sampled only 5 months following treatment.

PROCEDURES

Roots were sampled 1 m from the stem to a 20-cm depth for 8 to 10 trees at each site (Walkinshaw 1995). A cross-section of each root <1 cm in diameter was excised and placed unwashed into formalin-acetic acid-alcohol (FAA) (Sass 1951). After 2 to 4 weeks, roots were rinsed with 70 percent ethyl alcohol. Specimens were cut to 1 to 3 mm, dehydrated in ethyl alcohol series, embedded in paraffin and cut into 7- to 10-μm sections. Two or three sections that contained 9 to 18 roots from a single tree were mounted on a slide. Nine slides were prepared for each tree. Several staining schedules were used on root sections during the observation phase: acid fuchsin, Congo red, Giemsa, Groett's methenamine, safranin-aniline blue, toluidine blue, hematoxylin-eosin, Papanicolaou's schedule, and an acid-Schiff schedule (Haas 1980). Only the last three were used during the experimental phase. Root traits were scored as proportions or as real values. Papanicolaou's schedule was read for two slides with two or three sets of roots per slide. I used hematoxylin-eosin stain to verify nuclear viability in cells. Starch and tannin deposits were confirmed using an acid-Schiff schedule (Walkinshaw and Tiaras 1998). Cell traits used as dependent variables in the treatment evaluations are listed in table 1.

RESULTS

Initial Observations

Shedding of the root cortex was first indicated in a large number of cells, distributed at random, by the breakdown of starch grains. Nuclei with changed stain affinity were prominent in most parenchyma and cortical ray cells. Cytoplasm became condensed to a small volume in the cortical cell periphery. These cells appeared net-like with primary cell walls held to each other and to the thin residual of living cortical cells. Nuclear staining as a measure of loss of vitality indicated that death of the cortex shed occurs after the loss of starch grains (Greenberg 1997).

The proportion of roots with shedding was high in collections from 5- and IO-year-old trees in the Palustris Experimental

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

[2] Emeritus Scientist, USDA Forest Service, Southern Research Station, Pineville, LA 71360.

Table l-Cell traits used to evaluate root viability in loblolly pine

Trait	Description
Abnormal cambium	Cambial initials reduced in number or out of alignment. Necrotic derivations present.
Cortex shedding	Cortical cells dead and remain attached or are released into the soil.
Dead root	Cells with ruptured membranes. Tannin adheres to cell walls. Chromatin abnormal. Starch grains may or may not be present.
Nuclear stain	Degeneration (pyknosis) of **chromatin.** Altered staining throughout the tissues.
Number of	Number of starch-containing plastids per cell viewed at a single focus per cell length at 100 to 500 diameters.
Root diameter	Actual measurement of roots less than 3 mm. Estimates for larger roots. Diameter includes attached shed.
Size of	Size of starch grains scored as **1, 2,** or 3 for each cell. Range in actual size was 0.5 to 4.0 microns.
Starch use	Starch grains 50 percent or more degraded.
Tannin	Accumulation of tannin-containing cells in the cortex, rays and inner xylem. Number of cells with accumulation cl 0 to **>1** 000.

Forest (table 2); I collected root samples in the fall on two sites there. The biomass loss in shed material was 65 to '75 percent of the root as determined by light microscopy.

Mycorrhizal short roots died during cortex shedding. Tannin accumulated at their base and sealed the torn end of the dead short root. New lateral roots often emerged from the dead mycorrhizal short roots.

Table 2—Incidence of shedding in roots of plantation-grown loblolly pines on different sites

Number of roots sectioned	Proportion of roots with cortical shedding
111	0.90 ± 0.06
120	.78 ± .09
126	.80 ± .16
132	.70 ± .12
119	.69 ± .14
112	.73 ± .16

Starch grain degradation varied from 0 to 100 percent in cortical cells of loblolly pine roots (table 3). Values were low for the younger **5-year-old** trees and widely different in collections from IO-year-old trees.

Table 3-Variation in use of starch grains in the root cortex in loblolly pines[a]

Number of roots	Proportion of roots with starch utilization
101	0.93
122	.76
079	.41
064	.33
264	.17
258	.01

[a] Largest two samples of roots were taken from B-year-old trees. Other samples were from IO-year-old trees.

Experimental

An analysis of variance (ANOVA) procedure using "month after felling" as class gave a probability of p = 0.0001 for each dependent variable. Tukey's studentized range test (Snedecor 1956) indicated significance when comparisons were made of 5-month means and 0-, I-, 3- and 4-month means, respectively. Means for traits and treatments 5 months after felling are given in table 4. A plot of abnormal nuclei and dead roots 6 months after felling is given in figure 1. Means for other traits from 0 to 6 months after felling are given in figures 2 and 3.

DISCUSSION

Initial Observations

The cortical shedding in roots from felled loblolly pines appears to involve about 75 percent of the primary root biomass. Some of the biomass may be lost with the gradual disappearance of starch grains. Abnormal staining of chromatin in the nucleus indicated depletion of energy and death of the cortical cells. Cell mortality in the formation of shed material was unusual for the low incidence of tannin that accumulated. Wounds in the cortex were unusually few and microbial invasion of cells in the shed material was

Table 4-Cellular traits In sectioned roots sampled flve months after installing treatments

Trait	Fell 2/94	Fell 5/94	Girdle	Prune	Control
	Percent of roots				
Nuclei	50.0	40.0	9.0	2.0	0.0
Starch grain (no.)	1.0	2.4	5.2	4.0	10.2
Size of starch	30.0	0.6	1.5	1.2	2.3
Starch use		10.0	30.0	1.2	76.0
Tannin X 5	70:o	60.0	50.0	20.0	26.0
Cambium dam.	40.0	30.0	0.0	0.0	0.0

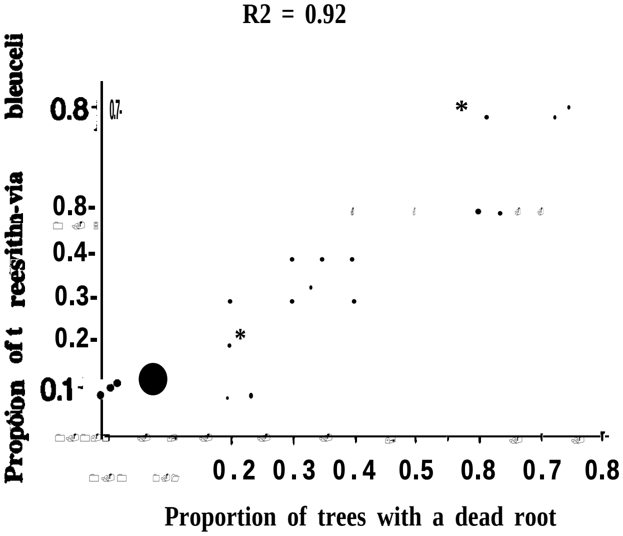

Figure l-Relationship between nuclear condition and dead roots 5 months after felling.

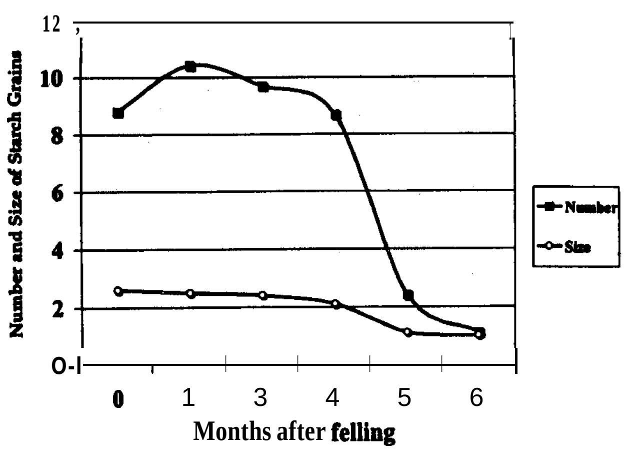

Figure P-Effect of felling on number and size of starch grains in cortical cells.

Root death was characterized by depletion of starch, abnormal staining of nuclei, and alteration of tannin deposits. Tannin was released from cell vacuoles and increased protein alteration. In roots of felled trees, the appearance of cortical cells after 5 and 6 months was similar to that of cells of cortex shed. Both conditions suggest nutrient starvation. In trees girdled or pruned, root anatomy did not differ from that of the control.

delayed until they were nearly devoid of cytoplasm. These events can be compared to shedding of above-ground plant parts (Kozlowski 1973). Although mycorrhizal root death and shedding occurred simultaneously, considerable tannin accumulated at the base of these short roots. This suggests a more active process than occurred in shed cells. Mycorrhizal roots are not connected to vascular tissue.

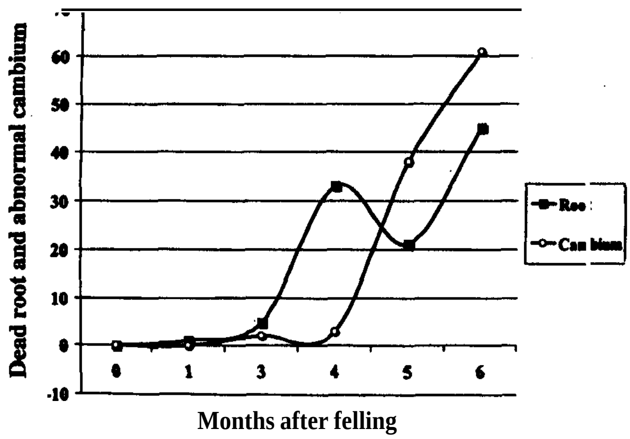

Figure 3—Delayed response of loblolly pine roots to felling.

Lateral roots form only when nuclear division occurs in the vascular zone (Smith and Read 1997); they are, therefore, only temporary structures in the below-ground biomass (Kozlowski 1971).

Experimental

Death of root cells in felled trees occurred in a sequence that has been described for other plant and animal cells (Ellis and others 1991, Greenberg 1997, Robbins 1987). Ample evidence shows that nuclear staining is a reliable indicator of cell death. In pine roots, nuclei are relatively large (8 μm) and easy to classify as active (bright red), quiescent (bluish purple), and dead (gray with black). Abnormal nuclei appeared in large numbers 5 months afler felling. This signaled root death.

Microscopical light observations have focused on anatomical details in only a few specimens (Eames and MacDaniels 1947, Esau 1953, Kozlowski and others 1991). This study considered thousands of observations and compared variables and means by standard statistical analysis. When the means of dependent variables were plotted, plot trends were apparent over time. However, the data taken over time are not independent and should be considered with caution. The easiest variable to quantify microscopically was the number of starch grains per cell. However, as cell death approached (5 months after felling), starch grains became so depleted that counts had to be made at 500 diameters. By contrast, nuclei were the same size or had enlarged before death occurred.

Often, silviculturists and pathologists consider below-ground tissue death to occur when trees are felled. However, Bormann (1981) showed that eastern white pine (*Pinus strobus* L.) trees that were not root grafted to intact standing trees were alive one growing season following cutting. Because trees in this study were young, extensive root grafting had not likely occurred (Kozlowski 1971). Three to four months after felling, the roots (small to large) from felled trees were not anatomically different from untreated controls. Pathogenic and saprophytic organisms might increase significantly in roots of freshly felled trees, but unless there is significant root grafting there should be little effect on standing trees. Stand density and tree age may also affect root interaction with microorganisms and the degree of root deterioration, but we did not measure those variables.

CONCLUSIONS

Death of cortical cells and mycorrhizae during the shedding process can cause a loss of 75 percent of the primary root biomass. A lot of starch grains are broken down during shedding, a process that can be reproduced by root starvation resulting from removal of above-ground tissues. Of the variables evaluated, disappearance of starch grains and abnormal nuclei staining are the most reliable when monitoring cell death. Roots of felled trees lived 4 months or longer. The extended life of a felled tree's roots probably will significantly affect microflora. The distribution of nutrients from extended root decay following harvest may affect nutrient availability for forest regeneration.

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MANAGING FORESTS FOR GYPSY MOTH (*LYMANTRIA DISPAR* L.) USING SILVICULTURE: TESTING THE EFFECTIVENESS OF SILVICULTURAL TREATMENTS IN REDUCING DEFOLIATION AND MORTALITY[1]

Kurt W. Gottschalk, Rose-Marie Muzika, and Mark J. Twery[2]

Poster Summary

Invasion of eastern forests by the exotic insect, gypsy moth (Lymantria dispar L.), has resulted in widespread defoliation and subsequent tree mortality. Disturbance from these factors varies widely across the landscape; some stands have little or no mortality while other stands have almost complete mortality. With average mortality rates of 25 to 35 percent, silvicultural treatments have been proposed as an alternative to insect suppression treatments to minimize gypsy moth effects. Study objectives were: 1) to evaluate the effectiveness of two silvicultural treatments (presalvage and sanitation thinnings) in minimizing gypsy moth effects on forests; and 2) to determine the mechanisms involved in silviculture-gypsy moth interactions. Only the first objective will be addressed in this presentation. Sanitation thinnings have as their primary objective to reduce the susceptibility of the stand to gypsy moth defoliation. The thinning treatment achieves this objective through manipulation of the specks composition, reducing the preferred host composition of mixed stands to 20 percent or less of the basal area. Presalvage thinnings have as their primary objective to reduce the vulnerability of the stand to gypsy moth-related mortality. The thinning treatment achieves this objective by removing trees with higher probabilities of mortality if defoliated (low crown vigor trees) and retaining trees with lower probabilities of mortality if defoliated (high crown vigor trees).

Four replicates of each thinning and adjacent unthinned treatment stands were installed prior to gypsy moth defoliation. Six of 16 stands were defoliated for 2 years by gypsy moth. Three years after defoliation ended, mortality was evaluated. Host preference class had a significant effect on defoliation patterns but thinning did not. Mortality was strongly influenced by defoliation patterns and by thinning. Thinning and defoliation had a significant interaction: in undefoliated stands, thinning had no effect on mortality, but in defoliated stands, it reduced mortality. Defoliated sanitation thinnings did not have a significant effect on either defoliation or mortality, but thinned stands did have lower mortality rates. Defoliated presalvage thinnings had significantly lower mortality rates than unthinned stands. These results support the use of silvicultural treatments prior to gypsy moth defoliation to minimize gypsy moth effects on tree mortality.

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-16, 1999.

[2] Research Forester, USDA Forest Service, Northeastern Research Station, Morgantown, WV; Assistant Professor, University of Missouri, Columbia, MO; and Research Forester, USDA Forest Service, Northeastern Research Station, Burlington, VT, respectively.

Landscape Management

Moderator:

JIM GULDIN
USDA Forest Service
Southern Research Station

OPERATIONAL SILVICULTURAL RESEARCH: THE FUTURE OF SILVICULTURAL RESEARCH?'

Richard F. Fisher[2]

In the spirit of the meeting's theme "Silvicultural Research-A Retrospective," the following invited paper proposes future processes of scientific research.

Silvicultural research has always been hampered by its lack of statistical soundness. We seldom have enough replications to avoid failing to find significant differences that actually do exist. We almost never replicate adequately across the population to which we wish to refer. These two problems are linked, and they arise due to technical rather than intellectual difficulties.

It is physically difficult to apply silvicultural practices to small plots, and the extent of tree roots allows trees to "sample" treatments that are some distance from the tree. This leads to silvicultural research requiring very large treatment plots. Finding sites on which to install experiments is difficult, and applying a variety of treatments at a site is expensive. We frequently install several replicates at the same site to save time and money. The large area required for these replicates and their cost generally argues for establishing only a few replicates - say three. This sets the stage for failure.

In the first place, three replicates may well be too few to handle the natural variation that we will encounter. This leads us to conclude that there are no differences when in fact there might be differences. Too frequently we report that there was "a trend but it was not significant". This ignores the fact that the statistical analysis has just told us that the apparent difference could quite likely be due to error! In other words, there is no difference given the variation we have encountered. We could investigate whether our experiment was adequate to find differences by using the variance that we have now determined to calculate how many replicates we would need to find a true difference, but we seldom do.

Secondly, expedience has led us to conduct our experiment at one site. We really want to say things about all similar sites and not just this one site, but we can't. We have failed to replicate across all similar sites, and what we have, if we refer to all similar sites, is pseudo-replication. Of course, you'll say, "how can I replicate across all similar sites when it is so difficult and expensive to install treatments". The answer is Operational Silvicultural Research - OSR, because we need our own acronym.

What is OSR? OSR = Operational Treatment + Plot + GPS + GIS + knowledge need + GIS + GPS + Data Collection + Analysis. It's not as complicated as it looks. Many similar sites receive different operational treatments every year. One simply needs to permanently establish a plot at each site to which one has access. This can easily be done by placing an iron rod in the ground, recording the exact location of that rod with a geographic positioning system (GPS), and recording the number of rows and the number of trees in a row necessary to make a 1/10 or 1/5 acre plot. This data is then transferred into your geographic information system (GIS) and stored for future use.

When this is done, our database is greatly expanded by the GIS multiplier. There is a great deal of information, e.g. soil type, planting method, plant stock, site preparation treatment, previous stand data, etc., already stored in the GIS and that data is now related to our plot. We now have a large number of "treatments" and we have gained a lot of supporting variables that could be used as covariates in future analyses. We have also dramatically increase the utility of our GIS!

When a need for knowledge of the influence of a particular silvicultural procedure arises, we return to the GIS and search for similar sites on which that and alternative procedures were performed at approximately the same time. We identify a subset of sites that can be measured in order to evaluate the procedure in question, these from our replicates. It is not important that the different procedures (treatments) do not occur on the same site, because we wish to generalize to all similar sites and therefore the variance between sites needs to be encompassed by our data set.

We now visit the various sites. We find the sites and the plots by using the known coordinates of the site and plot and our GPS. In order to find the exact plot corner, we use a metal detector to find the iron rod marking the known plot corner. We establish the plot from the row and tree data in the GIS, and we make the appropriate measurements for testing to determine the differential influence of the procedure in question.

Now we have data form replicates that truly represent the population of interest. If all things are equal, our analysis of the data will be simple and straightforward. If, however, a number of parameters vary from plot to plot, we will need to resort to covariate analysis in order to control for these differences. With modern statistical packages, this is a simple matter.

For some questions, we don't even need the pre-established plot. We can simply search the GIS for appropriate site for getting data to answer our question. Necessary information

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-16, 1999.

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such as initial planting density should be recorded in the GIS database.

What if we don't have enough replicates for our analysis? This is where cooperation comes into play. One might "borrow" plots form another land manager. Better yet, why not create a collective or cooperative? This would be a very low cost option, because there are no plots to install or maintain, and the co-op only swings into action when there is a question. This would also allow cooperators who have not carried out a particular practice to benefit from the experience of others.

Of course, OSR has its drawbacks. There may not be enough replicates to carry out a useful analysis. Certainly new or novel practices are unlikely to be sufficiently replicated in operational forestry. However, there's a mountain of knowledge in the forest that could be used to improve management if we only took advantage of it.

OSR is not a new concept. It is a form of statistical process control applied to the forest rather than to the plant. Mills have used a system of collecting data on many parameters and relating it to product quality for years. When quality is down they check to see which parameters are out of specification, and they adjust them to return to acceptable product quality.

It is true that the forest system is far more complex and variable than the plant system. That doesn't mean that with modem technology such as GPS, GIS, and SAS?, SPSS? or Sistat? we can't deal effectively with that complexity and variation. In fact, if we are to attain sustainable, higher yields at competitive costs, and protect the environment we must deal with them.

In this case, most of the technical work has been done for us. GPS, GIS and SAS? or other powerful, easy to use statistical analysis packages are already in place. The former model of silvicultural research was limited by technical difficulties. OSR is limited by intellectual difficulties, which are certainly cheaper if not easier to overcome.

LANDSCAPE ECOSYSTEM CLASSIFICATION ON THE CHEROKEE NATIONAL FOREST - PHASE 2[1]

Michelle A. Boyd and John C. Rennie[2]

Abstract-Successional vegetation was identified in each of two age classes (21-40 and 61-80 years old) based on sampling in 72 stands. Six seral communities were identified in the 21-40 age class: 1) Chestnut Oak-Red Maple-Virginia Pine, 2) Virginia Pine, 3) Mixed Pine, 4) White Pine-Tulip Poplar, 5) White Pine-Tulip Poplar-Mixed Oak understory, and 6) Hickory-Mixed Oak. Terrain shape index, landform index, slope position, and elevation were the site variables that contributed most to the classification. The communities identified in the 61-80 age class were: 1) Red Maple-Scarlet Oak-Yellow Pine, 2) Chestnut Oak-Hickory, 3) Red Maple-Mixed Oak, 4) Hemlock-Mixed Oak, 5) Hemlock-Hickory, and 6) Red Maple-Hickory-Tulip Poplar. The site variables that contributed most to the classification for this age class were landform index, and elevation. Successional trends were described based on the ranges of the site variables for each seral community and for the site units from a previous study using relatively undisturbed stands.

INTRODUCTION

As forests are managed for a wider array of products and amenities, management techniques must change from those aimed at single products to techniques that are more versatile. Classification of land is an essential step in management. Landscape Ecosystem Classification (LEC) is an ecologically-based approach to classification that can be used with a wide range of forest resources. LEC integrates landform, soil, and vegetation to identify ecologically equivalent sites (site units) and to provide information for multiple-use resource management decisions (Jones and Lloyd 1993).

The development of an LEC model involves four phases: Phase 1 - Identification of ecologically equivalent site units from relatively undisturbed vegetation; Phase 2 - Identification of seral communities in disturbed stands and subsequent comparison of this seral vegetation with vegetation in site units delineated in Phase 1; Phase 3 - Mapping of site units utilizing ground surveys and a geographical information system (GIS); and Phase 4 - Development of management strategies utilizing site unit attributes such as growth and yield, species composition, and successional trends.

PREVIOUS WORK

Development of a landscape ecosystem classification on the Tellico Ranger District of the Cherokee National Forest was started in 1992 under an agreement between the USDA Forest Service, Southeastern Forest Experiment Station and the University of Tennessee. Based on geologic formations, two areas were identified for study: the Foothills section (from 305 to 610 m in elevation) and the Mountain Highlands section (more than 610 m).

Phase 1 for the Foothills section was completed in 1994 (Yoke and Rennie 1996). Phase 1 for the Mountain Highlands was completed in 1996 (West and Rennie 1998). Results from Phase 1 consisted of models to predict site units (vegetation communities) from soil and site variables that could be measured in the field. Phase 1 work was based on data collected in older (>80 years), relatively undisturbed stands.

The goal of the study described here was to complete Phase 2 of the LEC for the Foothills section. Phase 2 was conducted in younger stands where more disturbance was expected. Vegetation was characterized in stands selected over a range of soil and site variables identified in Phase 1 to describe seral vegetation by site unit.

STUDY SITE

The study area was located in the southern unit of the Cherokee National Forest. Specifically, sampling was conducted within the Foothills section (22,800 hectare) of the Tellico Ranger District in Monroe County, Tennessee.

The climate of Monroe County is characterized by warm summers, mild winters and abundant precipitation. Soils are primarily channery silt loams and silt loams of the Ranger-Citico-Fletcher association. Most of the soils belong to the Ranger series (USDA 1981).

The USDA Forest Service acquired the majority of the Cherokee National Forest during the 1920's and 30's. The land had been heavily logged except for the most inaccessible stands. Past cutting is evidenced in the age class distribution of stands (USDA Forest Service 1996). Fifty-six percent of the stands in the Tellico Ranger District were between 61 and 80 years old. Another 18 percent were between 81 and 90 years old. Thus, 74 percent of the Tellico Ranger District was cut over between the early 1900's and the 1930's.

FIELD METHODS

The initial goal of this study was to sample stands from four age classes: 1) O-20 years, 2) 21-40 years, 3) 41-60 years, and 4) 61-80 years. Although 10 percent of the stands were younger than 20 years old, the vegetation was not suitable for the methods used in this study. Further, because only 3 percent of the stands in the District are in the 41 to 60 age range, an adequate sample did not exist (CISC data 1996).

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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Thus, stands were sampled from the two remaining age classes, 21-40 years and 61-80 years.

Within each of the two age classes, four plots were located in each of the eight combinations of slope position and aspect: upper side slopes, middle side slopes, lower side slopes and coves, and aspect: northerly (315-135 degrees) or southerly (136-314 degrees). The ninth category was ridges. This resulted in 72 plots.

Data were obtained from one set of nested plots per stand (fig. 1)(Yoke and Rennie 1996). Crown coverage by species was measured for three strata - 1) canopy trees, 2) saplings and tall shrubs, and 3) regeneration and low shrubs. Only relative dominance was estimated using a modification of Daubenmire's (1959) coverage classes-for the herb and vine stratum.

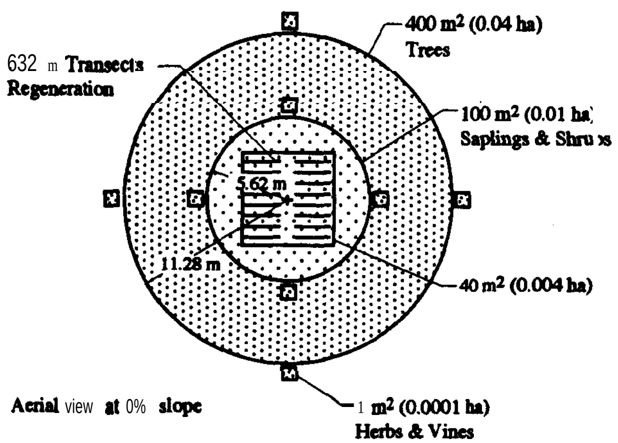

Figure l-Arrangement and sizes of plots used to sample vegetation for Phase 2 in Foothills section, Cherokee National Forest.

Six site variables were recorded at each plot: aspect, slope gradient, elevation, slope position, landform index (LI) (McNab 1993), and terrain shape index (TSI) (McNab 1989).

DATA ANALYSIS

Relative dominance by species was determined from crown coverage in each stratum. Relative density by species was calculated from the number of stems per plot for each stratum except the herb and vine stratum. These were used to calculate Importance Value 200 [(relative dominance+relative density)xlOO] for each stratum except the herb and vine layer where Importance Value 100 (relative dominancex100) was calculated.

Ordination and cluster analysis were performed on each age class matrix to delineate clusters of plots with similar species composition (seral communities). Initially, infrequent species were dropped from analysis, resulting in a final vegetation matrix containing 63 species in the 21-40 age class and 67 species in the 61-80 age class. Indirect gradient analysis was performed using a combination of detrended correspondence analysis (DCA using DECORANA: Hill 1979a), two-way indicator species analysis (TWINSPAN: Hill 1979b), and stepwise discriminant analysis (SDA). After DCA determined the position of plots in an ordination space, the subjectivity of seral community delineation based on the distances between points was reduced by assigning the clusters defined by TWINSPAN to each plot. SDA (SAS Institute 1988) was used to relate the site variables and seral communities.

Detrended canonical correspondence analysis (DCCA using CANOCO: ter Braak 1988) was used for direct gradient analysis. Using a combination of ordination and multiple regression, DCCA defines seral communities based on species composition. The variation among seral communities is explained by site variables.

RESULTS AND DISCUSSION

21-40 Age Class

DCA and DCCA resulted in similar patterns of plot distribution. Six seral communities were identified using DCA, in conjunction with TWINSPAN (fig. 2); each is described in detail in Boyd (1997). A great deal of overlap among seral communities is evident, indicating a high degree of species similarity. The length of the hypothetical environmental gradients on the plot ordination diagrams represents the length of the community gradient in units of standard deviation. Within a span of four standard deviations, a species will appear, rise to its mode, and disappear (Gauch 1982). A complete turnover of species is expected in four standard deviations. Plots separated by more than four standard deviations should have no species in common. Whitaker (1975) described this between-habitat diversity as beta diversity. In the plot ordination diagram (fig. 2), Axis 1 has a length of 2.871 standard deviations and Axis 2 has a length of 2.070 standard deviations. The length of each axis is too short for a complete turnover of species. As is evident in Figure 2, there is a great deal of blending among the site units, especially between Seral Communities 2 (Virginia Pine) and 3 (Mixed Pine). The two plots in Seral Community 6 (Hickory and Mixed Oak) lie well within Seral Communities 4 (White Pine-Tulip Poplar) and 5 (White Pine-Tulip Poplar-Mixed Oak understory), respectively.

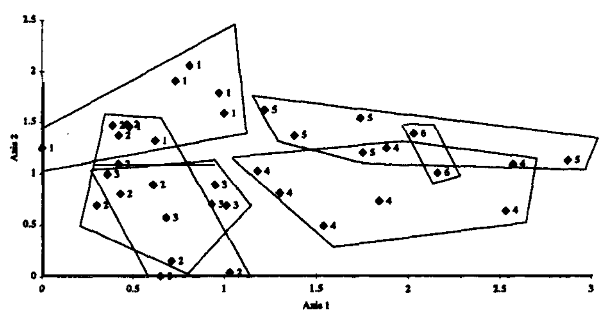

Figure 2—DCA plot ordination diagram for 21-40 age class using DECORANA. Each point represents an individual plot. Number indicates seral community delineated by TWINSPAN: 1=Chestnut Oak-Red Maple-Virginia Pine, 2=Virginia Pine, 3=Mixed Pine, 4=White Pine-Tulip Poplar, 5=White Pine-Tulip Poplar-Mixed Oak understory, 6=Hickory-Mixed Oak. Lines subjectively drawn to represent seral community membership. Based on 36 plots in the Foothills section, Cherokee National Forest.

Table l-Significant site variables selected by **stepwise** discriminant analysis for 21-40 age class in Foothills section, Cherokee National Forest

Site variables	R^2	F	Prob>F
Terrain shape index	0.7072	14.49	0.0001
Slope position	.3277	2.73	.0394
Landform index	.3056	2.55	.0495
Elevation	.2489	1.79	.1488

The hypothetical environmental gradients defined in the DCA plot ordination were related to site variables using SDA. The four variables selected by SDA as significant were TSI, **LI,** slope position, and elevation (table 1).

Variation in species composition among plots in the DCCA analysis is explained by the site variables through correlation coefficients of the site variables with the axes. Four variables were chosen from the six site variables. TSI, LI, and slope position are most highly correlated with Axis 1, whereas elevation is more highly correlated with Axis 2. The results of the DCCA analysis agree with those of the SDA analysis.

61-80 Age Class

DCA in conjunction with TWINSPAN defined six seral communities (fig. 3); each is described in detail in Boyd (1997). Although the seral communities are positioned close together, there is little overlap among seral communities. Thus, seral communities in the 61-80 age class have a greater degree of differentiation because of a lower degree of species similarity than in the 21-40 age class. Although the general pattern of plot distribution on the DCA (fig. 3) and DCCA plot ordination diagrams is similar, there is much more overlap among seral communities on the DCCA plot ordination diagram.

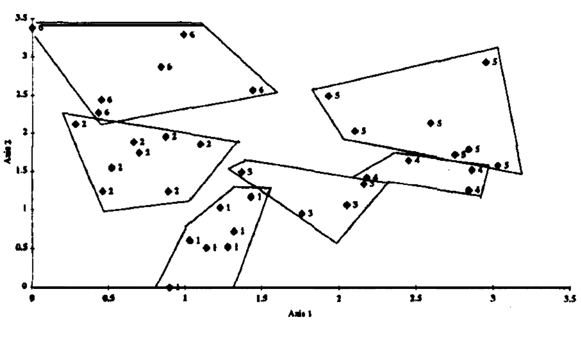

Figure **3—DCA** plot ordination diagram for 61-80 age class using DECORANA. Each point represents an individual plot. Number indicates seral community delineated by TWINSPAN: 1 **=Red** Maple-Scarlet Oak, **2=Chestnut** Oak-Hickory, **3=Red** Maple-Mixed Oak, **4=Hemlock-Mixed** Oak, **5=Hemlock-Hickory, 6=Red Maple-Hickory-**Tulip Poplar. Lines subjectively drawn to represent seral community membership. Based on 36 plots in the Foothills section, Cherokee National Forest.

Table **2—Significant** site variables selected by **stepwise** discriminant analysis for **61-80** age class in Foothills section, Cherokee National Forest

Site variables	R^2	F	Prob>F
Landform index	0.6962	13.75	0.0001
Elevation	.4567	4.87	.0023

When the site variables were related to the hypothetical environmental gradients defined in the DCA plot ordination diagram using SDA, two variables were selected: LI and elevation (table 2).

The site variables identified by DCCA as being correlated with variation in species composition among plots in DCCA were the same as those identified by SDA. LI is more highly correlated with Axis 1, whereas elevation is more highly correlated with Axis 2.

Successional Trends

The Phase 1 study in the Foothill section (Yoke and Rennie 1996) was conducted before it was recognized that the older, relatively undisturbed stands were more remote **and** on steeper land than the stands that had been logged and included in the current study. Therefore, the approach used in Phase 2 by Carter (1994) of employing the Phase 1 model to select younger stands was not feasible. It was necessary to examine the seral communities identified in the **21-40** age class and the 61-80 age class, along with the results of published studies on vegetational succession in the region, to relate the seral communities to the vegetation in each site unit.

For each age class, a model was developed to separate the seral communities using the significant site variables. For the 21-40 age class, Chestnut Oak-Red Maple-Virginia Pine occurred on the more exposed sites **(LI<0.26** and slope **position>50)** at higher elevations **(>475** m), while at the lower elevations **(<475m)** Virginia Pine occurred on the more convex sites (-0.05~TSlc0.01) with the Mixed Pines on the less convex site **(-0.03<TSI<0.01).** On the less exposed sites **(LI>0.26** and slope **position<50),** White Pine-Tulip Poplar occurred on the least concave sites **(0.02<TSI<0.17),** Hickory-Mixed Oak on the most concave sites **(TSI>0.46)** and White Pine-Tulip Poplar-Mixed Oak understory on the sites of intermediate concavity (0.01 **<TSI<0.46).**

For the 61-80 age class at lower elevation **(<457** m), Red Maple-Mixed Oak was found on the more exposed sites **(LI<0.25),** Chestnut Oak-Hickory on sites of intermediate exposure **(0.25<LI<0.35),** and Hemlock-Hickory on the least exposed sites **(LI>0.35).** At higher elevations **(>475m), Red-**Maple-Scarlet Oak-Yellow Pine was found on the more exposed sites **(LI<0.2),** Hemlock-Mixed Oak on the sites of intermediate exposure **(0.2<LI<0.35),** and Red Maple-Hickory-Tulip Poplar on the least exposed sites **(LI>0.35).**

Successional trends across the age classes are identified based on the ranges of the site variables for each seral community from this study and the site units from Yoke and Rennie (1996) (fig. 4). The Red Maple-Scarlet Oak-Yellow Pine seral community in the 61-80 age class is characterized by low landform index values (LI<0.2) and elevation greater than 457 m (1500 ft). Low landform index values indicate relatively unprotected, xeric sites. This seral community is developed from the Chestnut Oak-Red Maple-Virginia Pine seral community of the 21-40 age class, which is also characterized by low landform index values (LI<0.26) and elevation greater than 457 m (1500 ft).

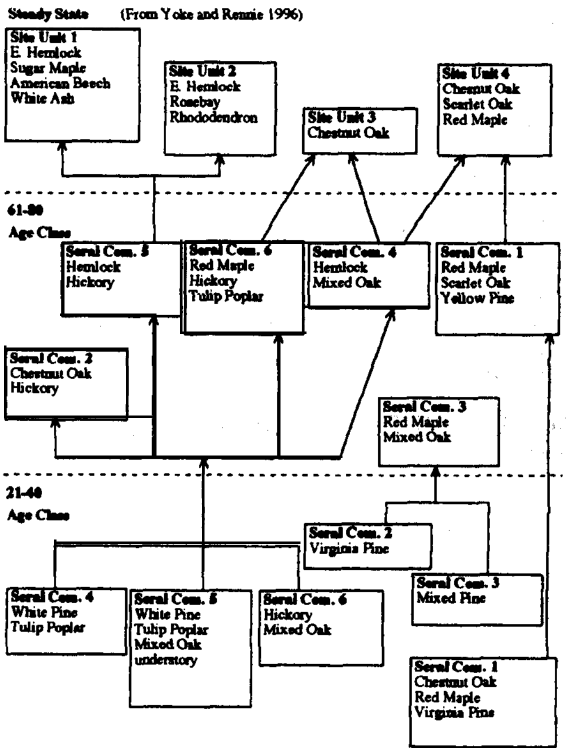

Figure 4—Flowchart of successional trends. Seral communities and site units connected by lines have similar site variable ranges.

The Red Maple-Mixed Oak seral community of the 61-80 age class has low landform index values (LI<0.25) with elevation less than 457 m. The Virginia Pine and Mixed Pine seral communities in the 21-40 age class are the associated successional stages. The Virginia Pine and Mixed Pine are both characterized by low landform index values (LI<0.26) and elevation less than 457 m. Both seral communities also have low terrain shape index ranges. The Virginia Pine seral community is distinguished by more convex-shaped areas with a TSI range from -0.05 to 0.01. The Mixed Pine seral community is characterized by somewhat less convex shape with a TSI range from -0.03 to 0.1. The combination of low LI and TSI values indicate these seral communities occur on unprotected, xeric ridges.

More mesic conditions, indicated by larger landform index values, are associated with Chestnut Oak-Hickory, Hemlock-Hickory, Hemlock-Mixed Oak and Red Maple-Hickory-Tulip Poplar seral communities of the 61-80 age class. They are characterized by LI greater than 0.2. The corresponding seral stages of the 21-40 age class are the White Pine-Tulip Poplar, White Pine-Tulip Poplar-Mixed Oak understory, and Hickory-Mixed Oak seral communities. The younger seral communities are characterized by LI greater than 0.26. They are further distinguished by TSI.

Yoke and Rennie (1996) identified four site units ranging from mesic to xeric. These site units were delineated by elevation and LI. Two mesic site units occurred below 410 m, the Eastern Hemlock-Sugar Maple-American Beech-White Ash (LI>0.55) and Eastern Hemlock-Rosebay Rhododendron (0.55>LI>0.4) site units. The more xeric Chestnut Oak (0.4>LI>0.3) and Chestnut Oak-Scarlet Oak-Red Maple (LI<0.3) occurred above 410 m.

The steady state site units occurring below 410 m and characterized by very high landform index values, are mesic in nature. Of the seral communities defined in the 61-80 age class, the Hemlock-Hickory occurs below 457 m (1500 ft) and has relatively high landform index values (LI>0.35). The Hemlock-Hickory of the 61-80 age class and its associated 21-40 seral communities, the White Pine-Tulip Poplar, White Pine-Tulip Poplar-Mixed Oak understory, and Hickory-Mixed Oak, are potential successional stages leading to the mesic steady state site units.

The Red Maple-Mixed Oak and Chestnut Oak-Hickory seral communities of the 61-80 age class do not correspond to any of the site units identified in Phase 1. These seral communities are characterized by LI less than 0.35 and elevation below 457 m. The low LI indicate that these seral communities occur on unprotected areas such as ridges below 457 m. The lack of a corresponding steady state site unit is most likely an artifact of sampling. Low elevation ridges and upper side slopes are very accessible to logging. Few stands if any are over 80 years of age in these areas.

The Chestnut Oak and Chestnut Oak-Scarlet Oak-Red Maple site units identified in steady state vegetation occur above 410 m and are more xeric in nature. The Chestnut Oak site unit ranges in LI from 0.4 to 0.3. The Red Maple-Hickory-Tulip Poplar seral community of the 61-80 age class occurs above 457 m and has LI greater than 0.35. This seral community and its associated 21-40 seral communities, the White Pine-Tulip Poplar, White Pine-Tulip Poplar-Mixed Oak understory, and Hickory-Mixed Oak, are potential successional stages for the Chestnut Oak site unit. The Chestnut Oak-Scarlet Oak-Red Maple site unit has LI less than 0.3, indicative of unprotected, xeric areas. The Red Maple-Scarlet Oak-Yellow Pine seral community of the 61-80 age class (LI<0.2) and its associated 21-40 seral community, the Chestnut Oak-Red Maple-Virginia Pine, are potential seral stages.

The Hemlock-Mixed Oak seral community identified in the 61-80 age class ranges in LI from 0.2 to 0.35. This range overlaps the LI ranges of the Chestnut Oak and Chestnut Oak-Scarlet Oak-Red Maple site units identified in Phase 1. The Hemlock-Mixed Oak seral community and its corresponding seral communities from the 21-40 age class, the White Pine-Tulip Poplar, White Pine-Tulip Poplar-Mixed Oak understory, and Hickory-Mixed Oak, are potential successional stages for either of the site units identified in Phase 1.

CONCLUSIONS

Although seral communities were identified in the 21-40 and the 61-80 age classes, successional trends to the site units from Phase 1 could not be clearly identified. This was the result of older, relatively undisturbed stands occurring only on steeper or more remote sites, and not distributed over the landscape. This points out that the application of Landscape Ecosystem Classification, with its integration of landform, soil, and vegetation to identify ecologically equivalent sites (site units), is limited to areas with vegetation of all age classes distributed over the full range of site variables.

Researchers and managers developing Landscape Ecosystem Classifications should examine the distribution of vegetation by age classes and site variables over the landscape in the planning stage. Consideration of all four phases in the planning stage will increase the likelihood of developing a working classification.

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PREDICTING THE PROBABILITY OF STAND DISTURBANCE'

Gregory A. Reams and Joseph M. McCollum[2]

Abstract-Forest managers are often interested in identifying and scheduling future stand treatment opportunities. One of the greatest management opportunities is presented following major stand level disturbances that result from natural or anthropogenic forces. Remeasurement data from the Forest Inventory and Analysis (FIA) permanent plot system are used to fit a set of models that predict the probability of harvest for the five FIA survey units of Georgia. We assume a logistic function that establishes asymptotes at 0 and 1. We found that geographic region, ownership, number of trees per acre, and average stand diameter are correlated to the probability of harvest, A plot was considered harvested if any tree > 5 in. d.b.h. was cut. The average probability of harvest over the last 8.5 years was approximately 33 percent for the central and southern regions of Georgia. The average rate of harvesting in northern Georgia was 21 percent. These models can be used to predict the probability of harvest for a set of stand conditions and when combined with area expansion factors, to estimate the acreage of harvested stands.

INTRODUCTION

A study to model disturbance rates resulted from two potential uses. Firstly, the recent move to annual forest inventories by the Forest Inventory and Analysis (FIA) program of the USDA Forest Service, Southern Research Station has raised some interesting questions regarding efficient allocation of sample plots. Specifically, the greatest change in an inventory often occurs in conjunction with major disturbances. A nonexhaustive list of disturbances that can significantly alter an inventory includes harvesting, insects and disease, and wind damage and other weather related events.

In the Southern U.S., harvesting is the largest disturbance and thus, estimating the probability of harvest and comparing the actual rates of disturbance to disturbance detection techniques is a prerequisite for implementation of an inventory based on disturbance detection. Second, and more important to the silvicultural community, is the need to estimate the type and acreage of stands available for site preparation, planting, or other treatment opportunities following harvest. The recently completed seventh forest survey of Georgia (Thompson 1998) provides an ideal opportunity to model harvesting rates.

INVENTORY METHODS

Estimates of change and rates of change were available from the 1997 remeasurement of 5,388 permanent sample plots established in the previous survey in 1989. The plot design for the previous inventory was based on a cluster of 10 points. Variable radius plots were systematically spaced within a single forest condition at three to five points. At each point, trees ≥5.0 in. d.b.h. were selected for measurement on a variable radius plot defined by a 37.5factor prism. Trees < 5.0 in. d.b.h. were tallied on a fixed-radius plot around each plot center.

MODEL DEVELOPMENT

When the dependent variable is an indicator variable, the shape of the response function will often be curvilinear. For our specific application of modeling harvest rates, the response variable is either 1 or 0 depending on whether an inventory plot was harvested or not. An additional necessary requirement is to use a model that has asymptotes at 0 and 1. The logistic function meets all of these prerequisites and has been used to model event probabilities such as individual tree mortality for several decades (Monserud 1976). The general form of the logistic function is:

$$p(h) = \frac{\exp(X)}{1+\exp(X)} + \varepsilon \qquad (1)$$

where

$p(h)$ = the probability of harvest,
$\exp(X)$ = the exponential function e^x,
X = the set of predictor variables, and
ε = the error term.

The probability of harvest is related to many variables, including volume per acre by tree species, size, quantity, and quality of the trees, and the species mix per unit area. The correlation between these potential predictor variables at time 1 (1989 measurement) and harvesting rates at time 2 (1997 measurement) can be easily investigated with FIA's remeasurement data. Other potentially influential variables such as operability, distance to mill, distance to roads or urban populations (Wear and others 1999), and planted versus natural stands are variables that were not included in this study. With the exception of planted versus natural stands, these variables could not be investigated because the variables are either not collected or readily available for analysis. Future studies are planned to investigate the excepted variables.

RESULTS AND DISCUSSION

The logistic regression model (1) was fit to the 1997 FIA remeasurement data for the five survey units (Southeast, Southwest, Central, North Central, and North) of Georgia (fig. 1). A sample plot is considered harvested if any tree (> 5 in. d.b.h. at time 1) was cut. This study does not distinguish levels of cutting and includes the full spectrum of harvesting practices. The average remeasurement interval across the state was 8.5 years. The average tree diameter by species group and number of trees per acre by species group are listed for each of the survey units (table 1).

The fitted coefficients to model (1) for each of the survey regions are listed in table 2. Under each survey unit are

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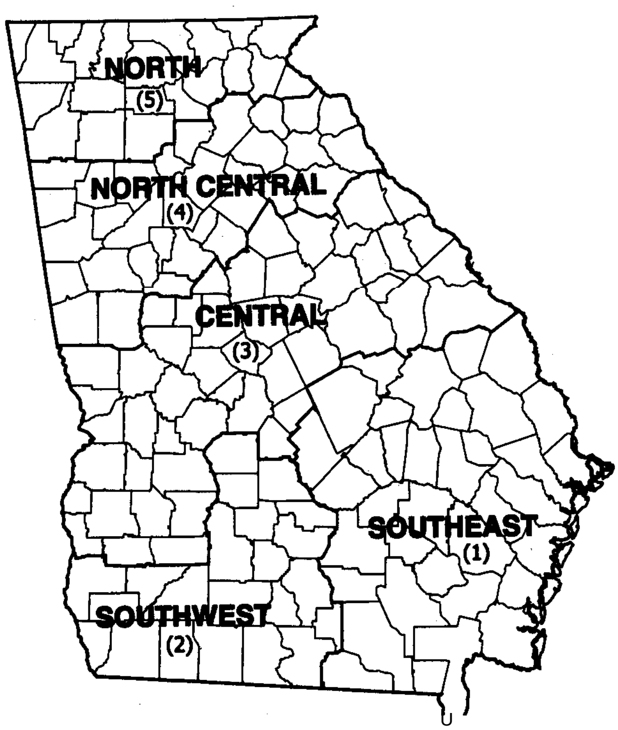

Figure I-The five forest survey regions in Georgia.

forward selection procedure for variable inclusion. Because users desire to differentiate harvest event probabilities by ownership, we retained all ownership variables in the models. With the exception of forest industry (FORCO) lands, nonindustrial private forest (NIPF) lands , and other corporate (CORP) lands, for both the interaction and main effects model in the Northern survey unit and the interaction model in the North Central survey unit, all ownership variables are different from each other at the p = 0.05 level. Forest industry, private nonindustrial, and other corporate lands have harvest rates greater than the government but are not distinguishable from each other.

Other significant variables (p = 0.05) in the models include mean initial stand diameter (d.b.h.), mean initial pine stand diameter (PDBH), mean initial hardwood stand diameter (HDBH), number of initial pine trees per acre (PTPA), number of initial hardwood trees acre (HTPA), and a number of interaction terms (table 1). All mean stand diameter and trees per acre variables are based on sample plots with trees > 5 in. d.b.h. Plots with no trees > 5 in. d.b.h. were excluded from model fitting.

Interpretation of the model coefficients proceeds as follows. Positive coefficients are associated with increased rates of harvest and negative coefficients with decreased rates of harvest. For example, in the main effects model for survey unit **1,** other corporate lands are harvested at higher rates than all other ownership categories (table 2). The variables

Table I-Average tree diameter and numbers of trees per acre for trees >5 inches d.b.h. by species group (all species, hardwoods, and conifers). Plots with no trees >5 Inches d.b.h. were excluded from the analysis. Average d.b.h. and number of trees per acre are based on time 1 measurements (1989). The Georgia survey units are the Southeastern (unit I), Southwestorn (unit 2), Central (unit 3), North Central (unit 4), and Northern (unit 5)

	Survey unit				
	1	2	3	4	5
Mean d.b.h.	11.37	12.18	11.63	11.59	11.18
Mean pine d.b.h.	10.30	11.70	11.26	10.68	11.10
Mean hardwood d.b.h.	12.66	12.69	11.93	12.31	12.30
No. treeslac	161.4	154.8	152.7	164.1	170.6
No. pine treeslac	109.3	79.1	68.6	77.2	62.1
No. hardwood treeslac	72.1	75.7	84.1	86.9	108.5

two models, the first is a main effects model and the second, an interaction effects model. The reason two different models are listed is to illustrate that a main effects model is overly restrictive and does not allow for the non-linear relationship between the predictor variables and predictant (fig. 2 and 3).

We used the logistic regression procedure in Statistical Analysis System (SAS) to fit the models and used the

that are the most difficult to interpret are the interaction terms between an ownership category and a stand level variable, such as PDBH. For example, for Southeastern (unit 1) Georgia there is an important positive interaction between NIPF lands and PDBH. The interpretation of this interaction is that as average pine diameter increases harvest rates accelerate faster on NIPF lands than on other land ownerships.

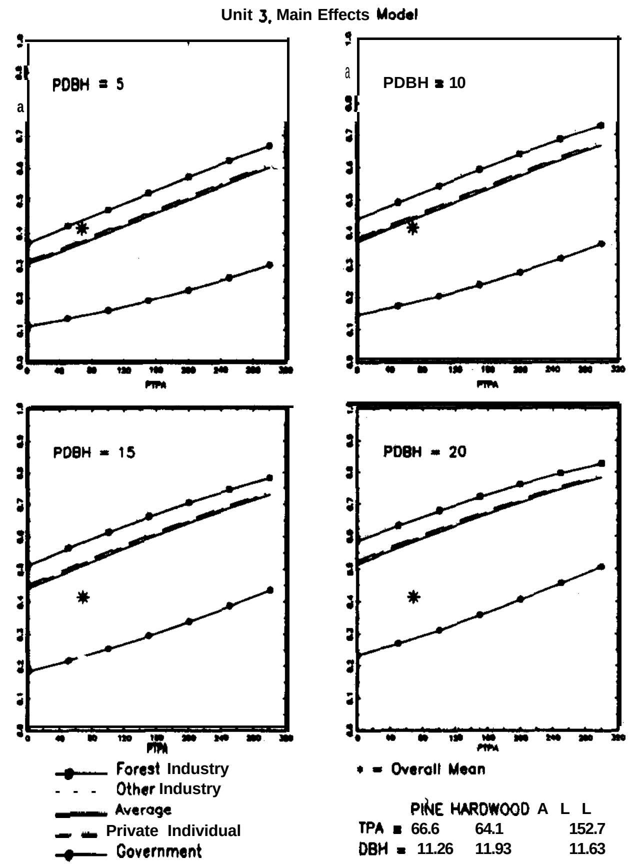

Figure P-The conditional probability of harvest as given by the main effects model for survey unit 3 (Central) Georgia, by average stand pine diameter (trees > 5 in. d.b.h.), number of pine trees/acre (trees > 5 in. d.b.h.), and ownership class. The lower right corner lists the mean sample value for all continuous variables in the model. The asterisk represents the average conditional probability of harvest for the survey unit.

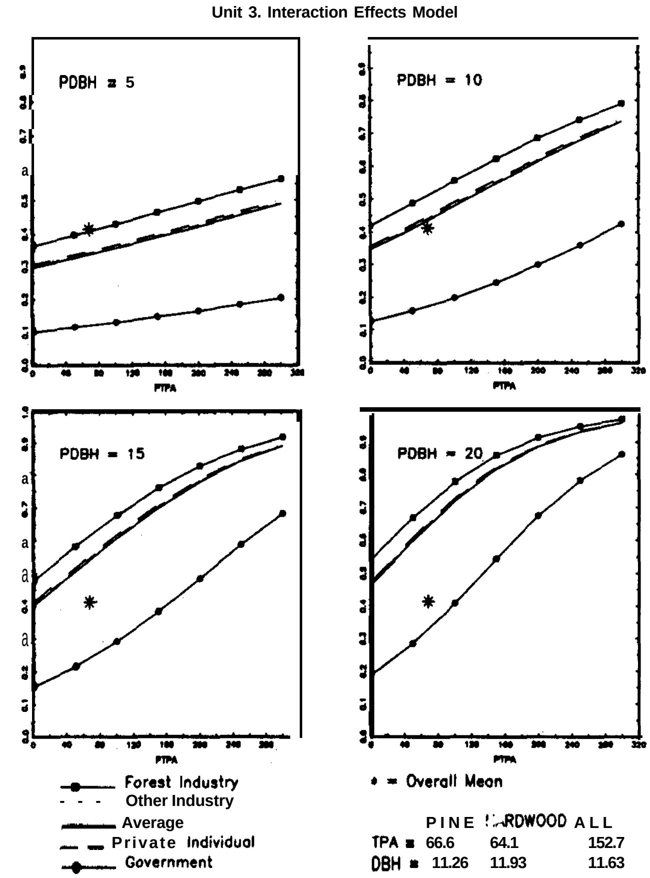

Figure 3-The conditional probability of harvest as estimated from the interaction effects model for survey unit 3 (Central) Georgia, by average stand pine diameter (trees > 5 in. d.b.h.), number of pine trees/acre (trees > 5 in. d.b.h.), and ownership class. The lower right corner lists the mean sample value for all continuous variables in the model. The asterisk represents the average conditional probability of harvest for the survey unit.

In general, across the five survey units in Georgia, harvest probabilities are greatest on sites with large pines and many of them. Ownership harvest rates vary by region; however, rates are always the lowest government controlled lands. Although there is the perception that harvest rates are greatest on FORCO lands, we found that this is not always true. For example, in southeastern (unit 1) Georgia, harvest rates are greatest on CORP lands and NIPF lands. Overall across the State, FORCO lands are harvested at the greatest rate, however NIPF and CORP lands have harvest rates approaching those of FORCO, and sometimes exceed FORCO especially in southern Georgia.

Harvest events over the last 8.5 years in Georgia have varied by region, with the greatest rates in central and southern Georgia. The rates gradually decrease moving to the northern region. The conditional probability of a harvest event (conditional on including only plots with trees >5 in. d.b.h.) in survey units 1 and 2 is 40 percent, 43 percent in unit 3, 38 percent in unit 4 and 23 percent in unit 5. Harvest event rates appear at first glance as extremely high, but remember this includes all types of harvesting, and we conditioned the data set to include only plots with trees >5 in. d.b.h. at time 1. The chance of a harvest event based on all plots is 31 percent for unit 1, 32 percent for unit 2, 35 percent for units 3 and 4, and 21 percent for unit 5. Final harvest occurred on 18 percent of all forestland in Georgia over the 8.5-year period (Thompson 1998). Final harvest is defined as the removal of the majority of the merchantable trees in a stand, leaving residual stand stocking less than 50 percent.

Example Using the Interaction Model for Unit 3

Assume the probability of harvest for a stand with the following attributes is needed. Assume the stand is on FORCO lands, and has a mean stand pine diameter (trees >5 in. d.b.h.) of 10 in. d.b.h., and 200 pine trees per acre (trees >5 in. d.b.h.). The interaction model coefficients for unit 3 (table 2) are:

$$X = -2.4223+1.6240(FORCO)+1.3623(NIPF)+1.3354(CORP)+0.0473(PDBH)+0.00055(PDBH)(PTPA).$$

Table 2-Estimated coefficients for the probability of harvest models for the five FIA survey units in Georgia. insert the value of X into oquation (1) to predict the probability of harvest. n_1 = number of plots harvested, n_2 = number of plots not harvested, n = n_1+n_2

Unit 1 n = 1636, n_1=653, n_2 = 983

Main effects model

X = -2.5436+1.4353*(FORCO)+1.6621*(NIPF)+1.9429*(CORP)
+0.0331*(PDBH)-0.0014*(HDBH)+0.0039*(PTPA)

Interaction effects model

X = -2.2400+1.4488*(FORCO)+1.5454*(NIPF)+1.9043*(CORP)
+0.0366*(NIPF)*(PDBH)-0.0026*(NIPF)*(PTPA)+0.0005*(PDBH)*(PTPA)
-0.0002*(HDBH)*(HTPA)

Unit 2 n=709, n_1=274, n_2=435

Main effects model

X = -2.3470+1.6563*(FORCO)+1.2819*(NIPF)+1.4056*(CORP)
+0.0567(PDBH)+0.0027(PTPA)-0.0033(HTPA)

Interaction effects model

X = -2.0289+1.5842*(FORCO)+0.6564*(NIPF)+1.4990*(CORP)
+0.0554*(NIPF)*(PDBH)+0.0005*(PDBH)*(PTPA)-0.00004*(PTPA)*(HTPA)

Unit 3 n=1307, n_1=540, n_2=767

Main effects model

X = -2.3601+1.5381*(FORCO)+1.2954*(NIPF)+1.2721*(CORP)
+0.0581*(PDBH)+0.00041*(PTPA)

Interaction effects model

X = -2.4223+1.6240*(FORCO)+1.3623(NIPF)+1.3354(CORP)
+0.0473(PDBH)+0.00055*(PDBH)*(PTPA)

Unit 4 n=736, n_1=279, n_2=457

Main effects model

X = -1.5705+0.5910*(FORCO)+0.0577*(NIPF)+0.4887*(CORP)
+0.0695*(PDBH)+0.0040*(PTPA)

Interaction effects model

X = -1.1042-2.9422*(FORCO)+0.0731*(NIPF)+0.4979*(CORP)
+0.2749*(FORCO)*(DBH)+0.1446*(FORCO)*(PDBH)+0.0497*(PDBH)
-0.0353*(HDBH)+0.0004*(PDBH)*(PTPA)

Unit 5 n=549, n_1=126, n_2=423

Main effects model

X = -1.4292+0.2123*(FORCO)+0.1699*(NIPF)+0.3415*(CORP)
+0.0476*(PDBH)+0.0019*(PTPA)-0.0044*(HTPA)

Interaction effects model

X = -1.1038+0.2054*(FORCO)+0.1084*(NIPF)+0.2945*(CORP)
+0.0514*(PDBH)-0.00055*(HDBH)*(HTPA)

To obtain the predicted probability proceed as follows:

$$X = -2.4223+1.6240(1)+1.3623(0)+1.3354(0)+ 0.0473(10)+0.00055(10)(200)$$
$$X = 0.7746$$

Inserting X = 0.7746 into model (1) results in:

$$p(h) = \frac{\exp(0.7746)}{1+\exp(0.7746)} = 0.6645$$

The predicted probability of harvest for a similar stand on government controlled lands is calculated as follows:

$$X = -2.4223+1.6240(0)+1.3623(0)+1.3354(0)+0.0473(10)+ 0.00055(10)(200)$$
$$X = -0.6494$$

Inserting X = -0.8494 into model (1) results in:

$$p(h) = \frac{\exp(-0.8494)}{1+\exp(-0.8494)} = 0.2995$$

CONCLUSION

We have demonstrated the utility of FIA data for harvest event rate modeling and found that region, ownership, average tree size, and the number of trees per acre influence rates. Rates of harvest increase with tree size and numbers of trees per acre, with a greater preference to pine. The greatest rates of harvest are in central and southern Georgia. We recommend the use of a logistic regression model or similar models where the response variable is bounded by zero and one. Models should include possible interaction terms and not restrict parameter estimation to main effects.

The number of acres impacted by harvest can be estimated by assigning a harvest probability to each plot and multiplying by an appropriate plot expansion factor and summing the resulting product. Future research will address final harvest models and, in addition to the variables investigated in this study, evaluate the possible effects of planted versus natural stands, accessibility, operability, and tract size. Thompson (1999) found that tract size is correlated to removal rates on NIPF lands in Florida.

Users of the harvest event models must be mindful that all models are based on plots with at least one tree greater than 5 in. d.b.h. Expansion of the modeled rates to an area basis must adjust for the conditional plot selection used in model development.

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SITE INDEX EVALUATIONS IN A It-IO-YEAR-OLD EASTERN WHITE PINE PLANTATION AT THE BILTMORE ESTATE, NC[1]

W. Henry McNab and Brian A. Ritter[2]

Abstract-The precision of three equations for estimating site index and the effects of four topographic variables on total height were evaluated in a 1.6-acre planted stand of 100-year-old eastern white pines (*Pinus strobus* L.) on the Biltmore Estate, near Asheville, NC. A polymorphic site index equation developed for the Southern Appalachian Mountains was only slightly more precise than a polymorphic equation developed for New Hampshire and an anamorphic equation developed for Wisconsin. A regression model that included age alone explained 72 percent of variation associated with stand total height. The inclusion of four significant topographic variables increased the explained variation to 91 percent.

INTRODUCTION

Eastern white pine is one of the most productive coniferous timber species in the Eastern U.S., and a considerable body of knowledge is available on its biology and management (Wilson and Hough 1966). White pine is widespread in the Southern Appalachians (Cope 1932) and, aside from published studies of site index (Beck 1971) and soil-site relationships (Ike and Huppuch 1968), little has been reported on its regional silviculture. However, considerable information on stand development in the Southern Appalachians is available from a small planting on the Biltmore Estate, near Asheville, NC. Since 1930, diameter growth and volume yields resulting from a thinning study have been periodically reported, most recently by Della-Bianca (1981). Little information has been reported on site quality relationships in this stand, such as evaluation of site index equations and site variables affecting height growth. This report presents a preliminary evaluation of site index equations for the Biltmore Estate's Old Orchard stand and the effects of topographic variables on the periodically measured average total stand height.

METHODS

Study Area

The study was conducted in the 7-acre Old Orchard plantation, several miles south of Asheville, NC. A plantation of 4-year-old eastern white pine seedlings was established in March 1899 on an eroded, abandoned pasture. In the fall of 1916, when the trees were 22 years old (from seed), researchers with the Appalachian Forest Experiment Station began a study to investigate the effect of stand density on growth and yield. They established three small plots (0.125 to 0.25 acre) that have been the basis of periodic reports on diameter and volume (Della-Bianca 1981). Individual trees on each plot were identified by number in 1916 and have been inventoried at ages 34, 41, 47, 52, 57, 75, and 100. The 100-year measurement was made in the spring of 1995. Subsequent references to tree ages are implied to be age from seed: references to time of measurement and tree age imply documentation in the spring of each year. For this investigation the three established plots form a single 0.5-acre measured stand. A 33-ft buffer zone around each plot results in a total delineated stand area of 1.6 acre.

Site Index Equations

We evaluated three white pine site index equations (table 1). Beck (1971) sampled 42 natural stands aged 44 to 70 years in the Southern Appalachian Mountains using stem analysis techniques to develop a polymorphic equation for site index ranging from 60 to 130 ft at 50 years. Gevorkiantz (1957) established 92 plots in natural stands in northern Wisconsin and developed anamorphic site index equations for stands up to 120 years of age with site indexes between 40 to 80 ft. Carmean and others (1989) reparameterized Gevorkiantz's (1957) original formulation for electronic solution and we used it in this study. Parresol and Vissage (1998) used data collected earlier from 196 natural stands in New Hampshire to develop polymorphic curves for stands up to 100 years and site index between 50 and 90. These three site index equations are based on total tree age. Models for planted stands were not available for ages greater than 50 years and, therefore, were not evaluated. Also not tested were several other equations for stands based on stand age measured at breast height.

Total Height Model

A total height regression model was developed to determine variation in height associated with site variables. Lohrey (1987) proposed the following model:

$$\log(H) = b0 + b1*(1/A) + b2(1/(A*A)) \qquad (1)$$

where

log = logarithm to base 10,
H = average total height of dominant trees (ft),
A = stand age from seed (years), and
b(I) = regression coefficients.

This model was also used to predict site index, which is equivalent to total height at age 50.

Data

In periodic inventories beginning at stand-age 34, the total height of five dominant trees was measured on each of the three plots. On these plots we selected the tree nearest plot center and midway along each of the four plot boundaries. This sampling design accounted for site quality variation in two directions: parallel and perpendicular to the direction of

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-16, 1999.

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Table I-Site index equations evaluated for eastern white pine in the Old Orchard Plantation, Biltmore Estate, near Asheville, NC

Site index equation	Formulation[a]
Beck (1971)'	H = (63.06+0.67*S)*(1-exp(-(0.00985+0.00033*S)*A))^2
Gevorkiantz (1957)	S = (0.5086*(H^1))*(1-exp(-0.024*A))^(-1.8942*(H^0))
Parresol and Vissage (1998)	S = exp(1.1881*(exp(-8.6188/A))*(ln(H)+(74.7099/A)-2.0862)+(0.592))

[a] H = dominant stand height (feet), S = site index (base age 50 years), A = total stand age (years), ln(x) = base e logarithm of x, exp = base of natural logarithm.
[b] Equation can not be inverted to directly solve for site index.

predominant slope gradient, which had been identified as a primary source of the variation. Average total height of the 1.8acre stand was determined from the 15 sample trees for each of seven measurement periods, i.e., 1929, 1936, 1942, 1947, 1953, 1967, and 1995. This resulted in 105 pairs of total height and age records. We used linear interpolation to estimate height of 10 trees for which 1929 and 1967 data were missing, and also for height at 50 years of age which had been measured at age 47 and 52. Topographic data collected at each of the 15 sample trees included aspect (nearest degree), slope gradient (nearest percent), landform index (a measure of slope position of the site), and terrain shape index (a measure of convexity or concavity of the site itself). We excluded elevation as a stand site variable because it varied by less than 25 ft.

Analysis
We evaluated the precision of each site index equation by calculating the difference between estimated and actual values (estimated - actual) determined at each of the seven periodic inventories. A regression model of total height and age was developed from periodic measurements of the same subset of 15 sample trees at various ages. We used stepwise multiple regression analysis implemented in SAS (1985) to develop models of total height as a function of age, aspect, slope gradient, landform index, and terrain shape index. A backward solution of the stepwise multiple regression model was used to reduce possibility of spurious results when multicollinearity could have been present (Zar 1996). Variables were excluded from the model at the 0.10 level of probability. Total height was transformed to log base 10 because the variance increased with age.

RESULTS AND DISCUSSION

Evaluation of Site Index Equations
Total height of the 15 sample trees averaged 62.0 (sd = 10.8) ft at 47 years and 67.2 (sd = 11.3) ft at 52 years. The interpolated height of 65.1 ft at age 50 was used as the best estimate of site index for the Old Orchard stand. Site index of 65 is at the lower limit of applicability for Beck (1971) and is about midway for the other two equations. The three equations provide similar estimates of site indexes at various ages (fig. 1). Minimum deviations occurred near the reference age (50 years), and greatest errors occurred in the youngest and oldest trees. Errors of estimated site index were of about the same magnitude for all equations (table 2). Overall, the equation developed by Beck (1971) is

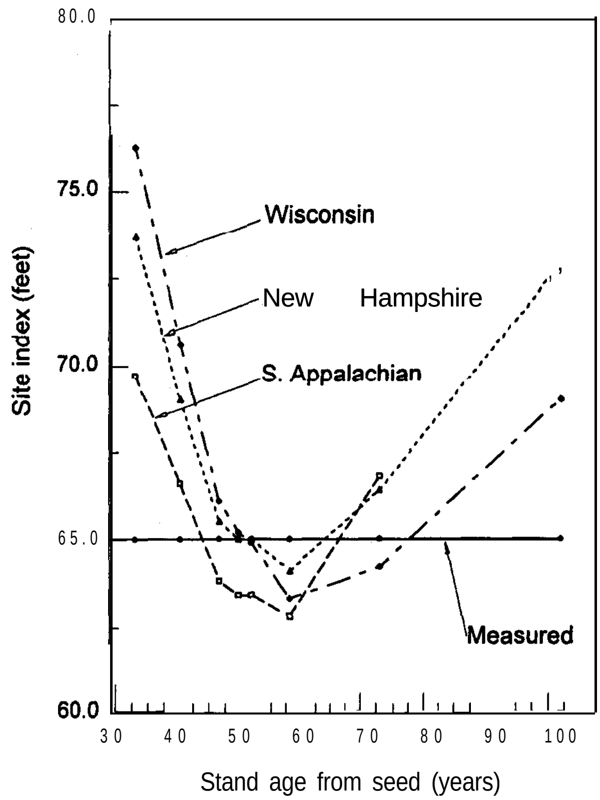

Figure I-Actual and estimated site index using three equations at seven periodic inventories (excluding 50 years) for the Old Orchard planting at the Biltmore Estate, North Carolina.

slightly more precise (mean absolute deviation = 2.8 ft), although there are few practical differences among the three equations. For all equations, most of the deviations were within 5 ft of the actual site index. Mean absolute deviation was 3.7 ft for the Gevorkiantz (1957) equation and 3.8 ft for Parresol and Vissage (1998).

We found several surprising results in this study. First, site index equations developed for white pine in Wisconsin and New England performed almost as well as equations

Table 2-Deviations of estimated eastern white pine site index from actual site index of three equations applied at seven ages at the Old Orchard Plantation, Biltmore Estate, near Asheville, NC

Site index equation	Deviations within +/-		
	o-2 ft	2-5 ft	5-12 ft
	------- *Percent* ------		
Beck (1971)	33.3	33.4	33.3
Gevorkiantz (1957)	42.8	28.6	28.6
Parresol and Vissage (1996)	42.9	14.2	42.9

developed relatively near the Biltmore Estate. Also, anamorphic curves developed by Gevorkiantz (1957) predicted site index about as well as polymorphic curves developed by Beck (1971) and Parresol and Vissage (1996). However, because evaluation consisted of only a single stand of low to average site quality, this study was a poor test of anamorphic versus polymorphic curves. We have not determined how site index equations developed specifically for planted stands might account for variations in the height growth of young stands, where vegetative competition has been reduced.

Height-Age Model

Mean stand tree heights ranged from 47 ft at 34 years to 112 ft at 100 years (fig. 2). Within-stand variation of the dominant component ranged from 25 ft at 34 years to over 40 ft at 100 years, indicating a broad range of site quality within in the Old Orchard stand. As the plantation aged, the pattern of total stand height increased almost linearly at a rate of about I-ft per year. The simple model of height as a function of age fits the stand data well and accounts for 72 percent of the height variation. The regression model predicted height of 64.5 ft at age 50, which agrees closely with the interpolated height of 65.1 ft.

Much of the variation in total height, over 20 ft at each measurement, results from sample tree location on the plot. Dominant trees on lower slope positions were as much as 20 ft taller than dominant trees on the upper slope. This marked variation in height in the Old Orchard plantation has been previously observed and has fostered discussion of actual site index values and site quality effect on diameter growth and volume yield (Della-Bianca 1961).

Height-Age-Site Variables Model

Slope gradient ranged between 14 and 41 percent (table 3). Total height of the 15 sample trees at age 100 was significantly correlated with only two topographic variables: landform index r = 0.67, p ~0.006) and terrain shape index r ▫ 0.56, p ~0.02). These two variables were also highly correlated with each other ® = 0.75, p ~0.001). When included in a multiple regression to predict total height relative to age for the 105 height-age pairs, all topographic variables were significant, accounting for 19 percent variation in total height. Next to age, the most important variable was landform index, which accounted for an

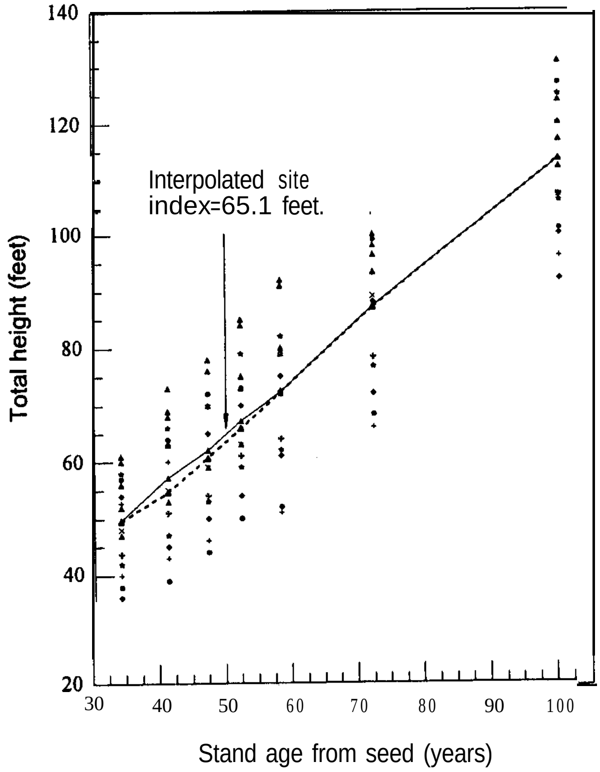

Figure P-Actual (solid line) and predicted (dashed line) total heights of the dominant stand at periodic ages of the Old Orchard planting at the Biltmore Estate, North Carolina. Points plotted vertically at each of the seven periodic inventories represent range of heights of 15 dominant sample trees.

additional 15 percent of variation, followed by gradient (2 percent), aspect (1 percent), and terrain shape index (1 percent). The effect of landform index and gradient on predicted height (fig. 3) accounts for much of the variation in sample trees' measured heights (fig. 2).

The influence of topographic variables on height growth has not been made clear in other studies. Ike and Huppuch (1966) found that growth increased with elevation, but decreased with slope gradient and was least on ridges. Foster (1959) reported that site index was lowest on upper slopes, but was decreased when elevation increased. Beck (1971) found little effect of site variables on white pine height growth. Slope position appears to be one of the most important variables affecting the species' height growth, as we found with the landform index variable. Compared to our single site in the Old Orchard planting, growth reported in other studies may have been affected by other, unmeasured environmental variables.

Overall, residuals-the differences between the calculated and actual values of heights-exhibited little discernable pattern when graphed on a stand basis, although a pattern was evident when they were examined on a plot basis. Tree heights on one unthinned plot were all underestimated and heights on the other unthinned plot were overestimated, indicating an unexplained source of variation in site quality. Residuals from the thinned portion of the stand were

Table 3—Statistics of topographic variables associated with 15 dominant eastern white pines sampled in the Old Orchard Plantation, Biltmore Estate, near Asheville, NC

Variable	Mean	Standard deviation	Minimum	Maximum
Aspect (degrees)	75.0	103.5	31 .0	338.0
Gradient (percent)	28.3	7.0	14.0	41.0
Landform index	.092	.022	.050	.122
Terrain shape index	-.023	.030	-.090	.013

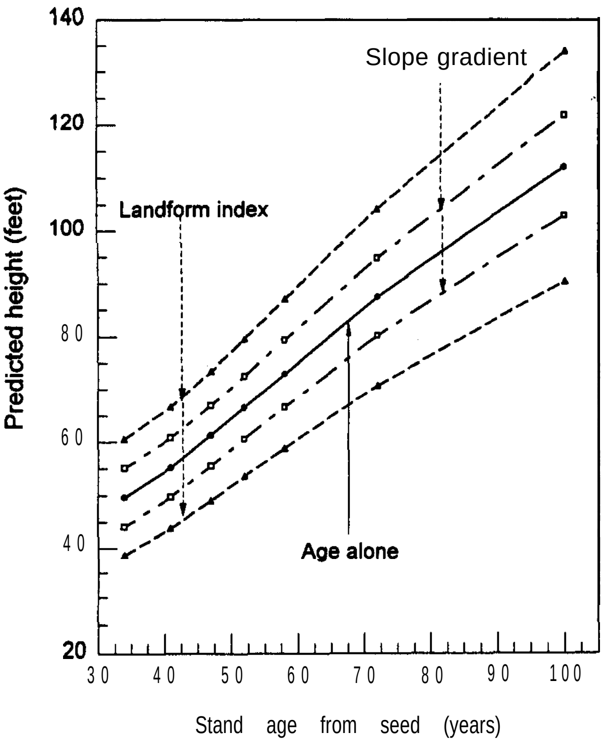

Figure 3-Predicted total height based on age compared with an equation based on age, landform index, and slope gradient for the Old Orchard planting at the Biltmore Estate, North Carolina. The two pairs of regressions show the effects of varying landform index or gradient individually between its minimum and maximum values while the other variable is held constant at the average value for the stand.

uniformly distributed, suggesting that tree heights are not correlated with stand basal area, a finding also reported by Beck (1971) in natural stands. In New Hampshire Adams (1935) reported that height increased as basal area was reduced. Ike and Huppuch (1968), however, reported a small increase in height as basal area increased. Variables accounting for effects of stand density on tree height were not explored in our regression analysis, but as reported by Lloyd and Jones (1982) for two species of southern pines, and might account for additional variation.

CONCLUSIONS

When evaluated in a small, planted stand of white pines on the Biltmore Estate, site index equations developed for the Southern Appalachian Mountains were only slightly more precise than equations developed in Wisconsin and New Hampshire. Topographic variables had a significant influence on height variation in the stand's 100-year-old dominant trees. Nevertheless, these site index and height growth relationships were based on data gathered from a single site and should not be extended to other locations without additional testing. These relationships, however, were not confounded by differing temperature and precipitation regimes, soils, or other unexplained sources of variation usually present in broader geographic regions. Results of this study should be useful in formulating hypotheses about site quality relationships of eastern white pine for use in the design and testing growth relationships.

ACKNOWLEDGMENTS

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LANDSCAPE SCALE MANAGEMENT IN THE OUACHITA MOUNTAINS-WHERE OPERATIONAL PRACTICES MEET RESEARCH'

Hunter Speed Jr., Ronald J. Perisho, Samuel Larry, and James M. Guldin[2]

Abstract-Implementation of ecosystem management on National Forest System lands in the Southern Region requires that the best available science be applied to support forest management practices. On the Ouachita National Forest in Arkansas, personnel from the Jessieville and Winona Ranger Districts and the Southern Research Station have developed working relationships that demonstrate how to conduct research in an operational context. Research projects on the districts' lands include GIS applications as well as landscape studies of vegetation, wildlife, hydrology, aquatic ecology, and social sciences. Advantages to the research community include in-kind staff support, study designs that reflect real-world issues, permanence and protection of plot identity, and opportunities to tap into monitoring funds. The cultural differences of time constraints and expected resource outputs that exist between Federal land managers and the research community are more challenging to overcome. The key elements outlined in this case study have application to research on National Forest System lands throughout the South.

INTRODUCTION

In 1992, then-Forest Service Chief Dale Robertson defined ecosystem management as *"managing National Forests in a healthy, diverse, productive, and sustainable manner."* But how, exactly, to implement ecosystem management is the subject of vigorous debate.

The practice of silviculture is changing from one of traditional, timber-production-oriented practices to a means of managing resources by ecological principles, process restoration, and habitat management. As a result, there is a pressing need for meaningful research to support a new foundation for evolving operational practices.

Under ecosystem management, the challenge for the research community is to provide scientific support for management alternatives. Opportunities for innovative research are many and varied. Ecosystem management implies a need not only to explore untested silvicultural practices, but also to consider a wider variety of resources at a variety of scales. Federal land managers seek timely research results that support, or that quantify the attributes of, new management practices. Scientists who can work within such constraints are enjoying an enhanced ability to participate in responsible management of the National Forest System (NFS) lands.

However, research under the auspices of ecosystem management must be useful if the results are to be widely applied. The best studies have the following attributes:

1. An operational scale;
2. The flexibility to work within, or to modify existing rules, regulations, standards, and guides;
3. The production of timely results:
4. Accessibility to a variety of customers; and
5. Pertinence to emerging issues.

The more attention researchers give to these principles when designing their studies, the more likely will national forest managers elect to work with them.

The goals of this paper are to help researchers better understand NFS management perspectives, to identify opportunities for more effective cooperation, and to discuss the effects of collaborative stewardship on both communities.

METHODS

In the Interior Highlands of Arkansas and Oklahoma, the Ouachita Mountains Ecosystem Management Research Program was established following the August 1990 "Walk in the Woods." The "Walk" was a field tour of the Ouachita National Forest (NF) for Sen. David Pryor (D-AR), hosted by then-Forest Service Chief Dale Robertson, then-Regional Forester Jack Alcock, then-Southern Research Station Director Tom Ellis, then-Ouachita Forest Supervisor Mike Curran, and Southern Research Station research forester Jim Baker. All participants agreed that the Ouachita NF should reduce the use of clearcutting and planting as a standard reproduction cutting method, and turn to alternative reproduction cutting methods that retain a portion of the overstory and that rely on natural regeneration. However, they recognized that research supporting alternative methods in shortleaf pine (*Pinus echinata* Mill.) and pine-hardwood stands of the Interior Highlands was virtually nonexistent.

As a result, Southern Research Station scientists began developing a research program that would support the changes upon which the Ouachita was to embark. After some debate and supplemental research funding obtained by Sen. Dale Bumpers (D-AR), scientists developed a three-phase research approach.

Phase I was a demonstration that explored not only different silvicultural practices, but also new ways for scientists and land managers to interact. Phase I demonstrations provided valuable, high-profile field tours. More than 2,000 people viewed Phase I stands early in the project.

Phase II was an experimental phase conducted at the stand level, and established the most likely reproduction cutting

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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alternatives in a statistically rigorous, replicated scientific study. Phase II was conducted in 52 40-ac stands, in which four sets of 13 reproduction cutting treatments were applied across the Ouachita and Ozark National Forests in Arkansas and Oklahoma. These sites reflect an intensive sample design that included pretreatment and post-treatment monitoring by more than 50 scientists in seven research groups. Treatments were applied during the summer of 1993, and regeneration establishment and development commenced with the 1994 growing season. In the summer of 1998, the study was in its fifth growing season after treatment.

Phase Ill is a landscape-scale study comparing different intensities of management across discrete watersheds using time rather than space for experimental replication. Four years of baseline data in vegetation, wildlife, hydrology, and aquatic ecology studies had been collected by the end of 1998, and seven different landscape treatments are being conducted in the summer and fall of 1999. This will provide a worst-case set of treatments to these ecosystems; the post-treatment data collection will provide quantifiable information about ecosystem changes that result from applying treatments across an entire landscape. Three of the four watersheds in Phase Ill are located on the Jessieville and Winona Ranger District of the Ouachita National Forest. The fourth is found on nearby forest lands managed by Weyerhaeuser Company.

Studies like these give research scientists a unique opportunity to advise-and be advised by-practicing land managers. Research studies on NFS lands present opportunities for researchers to work with land managers, to provide some response to questions posed by agency partners and the public, and contribute mutual support in study design, installation, treatment, and monitoring.

RESEARCH-MANAGEMENT COOPERATION-THE RUDIMENTS OF THE PROCESS

Scientists are used to a high degree of autonomy over their studies. However, the scientist who chooses to pursue a cooperative relationship with national forest managers is in an unusual position; he or she must surrender some control over the study to facilitate its implementation in an operational context. For those scientists who can tolerate a certain loss of autonomy over their research, results can be rewarding.

Three steps can be taken to build effective cooperation between research and management. The research scientist must first develop an effective professional relationship with the appropriate national forest partner. This relationship is essential in identifying and closing the gaps in research results that affect management decisions. It provides a framework upon which appropriate and collaborative studies can be designed and conducted. Establishing such relationships requires a commitment of time, which some researchers might not want to invest. But others will welcome interaction with practicing professionals who are eager to get research results based on operational treatments.

Second, installing studies on NFS lands requires conforming with planning regulations outlined in the National Forest Management Act of 1976 (NFMA) and the National Environmental Policy Act of 1969 (NEPA). Provisions in these laws require that alternative methods for implementing a project are properly proposed and explained in an environmental assessment (EA) or, if necessary, an environmental impact statement (EIS). The alternatives must be made available for public review, comment and, if warranted, revision. Finally, they must be approved by decision-makers and made subject to the appeal process. Although some scientists might consider this a disadvantage, many are discovering that these provisions apply to their research whether the treatments they propose are to be conducted on national forests or on private lands. Ranger district personnel, who are trained in NEPA analysis, will produce better EA's in less time than researchers could.

Third, scientists will have to submit their research to an interdisciplinary team (IDT) of district personnel. Federal land managers typically use an IDT to develop operational details of a proposed project, as well as acceptable alternatives to the proposed action. The research scientists participation in IDT meetings will help ensure that the intended treatment will be effective, efficient, and acceptable to both manager and scientist.

These steps inevitably will result in research being conducted more slowly than might be possible on private lands. Research scientists often chafe at the uncertainties of time associated with national forest operations-especially those elements that are subject to public involvement. It may often take 6 to 9 months from the development of alternatives to the closing of the appeal period.

ADVANTAGES OF RESEARCH-MANAGEMENT COOPERATION

Formal cooperative relationships among research scientists and Federal land managers have a number of advantages, ranging from specific practical assets to broad, overarching goals.

The long-term stability and credibility of the research mission will be enhanced in two important ways. First, study design will improve as field managers who daily face real-world problems have access to timely research results, and as citizens are better informed to comment on the proposed treatments. For example, scientists conducting the Ouachita research were uncertain whether to include clearcutting in the Phase II research study. They got endorsement for its inclusion from an unexpected source-a handful of citizens affiliated with the environmental community, who felt that clearcutting would not measure up when compared to alternative treatments. Then insisted that it be included in the study. Similarly, national forest personnel suggested testing low-intensity site preparation and release treatments in the Phase II study. This was clearly the direction in which management practices were headed on Federal lands, and there is a shortage of data relating to low-intensity methods of site preparation and release. The study was improved markedly as a result of those suggestions.

A second long-term advantage is the stability of Federal land tenure compared to private lands. NFS lands are much less likely to change hands over time. Long-term studies are therefore less likely to be affected by changing management conditions or access constraints that would occur with changes in land ownership in the private sector.

Other advantages relate to the indirect operational support that research can acquire for project monitoring on NFS lands. Specific rules prohibit national forests from spending dollars on research, and vice versa. However, if national forests conduct operational practices as part of their annual plan of work, research scientists can monitor those practices if the monitoring plan is specified in a NFS administrative study. In effect, then, research studies can benefit from in-kind support from the national forests.

Examples of the indirect operational support that ranger district personnel provide includes the time spent in project planning, project administration, purchasing and contracting, contract inspection, sale preparation, and other work to complete an approved project. In addition, the benefits that research scientists gain from access to local knowledge of the area, and to analytical tools such as Geographic Information Systems (GIS) and data bases, represent valuable contributions to monitoring studies.

Indirect financial support can be provided as well, subject to very specific conditions. Certain elements of the monitoring plan may qualify for proceeds from commercial timber sales under the Knutsen-Vandenberg (K-V) Act of 1933. Under that law and the administrative guidelines by which it is implemented, proceeds from a commercial timber sale can be invested for up to 5 years following harvest if such monies are spent on monitoring within the context of an administrative study by national forest personnel.

There are, of course, very specific constraints on what can be monitored, the geographic area within which monitoring can occur, and the time frame within which monitoring is to occur. However, there are no constraints on who designs the administrative study, nor on whether the study can be designed with statistical rigor. If the monitoring of K-V-funded treatments is designed in a statistically robust manner, and if that monitoring meets national forest management objectives, all parties benefit by having a research scientist use those monitoring data to test hypotheses in an experimental context.

The funding available under the K-V Act can be substantial. For example, three 40-acre stands containing an average harvest of 5 thousand board feet (mbf)/acre might sell for $200/mbf, or $120,000. After required allocations to the US. Treasury and county governments, remaining funds can be made available for improvements to the sale area, and to monitor the effects of those improvements. If monitoring were conducted according to a valid statistical design, the scientist would be able to apply the data not only in ways consistent with statistical principles but also to receive the in-kind support of national forest personnel charging their time to K-V funds.

The critical link is to develop a plan for data collection that meets both the strict definitions and guidelines set forth by agency policy, and the accepted principles of experimental design. A researcher must therefore prepare a study plan for national forest managers that qualifies as a NFS administrative study. The study plan must specify the monitoring to be conducted, the statistical design to be used, and the costs that will be incurred.

DISADVANTAGES OF RESEARCH-MANAGEMENT COOPERATION

There are some disadvantages that might impede fully cooperative relationships between scientists and national forest management staff. Four of the most common points where problems might occur deal with the process-related issues described above.

First, scientists and managers may be unable, by reason of distance or access, to develop the close working relationship required to develop research approaches to management issues. Proximity promotes cooperation. For example, in the Ouachita Ecosystem Management research study, one key element of success was locating Southern Research Station scientists with the Supervisor's office staff on the Ouachita National Forest in Hot Springs in order to develop mutual trust and support.

Second, some research projects simply cannot proceed under time delays that occasionally slow the course of forest planning. For example, research budgets cannot easily or reliably be carried over from one fiscal year to the next. If a study is planned, and scientists allocate funds to conduct the study in a given fiscal year, funding may be lost if the study is postponed. Repeated deferrals of projects may degrade cooperative relationships.

Third, a scientist may find that public scrutiny and management modifications would result in unacceptable changes to the study design, invalidating the statistical basis upon which the study is founded. In such circumstances, the best option for conducting good science might be to withdraw the study from the operational process. On the other hand, it may provide the opportunity to design alternative approaches during public scoping and IDT meetings that would retain the quality assurance and quality control of the experiment.

Finally, it may be impossible to modify a study plan so that it can be executed within the context of a national forest administrative study or monitoring framework. Some experimental designs, for example, require collection of time-dependent data, and the forest manager may not able to guarantee the personnel or resources necessary to collect the data in a timely manner. Similarly, some data collection protocols are fairly complicated, and it may be difficult to find national forest personnel who have the technical skill to implement monitoring that ensures data quality.

SUMMARY

Collaboration between research scientists and national forest managers is increasing, due to both an increasing diversity of management practices and a growing uncertainty about the effects of those practices. Cooperation undoubtedly benefits both sides. National forest managers can build credibility for their management programs by enlisting research scientists to study current practices and techniques, and to quantify their effects. If practices involve timber harvest, monetary proceeds can help meet ranger district and national forest resource targets, as well as support the monitoring necessary to generate data. Research scientists and managers alike gain from their mutual association; researchers by tempering ideas with practical applications, and managers by exposure to cutting-edge science and different perspectives. Finally, all will benefit from programmatic diversity, collaboration, and cooperation, which are proving to be key administrative concepts in implementing ecosystem management.

There may be disadvantages to developing the necessary cooperative relationships to make this work. But when conditions fall into place, as we think they have in the Ouachita Ecosystem Management Research Project, the benefits reward everyone involved.

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NON-TRADITIONAL PINE/HARDWOOD MANAGEMENT IN OKLAHOMA AND ARKANSAS'

Bryan W. Aday, Lawrence R. Gering, Robert F. Wittwer, and James M. Guldin[2]

Abstract-Twelve different shortleaf pine (*Pinus echinata* Mill.) reproduction cutting treatments and an unmanaged control were set up in a completely randomized block design with replication; these treatments included two levels of hardwood retention (O-5 ft^2 BA per acre and IO-20 ft^2 BA per acre). Differences in growth and yield of the residual pine stands were found between various combinations of harvesting treatmer ts and levels of hardwood retention. The findings will be useful to forest managers in this region by helping them meet the multiple objectives demanded by the public while maintaining a steady timber supply.

INTRODUCTION

Public and private lands are receiving increased pressure for non-commodity values while still attempting to provide our nation's wood supply. At the same time, more stringent environmental regulations and societal demands are determining how forests are to be managed. The objectives of this study were to determine whether natural stands of shortleaf pine, with minor and varying amounts of hardwood, could be regenerated under a variety of reproduction cutting methods. The objectives of this paper are to report on the growth and yield of the residual stands as a result of treatment. The impact of hardwood retention on pine growth was also investigated. This study is part of the Ouachita Mountains Ecosystem Management Research Project, a cooperative effort between the Southern Research Station, Ouachita and Ozark National Forests, and various cooperators, including Oklahoma State University.

Study plots were located on the Ouachita National Forest in eastern Oklahoma and western Arkansas and the Ozark National Forest in northwestern Arkansas. Random selection led to plots being located in all ranger districts on the Ouachita National Forest except the Winona in the extreme eastern edge of the Forest and the Tiak District in the coastal plain of extreme southeastern Oklahoma. In addition, several ranger districts in the southern portion of the Ozark National Forest were included in the study because they supported relatively pure stands of shortleaf pine and pine-hardwood that met the criteria of maturity, stocking, and site conditions.

SELECTION OF SAMPLE STANDS

The statistical design structure used in this study is a split-plot within a completely randomized block design with a 13 x 2 factorial treatment structure. The location of the study was blocked by four ecoregions as follows:
a) Arkansas Rivers and Valleys (NORTH)
b) western half of the Central Ouachita Mountains (WEST)
c) eastern half of the Central Ouachita Mountains (EAST)
d) South Fork subregion of the Central Ouachita Mountains (SOUTH)

Treatments

The whole-plot treatment in this study is reproduction cutting method. Thirteen reproduction cutting treatments including two controls were applied in each ecoregion for a total of 52 research stands. The two controls are:
a) clearcutting, not split (CCNS)
b) unmanaged control, not split (UC)

The inclusion of clearcutting in the study as a control treatment is similar in scientific justification to the inclusion of the unmanaged control. These served to evaluate the extremes in reproduction cutting intensity. Clearcutting will anchor one end of the study as the most intensive and possibly the most site-disturbing of the reproduction cutting methods once commonly imposed in the region. The unmanaged control will anchor the other extreme of the study in that it represents minimum human-induced disturbance (Guldin and others 1993).

A separate site preparation study is being conducted on the 52 research stands. Treatments labeled "split" have had different site preparation techniques applied to quadrants of the stand, while those labeled "not split" have had a uniform site preparation method applied to the whole stand. This site preparation study involves stand regeneration rather than growth of the residual stand after treatments are applied. Five even-aged treatments were implemented in the study. They are as follows:
a) seed-tree pine, split (STP)
b) seed-tree pine/hardwood, split (STPH)
c) sheltetwood pine, split (SWP)
d) sheltetwood pine/hardwood, split (SWPH)
e) shelterwood pine/hardwood, not split (SWW)

Six uneven-aged treatments were also implemented. They include:
a) group selection pine, not split (GSP)
(no trees retained in groups, pines and hardwoods between groups)
b) group selection pine/hardwood, not split (GSPH)
(hardwoods retained within groups, pines and hardwoods between groups)
c) single-tree selection pine, split (STSP)
d) single-tree selection pine/hardwood, split (STSH)
e) single-tree selection pine/hardwood, not split (STSW)
9 single-tree selection pine/hardwood, low impact, split (STSL)

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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Treatments labeled “pine” have minimal retention of midstory and overstory hardwoods after reproduction cutting is applied to the stand. Those treatments labeled “pine/hardwood” have some retention of midstory and overstory hardwoods after cutting is applied (table 1). After treatments were applied actual residual basal area levels for pine and hardwoods were recorded. The single-tree selection treatment in the uneven-aged methods labeled “low impact” utilizes reproduction cutting openings in the forest canopy less than 50 feet in diameter.

Table l-Treatments with target and actual observed hardwood residual basal area levels

Treatment	Residual hardwood basal area	
	Target	Actual
	-------- Ft^2/acre --------	
CCNS	0-5	5
GSP	10	24
GSPH	10	26
STP	0-5	10
STPH	10	10
STSH	10	14
STSL	10	20
STSP	0-5	11
STSW	10	13
SWP	o-5	11
SWPH	10	14
sww	10	13
UC	__[a]	29

[a] Residual basal areas of unmanaged control stands are the same as pre-treatment conditions.

In the summer and fall of 1991 52 natural stands were selected for use in this study, and the treatment to be applied to each one of these stands was randomly selected. These stands were selected from a list of stands on the two National Forests which were to be harvested soon. Each of these stands selected is at least 35 acres in size, had pre-treatment shortleaf pine basal areas between 60-l 10 ft^2/ac, and pre-treatment hardwood basal areas between 20-50 ft^2/ac. Reproduction cuttings occurred between May 15 and September 15, 1993.

Physiographic Zone

The sub-plot treatment in this study is physiographic zone. Each of the 52 research stands were split into two physiographic zones. The first is the timber management zone (TMZ) where reproduction cutting treatments were applied. The other is the streamside management zones (SMZ) along streams within the stand where no cutting treatments have been applied.

MEASUREMENT OF SAMPLE STANDS

Dates and Procedures

Measurement of shortleaf pine and hardwoods on each of the 52 stands was conducted in the dormant season of 1993-94, immediately following application of the reproduction cuttings. These measurements are referred to as the postharvest year 0 measurements. The stands were measured again following the same procedures in the dormant season of 1995-96, two years after the postharvest year 0 measurements were taken. This second measurement is referred to as postharvest year 2.

All measurements utilized in this study were taken by crews from the USDA Forest Service Southern Research Station located in Hot Springs, Arkansas. Within each of the 52 sample stands, 14 measurement plots were permanently located for a total of 726 measurement plots for the whole study. Twelve of these plots are located in the timber management zones (TMZ) of each stand, and the remaining two are located in the streamside management zones (SMZ) within the stand. For purposes of this study, fixed radius 0.1 ac plots were utilized. All trees within the 37.24 ft radius of the fixed plot were classified according to species, measured for dbh to the nearest 0.1 in. with a diameter tape, and mapped for location from plot center by compass azimuth, distance, and slope. During the postharvest year 0 measurement, numbered metal tags were placed at the base of each tree within the plot. Measurements of each plot were began at a compass azimuth of 0 degrees magnetic, and proceeded clockwise around the plot.

A subsample of both midstory and overstory shortleaf pines was selected on each plot for height measurements. The subsample trees on each plot chosen for height measurement were selected as follows:

Even-aged treatments-Using the tree tag numbers, the first shortleaf pine was selected for measurement of total height and height to base of live crown to the nearest 0.1 ft and dbh to the nearest 0.1 in. These height measurements were repeated on the 4th and 7th pines located on the plot. If this selection process resulted in fewer than three pines per plot, the process was repeated beginning with the 2nd pine, proceeding to the 5th and 8th pines.

Uneven-aged treatments-Using the tree tag numbers, the first shortleaf pine was selected for measurement. These measurements were repeated on the 4th, 7th, and IO” pines located on the plot. If this selection process resulted in fewer than four pines per plot, the process was repeated beginning with the 2nd pine, proceeding to the 5th, 8th, and 1 1th pines.

Within the 624 plots located in TMZ zones, 1643 pines were selected for height measurement. Among the 104 plots located in SMZ zones, 330 pines were selected for the height subsample. These tree measurements were placed into two separate data sets; one for trees within TMZ's and the other data set for trees within SMZ's.

Computation of Stand Tables

Postharvest year 0 shortleaf pine stand tables based on measurement of plots within TMZ's for each of the 52 stands were computed using the postharvest year 0 TMZ measurement data. Stand tables based on plots within SMZ zones were created for each stand at postharvest year 0 also. These stand tables consisted of pine trees per acre and pine basal area per acre by one-inch diameter classes for each research stand. Postharvest year 2 shortleaf pine stand tables based on both TMZ and SMZ plots were calculated for each stand following the same procedure.

ANALYSES AND RESULTS

Creation of Local Volume Tables

Two local volume tables were generated to predict shortleaf pine volume on the Ouachita/Ozark National Forests. One table was generated to predict volumes within timber management zones, while the other was generated to predict volumes within streamside management zones. The height subsample data set from plots within TMZ's was used to produce the TMZ volume table, and the height subsample data set from plots within SMZ's was used to create the SMZ volume table.

Murphy and Farrar's (1987) volume prediction equations for natural shortleaf pine were applied to each tree within the TMZ and SMZ height subsample data sets. These equations use tree dbh, total height, and height to the base of live crown as input variables. These equations generate live crown ratio, individual tree basal area (ft^2), total cubic volume (ft^3), sawlog cubic volume (ft^3), Scribner board foot volume, and total weight in green tons for each tree in the data sets.

The Statistical Analysis System (SAS 1985) was used to create regression equations based on the predictions generated by Murphy and Farrar's equations. Regression analysis was used to compare the natural logarithm of total cubic volume (TCV) with the natural logarithm of individual tree basal area. This was also done for sawlog cubic volume (SCV), Scribner board foot volume (SBF), and total weight in green tons (TON). By using this procedure, separate regression equations for TCV, SCV, SBF, and TON were fitted based on the trees measured in both TMZ and SMZ height subsamples (table 2).

The SMZ regression equations were compared to the corresponding TMZ regression equations. The slope of the SMZ sawlog cubic volume equation was found to be significantly different ($p = 0.0001$) than the slope of the TMZ sawlog cubic volume equation. The slope of the SMZ Scribner board foot volume equation was also found to be significantly different ($p = 0.0001$) than the slope of the TMZ Scribner board foot volume equation. These significant differences justify the need for separate local volume tables to estimate volumes within TMZ's and SMZ's.

Individual tree basal area for each one-inch diameter class ranging from four to twenty-seven was entered into each TMZ regression equation to create the TMZ local volume table. For example, to predict volume for a tree which falls within the ten-inch diameter class, the individual basal area of a tree which has a dbh of 10.0 in. (0.54542 ft^2) was entered into the TCV regression equation, SCV equation, SBF equation, and the TON equation. The SMZ local volume table was created using the same procedures that were used in creation of the TMZ local volume table.

Volume Estimations and Calculation of Growth

The TMZ and SMZ local volume tables were applied to each of the 52 TMZ and SMZ postharvest year 0 stand tables provided by the USDA Forest Service Southern Research Station. This resulted in two stock tables for each of the 52 research stands. The postharvest year 2 volume estimations were generated using the same procedure described above, except the postharvest year 2 stand tables were substituted in place of the postharvest year 0 stand tables used before. Trees per acre, basal area per acre, TCV, SCV, SBF, and TON per acre growth of each stand for the two-year period was calculated by subtracting the postharvest year 0 estimates from the postharvest year 2 estimates. Mean TCV, SCV, SBF, and TON growth per acre was calculated by physiographic zone, ecoregion, and by reproduction cutting treatment.

Analyses of Growth

The Statistical Analysis System was used to analyze tree growth in each physiographic zone within each of the research stands. The "mixed" procedure was used to analyze TCV, SCV, SBF, and TON growth per acre. These four analyses were done separately with separate "mixed"

Table 2—Equations[a] used to generate volume tables

Estimation	Equations: SMZ	Equations: TMZ
Total volume (ft^3)	e ^ (3.467464 + 1.361109 . lnBA)	e ^ (3.487289 + 1.352662 * lnBA)
Sawlog volume (ft^3)	e ^ (3.302348 + 1.397012 * lnBA)	e ^ (3.305453 + 1.526473 * lnBA)
Scribner volume (bd. ft)	e ^ (4.887563 + 1.642242 * lnBA)	e ^ (4.891052 + 1.805774 . lnBA)
Total green tons	[e ^ (7.705619 + 1.293416 . lnBA)] 2000	[e ^ (7.722917 + 1.298020 * lnBA)] 2000

[a] lnBA = Natural logarithm of individual tree basal area.

procedure statements. Within each analysis least squares comparisons of reproduction cutting treatment means were also conducted. In each of the analyses, physiographic zone did not significantly affect shortleaf pine growth (p-values range from 0.3405 to 0.5828). The physiographic zone by reproduction cutting treatment interaction also did not affect growth significantly (p-values range from 0.4939 to 0.5584) in any of the four analyses.

Conclusions on the effect of hardwood retention on pine growth cannot be determined by this study due to the inaccuracy of residual hardwood basal area adjustments. After reproduction cutting treatments were applied residual hardwood basal area level differences between treatments labeled "pine" and those labeled "pine/hardwood" were almost nonexistent (table 1). Actual residual hardwood basal area levels for treatments labeled "pine/hardwood" tended not to deviate greatly from the target level of 10 $ft^2/ac.$, but actual hardwood residual basal area levels of treatments labeled "pine" deviated greatly from the target level of O-5 $ft^2/ac.$ In these treatments, the actual levels were very similar to those of "pine/hardwood" treatments.

Least squares comparisons of treatment means identified in both TCV and TON analyses three groups of treatment means which were significantly similar at the alpha = 0.10 level (table 3). The highest growth rate in both analyses was the UC with approximately 100 ft^3 of TCV per acre or 3.1 TON per acre. Treatments utilizing uneven-aged management (GSP, GSPH, STSH, STSL, STSP, STSW) yielded an average of about 70 ft^3 of TCV per acre or 2.2 TON per acre. The GSPH treatment displayed the highest growth rate of the uneven-aged management stands. Even-aged treatments (STP, STPH, SWP, SWPH, SWW) on the average had the slowest growth rates at approximately 50 ft^3 of TCV per acre or 1.8 TON per acre. Of the even-aged treatments, the SWW cutting grew at the highest rate.

The SCV and SBF analyses both found that cutting treatment had a significant effect (p-values of 0.0854 and 0.0724) on shortleaf pine growth per acre. It seems that cutting treatment had a slightly more significant effect on sawtimber size trees than it did on smaller, pulpwood size timber. Least squares comparisons of treatment means found four groups of means which were significantly similar at the alpha = 0.10 level in the SCV analysis (table 3). In the SBF analysis, three groups were identified. As in the TCV and TON analyses, the UC exhibited the highest per acre growth rate with 115 ft^3 of SCV per acre or 890 SBF per acre. Uneven-aged treatments as a whole produced approximately 80 ft^3 of SCV or 430 SBF of per acre growth. The GSPH treatment produced the highest growth rate of the uneven-aged treatments. As a whole, the slowest growth rates in terms of SCV and SBF were observed with even-aged management applications. As above, the fastest growing even-aged treatment was the SWW.

Uneven-aged management produced higher growth rates per acre than even-aged management. This is not surprising, and is consistent with uneven-management strategies which involve regenerating small openings in the forest stand while at the same time increasing standing volume of residual trees in the rest of the stand. In some even-aged practices such as seed-tree cuts, the most important objective is regeneration of the stand, while significant increases in volume of the residual seed trees are not expected. Very low per acre growth rates in seed-tree treatments seen in this study are due to low numbers of trees per acre, and the fact that residual trees left for seed production are generally large mature to over-mature

Table 3—Shortleaf pine total cubic, sawlog cubic, and Scribner board foot volume growth[a] and total green ton growth[a] per acre overall treatment means[b] in the Ouachita/Ozark National Forests

Treatment	Total volume	Sawlog volume	Scribner board foot volume	Total ton (green)
	------- Ft^3 -------			
CCNS	-88.5 a	-47.7 a	-224 a	-2.43 a
GSP	12.4 ab	29.8 abc	132 ab	.41 ab
GSPH	124.7 c	138.3 d	718 c	4.11 c
STP	25.1 ab	30.3 abc	174 ab	.83 b
STPH	19.9 ab	20.9 ab	119 ab	.62 ab
STSH	99.0 bc	107.9 bcd	573 bc	3.27 bc
STSL	82.8 bc	88.7 bcd	488 bc	2.70 bc
STSP	44.9 bc	83.8 bcd	383 bc	1.39 bc
STSW	50.1 bc	56.2 bcd	326 bc	1.58 bc
SWP	19.5 ab	22.3 ab	157 ab	.56 ab
SWPH	87.8 bc	90.6 bcd	468 bc	2.94 bc
SWW	99.6 bc	93.6 bcd	591 bc	3.23 bc
UC	98.4 bc	115.6 cd	688 c	3.10 bc

[a] Growth is for the P-year period between postharvest year 0 and postharvest year 2 measurements.
[b] Treatment means within the same column with the same letter are not significantly different at the alpha = 0.10 level.

individuals. Other even-aged strategies such as sheltetwood treatments rely upon residual overstory pines to regenerate the stand while increasing in volume themselves. In this study, shelterwood treatments produced moderate to high growth levels very similar to those levels observed in uneven-aged, single-tree selection treatments.

CONCLUSIONS AND RECOMMENDATIONS

Foresters managing the Ouachita/Ozark National Forests under principles of ecosystem management can use this information to predict yields of various forest stands under silvilcultural treatments similar to those implemented in this study. This study could also serve as an example for nonindustrial private forest landowners, or for when forest researchers plan and implement more long-term growth and yield studies in this region of Arkansas and Oklahoma.

Forest stands within timber management zones and streamside management zones exhibited similar growth rates in the region involved in the study. The short growth period of two growing seasons in this study found significant differences among reproduction cutting treatments, but a longer growth period will more likely identify larger differences in growth characteristics of the residual stand. It is not uncommon to see little response to silvilcultural treatments the first growing season after implementation of the prescription. Future studies in this area could use procedures similar to those used in this study, but over longer periods of time.

In order to effectively study the effect of hardwoods retained in the midstory and overstory of the forest canopy on pine growth and yield, careful implementation of residual hardwood basal areas must be practiced. Care must taken as stands are marked for basal area reductions, as well as when partial harvests are implemented. Frequent checking of hardwood basal area with prisms as basal area reductions are being applied is one way to help address the problem of actual residual basal area vs. target residual basal area deviation. Improving marking accuracy in forest stands may require progress in silvicultural theory, and greater emphasis in continuing education and forestry curricula (Guldin and others 1995).

Although there is much literature on forest stand response to basal area reduction, mid-rotation thinning studies are the most common. There is little information on response of residual stands to implementation of reproduction cuttings, especially in even-aged silviculture systems. Studies on this response are more common in uneven-aged systems where forest regeneration and residual stand growth are of equal importance at a given time. Forest managers have many options when considering silvilcultural systems and management prescriptions to allow for adequate forest regeneration and growth of the residual stand at the same time. While this study is limited by a short time frame in which to analyze forest growth, it provides information that can help managers in the decision making process.

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OLD-GROWTH MONTANE LONGLEAF PINE STAND STRUCTURE: A PRELIMINARY ASSESSMENT'

J. Morgan Varner III, John S. Kush, and Ralph S. Meldahl[2]

Abstract-While a limited volume of literature exists on old-growth longleaf pine forest stand structure, even less is known of areas outside the Coastal Plain physiographic province. We quantified old-growth montane longleaf pine stands along Choccolocco Mountain on Fort McClellan, Alabama. Fort McClellan's remnant population represents the largest and most pristine example of the disappearing montane longleaf pine forest. We present data on stand characteristics including diameter distribution, stand density, crown class distribution, snag density, and age class structure. Stands examined contain trees older than 200 years, and diameters exceeding 25 inches DBH. Additionally, we present evidence that montane longleaf pine stands exist on all aspects (N, NE, E, etc...), contrary to prior investigations that limited longleaf sites to only southerly aspects. By gaining a better understanding of montane longleaf pine forests, we will be better able to restore and manage this imperiled ecosystem.

INTRODUCTION

Longleaf pine (*Pinus palustris* Mill.) forests once covered over 90 million acres prior to European settlement. Over the past 300 years, these forests have decreased in acreage 97 percent, of this only 9755 acres, scattered over fourteen known tracts, remain in an old-growth condition (Outcalt and Sheffield 1996, Means 1996). With these declines continuing, understanding the remaining longleaf pine forests is critical to any ecosystem-based restoration or management.

The primeval longleaf pine forest was described as an open, park-like "savanna". This open savanna was described as an uneven-aged forest comprised of a mosaic of even-aged patches. These patches arose from large canopy gaps (usually 0.1 to 0.5 acre) caused by large storm events, lightning strikes, and high temperature fires (Schwarz 1907). These canopy gaps then provided a suitable environment for seedling germination and establishment.

The few sites where age and stand structure and dynamics have been investigated lie within the Coastal Plain physiographic province. However, longleaf pine forests, while commonly associated with the Coastal Plain, exist over a wide geographic range including the Piedmont, Cumberiand Plateau, Ridge and Valley, and Blue Ridge physiographic provinces. The longleaf forests of the Ridge and Valley and Blue Ridge are often termed "montane." While some large vestiges of pristine longleaf forest exist in the Coastal Plain, the montane longleaf forest remains as isolated, fire-suppressed fragments in the mountainous terrain of northeastern Alabama and northwestern Georgia. Fort McClellan, however, contains several patches of frequently burned longleaf pine forest, including at least ten old-growth stands. These remnants of a once widespread forest type can provide managers and biologists with an understanding of stand structure, seedling replacement patterns, longevity, and influences of disturbance on stand and age structure in pristine montane longleaf pine forests.

METHODS

We studied montane longleaf pine stands at Fort McClellan, a U.S. Department of Defense Army post in northeastern Alabama. Fort McClellan contains a large portion of the Choccolocco Mountain Range, lying within the Blue Ridge physiographic province (Harper 1943). Fort McClellan contains the best example of the critically endangered montane longleaf pine forest (Garland 1997). Fort McClellan was surveyed for the presence of old-growth longleaf pine stands from January to December 1998. To date, nine areas have been located containing stands with a multitude of trees with > 150 rings. The two stands with the best evidence of frequent fire and largest spatial extent were chosen to be intensively measured to analyze stand and age structure and dynamics.

The two stands, the Caffey Hill Old-growth Area and Red-tail Ridge Reserve, are located from 1000 to 1500 feet above MSL on spur ridges west of Choccolocco Mountain. Both stands typify the classic biotic and abiotic environment of the montane longleaf pine forest. Slopes on Caffey Hill range from 40 to 60 percent, and at Red-tail Ridge from 30 to 50 percent. Soils of the two stands are mapped as Rough Stony Land: extremely rocky, highly erodible, with high runoff, and low infiltration (Harlin and others 1961). Within each site, all trees > one inch diameter at breast height (DBH) were measured for DBH (to nearest 0.1 inch) and crown class, and all trees > four inches DBH were cored completely through at four feet. Cores were mounted and sanded for microscope examination to determine tree age. Since longleaf pine does not produce annual growth rings during its juvenile grass stage, true age can not be determined (Pessin 1934). We used ring count at four feet as a surrogate for age, as has been done in previous studies (Platt and others 1988, Meldahl and others 1999).

RESULTS AND DISCUSSION

Montane Longleaf Pine Forest Stand Structure

Differences exist between diameter distributions of Caffey Hill and Red-tail Ridge (fig. 1). While both distributions mimic the wave-like reverse-j shaped curves found in previous studies of old-growth longleaf pine forests (Platt and others 1988; Meldahl and others 1999), Red-tail Ridge lacks adequate representation in the two and four inch size classes. This disparity is probably due to nearly annual burning along Red-tail Ridge for the past 11 years (Personal communication. Gordon Horsley. 1999. Forester, Directorate of the Environment, Fort McClellan, AL 36205). Accounting

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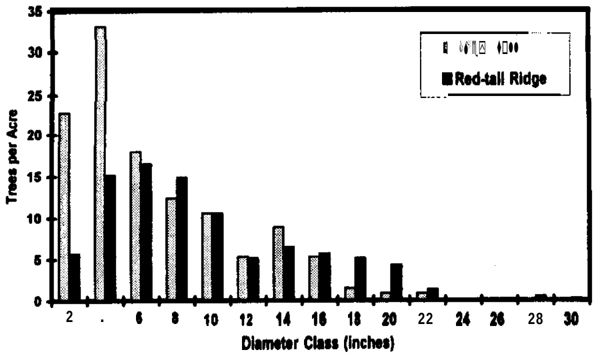

Figure l-Diameter distributions of two old-growth montane **longleaf** pine stands at Fort McClellan, AL.

for this disparity, the only other difference is the larger representation in large size classes present at Red-tail Ridge. This could be due to Red-tail Ridge being 300 feet lower in elevation than Caffey Hill, but may be a relict of past land use. The difference in these two stands from described Coastal Plain old-growth stands is that they lack representation in the larger diameter classes (above 20 inches).

Stand density varied between the two stands (table 1). The **27+** trees per acre disparity on Red-tail Ridge is obviously from the two and four inch diameter classes. This absence also increases the mean diameter of Red-tail Ridge. Snag density of both stands was much lower (3.5 at Caffey Hill, 4.5 at Red-tail Ridge) than previous reports of six to seven per acre in Coastal Plain old-growth **longleaf** pine stands (**Schwarz** 1907, J. S. Kush, unpublished data on Flomaton Natural Area). Crown classes (1 **=dominant, 2=co-dominant, 3=intermediate,** and **4=overtopped)** were averaged for comparison between stands. Caffey Hill and Red-tail Ridge averaged 2.6 and 2.8, values similar to the Flomaton Natural Area, a Coastal Plain old-growth **longleaf** pine stand (J. S. Kush, unpublished data).

Table l-Structural characteristics of two old-growth montane longleaf pine stands located within Fort McClellan, AL

Character	Stand: Caffey Hill	Stand: Red-tail Ridge
Stem density (trees/acre)	117.7	90.3
Snag density (trees/acre)	3.5	4.5
Basal area (ff/acre)	35.9	49.5
Arithmetic mean diameter (in.)	6.0	8.4
Quadratic mean diameter (in.)	7.5	10.0
Crown class value	2.60	2.8
Maximum age (rings **@d.b.h.)**	**228+**	238
Mean age (trees > 4" d.b.h.)	64	72

Montane Longleaf Pine Forest Age Structure

Within the Caffey Hill Old-growth Area, 189 trees were cored and aged. Ring counts of trees ranged from 12 to **228+** years. The two oldest individuals both contained rotten centers indicating **redheart** disease. At Red-tail Ridge Reserve, 202 trees were cored and aged. Ring counts of trees ranged from 14 to 238 years. Using five-year age classes, we created age structure relationships for both stands (fig. 2). Five-year age classes were used due to the more frequent seed crops in montane **longleaf** pine stands (Boyer 1987).

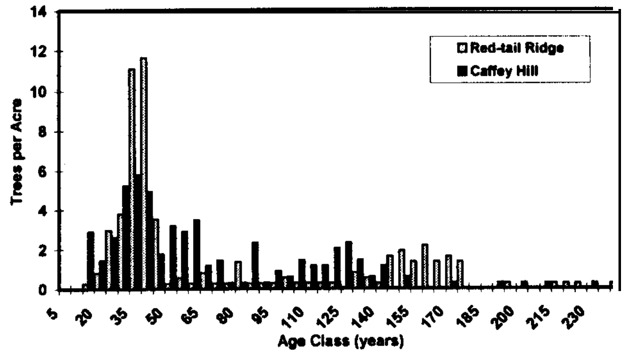

Figure P-Age structure of two old-growth montane **longleaf** pine stands at Fort McClellan, AL.

The irregularly skewed distribution of each age class distribution results from the dynamics associated with successful or failed regeneration attempts, small and **large-**scale mortality events, and variability in disturbance in the montane **longleaf** pine forest. Several distinct age classes are present in both stands. Peaks are found in the 35-40, **55, 65, 90,** and **130-year** age classes at Caffey Hill, and in the 35-45, 85, and 150-l **80-year** age classes at Red-tail Ridge. Aside from the **35-40** year age classes, age structure does not appear to be homogeneous over the Fort McClellan landscape. The variable peaks in each distribution probably occur in response to a seed crop year when a large-scale environment was favorable to seedling germination (exposed soil), seedling survival (decreased competition), and reduced canopy closure. The absence of the youngest age classes at Red-tail Ridge supports the annual burning hypothesis referred to above. Lastly, as has been observed in prior studies, troughs exist between age classes (Platt and others 1988, Meldahl and others In press). Troughs are caused by a number of factors, including lack of disturbance, absence of adequate seed crop, or dense overstory. Troughs may or may not occur during a seed crop year, during variable seedling environments and disturbance regimes. Understanding past environments and disturbances is difficult, but further analyses should help explain these dynamics at Caffey Hill and Red-tail Ridge.

Montane Longleaf Pine Sites

Early investigators found montane **longleaf** pine stands on southerly and western facing slopes, as well as north-facing slopes (Harper 1943). Recent investigators (Maceina 1996) and forest managers treat only southerly aspects (specifically, S and SW aspects) as longleaf pine sites. In our survey of the Fort McClellan landscape, we found stands on all aspects, including north and northeast slopes. This observation is critical; if managers only manage for longleaf stands on southerly aspects, a large potential acreage may be lost or forgotten.

CONCLUSIONS

This study of old-growth montane longleaf pine stands gives evidence for structural similarities across a montane longleaf pine landscape, distinct peaks and troughs in age class distributions, widespread occurrence of longleaf pine sites, and provides descriptive data on a critically endangered ecosystem. These data, and inferences derived from them, can give managers and scientists a better understanding of long-term replacement and maintenance dynamics in old-growth longleaf pine forests. From this understanding, we can then begin to restore and manage the montane longleaf pine forest ecosystem.

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APPLICATION OF GPS TECHNOLOGY TO MONITOR TRAFFIC INTENSITY AND SOIL IMPACTS IN A FOREST HARVEST OPERATION[1]

Emily A. Carter, Timothy P. McDonald, and John L. Torbert[2]

Abstract-A study was initiated in the Winter of 1996 to examine the utility of employing Global Positioning Systems (GPS) to monitor harvest traffic throughout a loblolly pine plantation and utilize traffic intensity information to assess impacts of select soil physical properties. Traffic maps prepared from GPS positional data indicated the highest concentration of traffic intensities occurred in the landings and skid trails (11 or more) while approximately 94 percent of the site was subjected to 10 or less passes. Estimates of bulk density and gravimetric water content did not approach levels in any traffic intensity class considered to be restrictive to root penetration for either surface or subsurface layers. Soil strength levels for each traffic intensity class in the surface layer did not indicate the presence of an impenetrable layer but subsoil modification may be necessary to provide a proper environment for regeneration.

INTRODUCTION

Mechanized forest harvest operations can alter soil physical properties which have the potential to influence subsequent management prescriptions and future forest productivity and soil sustainability. In the past, critical information on trafficking damage has relied on the tabulation of subjective surface disturbance classes, the measurement of changes in soil physical properties or a combination of the two methods. Both methods are hampered by the significant amount of time and labor required to implement them and the lack of accuracy required to truly estimate soil disturbance and soil compaction. Global Positioning Systems (GPS) have been employed recently in numerous forestry activities including utilization in thinnings, tracking movements of site preparation equipment, and locating soil disturbances related to harvest activities (McMahon 1997; Stjernberg 1997; Thor and others 1997). Recent studies have evaluated GPS systems and data to depict traffic maps of intensities, or the number of traffic passes to which a ground area of specific dimension has been subjected, and their distribution (McDonald and others 1998b; 1998c; McMahon 1997). Knowledge of the location of traffic intensities and their geographic distribution in a harvested landscape has the potential to provide a means of evaluating soil physical response to trafficking (Carter and McDonald 1998). Linking traffic damage to soil response may provide a framework for future decision making in application of site preparation and prediction of regeneration potential.

OBJECTIVE

The study was conducted in a loblolly pine plantation in the Piedmont region of Alabama with the following objectives: (1) the evaluation of GPS technology to monitor trafficking patterns and intensities, (2) measurement of the response of select soil physical properties to trafficking, and (3) correlation of soil changes to harvest traffic intensities.

MATERIALS AND METHODS

Site Characteristics

The study site was located in a 20-year-old loblolly pine (*Pinus taeda* L.) plantation, approximately 25.4 hectares in size, in Lee County, Alabama. Tree basal area was estimated to be 120 ft^2 per acre of loblolly pine and 20 ft^2 of hardwood with an expected yield of 90 green tons per acre. Soils within the harvest tract were primarily classified as clayey, kaolinitic, thermic members of the Typic Rhodudults (U.S. Department of Agriculture, Soil Conservation Service 1975). Two slope phases of the Gwinnett series were present within the portions of the harvest tract under evaluation.

Harvest and Global Positioning Systems

The harvest system configuration consisted of a single feller buncher (Hydroax 511 E), two grapple skidders (Timberjack 460D and 45OC) pulling to two separate decks, and two loaders (Prentice 270) located at each deck and equipped with an integrated delimber/slasher. Production averaged approximately seven to eight loads per day.

Global Positioning System data was collected by means of two types of GPS receivers: a Trimble ProXR and Trimble GeoExplorer. The final GPS and harvest system configuration consisted of the GeoExplorer mounted on the feller-buncher and two ProXrs mounted on each skidder. Data were collected in 2-second increments throughout the harvest day, differentially corrected in the laboratory, and exported to a GIS based system for editing. Detailed information on the transformation of vector based data into raster based maps used in this study has been previously published (McDonald and others 1998a).

Soil Physical Properties

The impact of traffic intensity on soil response was assessed by evaluating soil physical properties at select point locations corresponding to a specific traffic intensity. The relationship between soil physical response and traffic intensity was determined by fixing a ground position by GPS, matching coordinates to traffic maps and by collecting soil samples from these locations. A grid approximately 60 x 73 m in size (-0.4 ha) was established and soil physical data collected in situ or by removal of soil cores at each point. Soil strength was measured on a 3- x 6-m grid and soil bulk density and gravimetric water content evaluated on a 6- x 6-m grid basis. Soil penetrometer data was collected by a Rimik CP20 recording cone penetrometer to a depth of

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0.40 m in 0.025-m increments (ASAE 1997). Soil bulk density and gravimetric water content data were collected by removing soil cores to a depth of 0.2 or 0.4 m, subdividing each core into 0.10-m increments, weighing field moist samples, drying each soil sample for 24 hours at 105 °C and weighing to obtain dry weights (Blake and Hartge 1986). Final soil dry bulk density and gravimetric water content were computed using standard equations to estimate each soil property and correlated to a specific traffic intensity. Traffic intensities greater than four were combined to equally distribute sample numbers for statistical estimations.

RESULTS

Traffic Intensity

Traffic maps depicting intensities and patterns within the harvest area under evaluation have been previously published (McDonald and others 1998b; 1998c). Traffic maps prepared from the GPS data indicated a higher intensity of trafficking in areas designated as landings and skid trails, both primary and secondary, and the degree of intensity reduced as traffic dispersed toward the outer sections of the harvest tract.

Evaluation of traffic intensities over the 25.4-ha harvest tract indicated approximately 94 percent of the harvest tract was subjected to 10 or less passes and 6 percent of the trafficked area sustained 11 or more passes; the highest number of passes recorded within one grid cell was 173 (table 1). Untrafficked areas (zero passes) comprised the largest area within the harvest tract and successive percentages of each traffic class declined as traffic intensity increased. A subsection of the harvest tract (- 5.3 ha) examined for traffic intensity showed similar trends in the percent of area which sustained impacts of <10 and >1 1 as well as a decline in areal percentage with intensity; the highest number of passes recorded within this section was 104. Similar results in the distribution of traffic intensity and patterns in another tract harvested under similar conditions were reported by McDonald and others (1998b; 1998c).

Table 1—Areal percentages of traffic intensities throughout the whole and subsection of a harvested loblolly pine plantation, Alabama

Traffic intensity	Frequency 25.4 ha	5.3 ha
	------- *Percent* ------	
0	55.7	37.6
1	13.5	18.4
2	8.2	12.4
3	5.3	8.4
4	3.5	5.6
5	2.5	3.9
6	1.8	2.7
7	1.3	1.9
8	1.0	1.4
9	.81	1.1
10	.64	.87
11+	5.8	5.7
Σ O-10	94.3	94.3

Soil Response and Traffic Intensity

Soil physical properties were modified in response to traffic intensity and achieved a peak value at a specific traffic intensity (tables 2 and 3). Soil bulk density and mechanical impedance values in the 0- to 1 O-cm layer achieved a maximum response of 1 .12 Mg per m^3 and 1.60 MPa at the three and one pass level, respectively, and declined as

Table P-Mean bulk density (BD) (Mg m^{-3}) and gravlmetric water content (GMC) (percent) (w/w) with coefficients of variation (CV) (percent) of surface (O-0.10 m) and subsurface (0.10-0.20 m) soil layers by traffic intensity for a harvested loblolly pine plantation, Alabama

Traffic intensity	Soil physical properties: BD (0.1 m)	CV	BD (0.2 m)	CV	GMC (0.1 m)	CV	GMC (0.2 m)	CV
0	0.98	19.4	1.35	11.9	24.9	36.6	22.1	13.1
1	1.01	17.8	1.31	10.7	21.2	32.1	21.5	20.0
2	1.10	12.7	1.27	9.5	22.4	21.0	23.6	19.5
3	1.12	28.6	1.28	13.3	23.2	21.1	23.3	17.6
4	1.09	19.5	1.35	8.2	21.8	26.2	23.4	13.7
5-9	1.08	20.4	1.29	16.3	24.6	24.4	24.4	20.1
1 O-24	1.02	29.4	1.28	12.5	26.0	23.9	25.7	15.6

Table 3-Mean cone index (CI) (MPa) with coefficients of variation (percent) of surface (0.0–0.10 m) and subsurface (0.10-0.20 m) soil layers for a harvested loblolly pine plantation, Alabama

	Soil physical properties			
Traffic intensity	CI (0.10 m)	CV	CI (0.20 m)	c v
0	1.20	62.5	1.90	36.3
1	1.60	37.5	2.24	32.6
2	1.40	38.6	2.06	25.7
3	1.50	42.7	2.31	25.5
4	1.51	50.3	2.37	25.7
5-7	1.48	52.0	2.06	38.4
8-l 0	1.45	46.9	2.16	25.5
1 l-24	1.40	26.4	2.06	19.9

traffic intensity increased. The highest level of gravimetric water content of 26 percent occurred within the highest **traffic** intensity range. Changes in bulk density and cone index values in the IO- to 20-cm layer appeared to peak at 1.35 Mg per m^3 and 2.37 MPa after four passes and declined slightly thereafter: gravimetric water content increased to a maximum value of 25.7 percent at the highest traffic intensity range.

Trends in the response of soil physical properties to traffic intensity was examined by plotting all possible data pairs and determining the best mathematical description of the relationship. The relationship between soil physical response and traffic intensity was not evident in any data set with the exception of the bulk density and gravimetric water content in the 0- to IO-cm layer (figs. 1 and 2). A quadratic function provided the best fit for bulk density (r^2 = 0.51) and gravimetric water content ® ^{2} = 0.51) in the surface layer of the trafficked soil; r ^{2} values for other physical properties under consideration were less than 0.30 for all subsurface soil properties data and surface layer soil strength. Bulk density versus traffic intensity when all data was considered appeared to peak at approximately seven passes and 1 .1 5 Mg per m^3 while gravimetric soil moisture content declined to 23 percent at an intensity of 4 passes before increasing with successive traffic intensities.

DISCUSSION

Monitoring harvest traffic by GPS yielded valuable information related to the intensity of trafficking throughout the harvest tract and its location in the landscape. Traffic intensities recorded by GPS were highest in landings and skid trails on approximately 6 percent of the harvest tract while traffic intensities of ≤ 10 dominated the tract. Information on the degree of traffic intensity and its distribution over a forested landscape has not been previously available. Rather, the degree and intensity of disturbance associated with harvesting and its distribution have been utilized as an indicator of traffic intensity and impact (Aust and others 1998, Carter and others 1997).

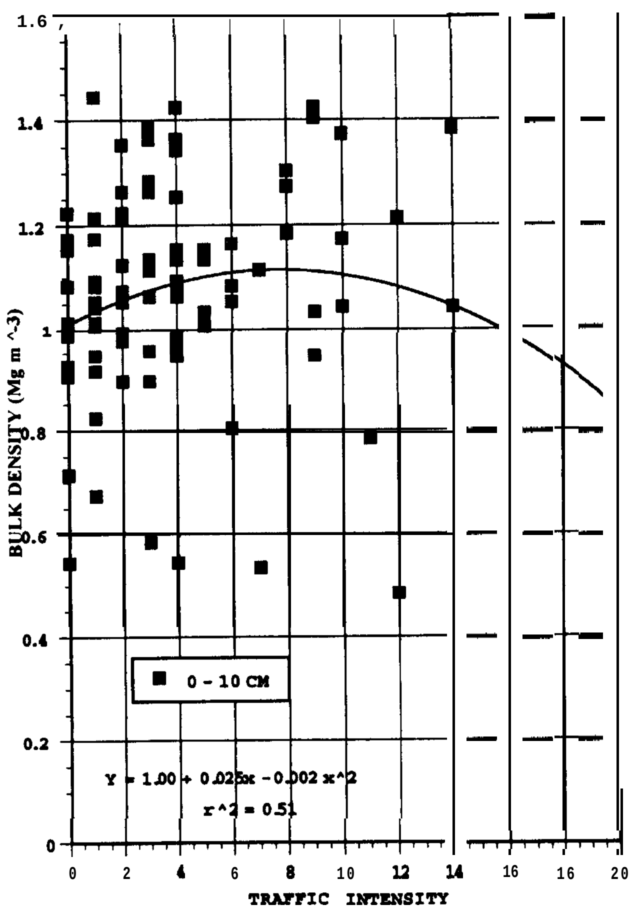

Figure l-Relationship between bulk density (Mg/m ^{3}) and traffic intensity of the surface layer of a Gwinnett sandy loam soil in a harvested loblolly pine plantation, Alabama.

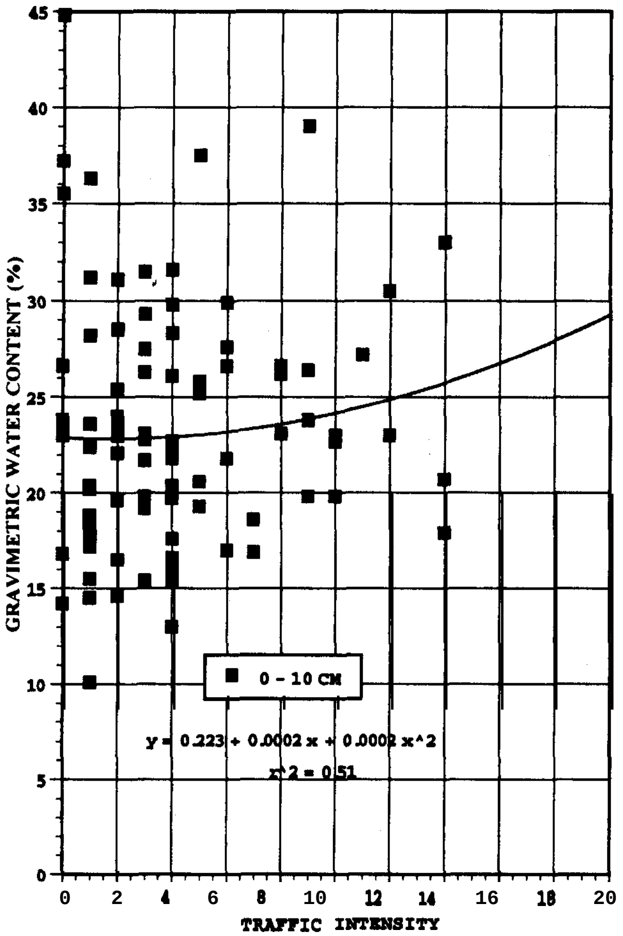

Figure P-Relationship between gravimetric water content (w/w) (percent) and traffic intensity of the surface layer of a Gwinnett sandy loam soil in a harvested loblolly pine plantation, Alabama.

The use of GPS equipment to monitor harvest **traffic** has the potential to provide a permanent record of traffic related impacts and assist in decision making processes on site preparation activities and regeneration potential within a harvested tract.

Soil bulk density and soil strength are expected to increase in response to machine traffic due to soil volume reductions and closer proximity of soil particles and aggregates (**Greacen** and Sands 1980). The change in bulk density, gravimetric water content and soil strength in this study indicated a response to machine trafficking, especially in the surface layer. Bulk density increased by approximately 15 percent in the surface layer compared to the untrafficked condition (zero traffic intensity) and to a lesser degree in the subsurface layer. These results are within the range of percentages (3 and 50 percent) that have been previously reported in studies of bulk density changes in trafficked sites (Froehlich and McNabb 1983, **Hatchell** and others 1970, lncerti and others 1987, Wronski 1984). The maximum compaction status achieved after three passes was consistent with previously reported studies in which higher incremental changes in bulk density occurred within the first five **traffic** passes followed by progressively smaller increments of change (Greene and Stuart 1985, Hatchell and others 1970, Meek 1996). It should be expected that the results would vary with temporal and spatial changes in study conditions as underscored in studies by McNabb and Startsev (1995) and Meek (1996). They noted that differences in soil moisture status and texture contributed to a wide range of bulk density values as well as the point of maximum response to traffic intensity. Subsoil bulk density response did not exhibit a clear trend with **traffic** intensity and may reflect inherently different soil conditions at the time of trafficking.

The relationship between bulk density and traffic intensity under constant soil moisture conditions resembled results reported by Ayers and Perumpal(1982) for cone index values in which cone index increased with successive compaction efforts at a standard moisture content. Further investigation into this relationship may be warranted to predict maximum bulk density (and soil strength) under standard traffic conditions and soil moisture.

Gravimetric water content declined with successive traffic intensities until a maximum soil moisture content of 26 percent was attained at the maximum traffic intensity (10 to 24). Reductions in the percent of water may be an indication of a loss of capillary pore space in response to trafficking. Hill and Sumner (1967) theorized that differences in soil moisture content after compaction would occur depending on soil texture. They noted sandy loam soils would experience a loss of total porosity at the expense of the capillary pores and as a result, hold less water. The surface soil layer under consideration was classified as a sandy loam which may account for the results obtained in the study. Gravimetric water content increased in response to **traffic** intensity in subsoil layers and may be indicative of the response of a clay soil to compaction through an increase in capillary pore space and water holding capacity as noted by Hill and Sumner (1967).

Soil strength increased to its highest level in the surface layer after one pass and declined thereafter; four passes elevated soil strength to its highest level in the subsoil layer. Soil strength response may be the result of increased compaction effort under a constant soil moisture content at the time of compaction as demonstrated by Ayers and Perumpal (1982). They noted that minimal changes in soil strength occurred under conditions of elevated soil moisture contents and increasing bulk density. Soil moisture conditions were expected to be elevated within the soil body under consideration as harvesting occurred in winter of 1998 when moisture was plentiful. Soil strength changes might have been minimal under these conditions elucidated by the authors.

SUMMARY

Traffic maps depicting patterns and intensities of harvest traffic were produced through the collection of positional data by a standard GPS. A majority of the site experienced ≤ 10 passes after trafficking by a feller-buncher, multiple skidders, or both. Soil impacts examined by measuring soil physical response at locations correlated to traffic intensity indicated that changes in bulk density, soil strength, and soil moisture would not be expected to significantly impact pine regeneration in surface layers; soil strength levels **>2.0 MPa** often encountered in subsoil layers may be indicative of limitations to root growth. Further elaboration of soil physical response to trafficking under a range of site conditions would be beneficial in understanding this complex relationship.

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RCWFAT AN ARC/INFO AML PROGRAM TO ASSIST IN EVALUATING RCW HABITAT REQUIREMENTS'

Donald J. Lipscomb and Thomas M. Williams[2]

Abstract-RCWFAT is and ARC/INFO AML program that calculates habitat requirements of Red Cockaded Woodpecker according to Fish and Wildlife Service guidelines for Private Landowners. The program maps cluster zones and potential foraging habitat from two ARC/INFO coverages of tree locations and stand volume estimates. The program has several different options that allow user input if biological information is known about the woodpecker population. It can also make all maps based entirely on cavity tree geometry.

INTRODUCTION

The Red-Cockaded Woodpecker is an integral part of the longleaf pine ecosystem and decline of the longleaf ecosystem is a major factor causing it to become an endangered species. Landowners interested in longer rotation longleaf pine are likely to become involved with this endangered species. The U.S. Fish and Wildlife Service is developing programs to assist private landowners with dealing with this species. The Private Landowner Guidelines (Costa 1992) and Safe Harbor (Costa and Kennedy 1996) programs are designed to promote RCW recovery while allowing private landowners use of their land. Participation in these programs involves including RCW habitat requirements in forest management planning.

These Private Land Owner Guidelines specify habitat requirements that research has indicated are the minimum requirements for survival of a group of woodpeckers. The guidelines include two geographic areas defined by a cluster of RCW cavity trees, The cluster area is a zone extending 200 feet from all cavity trees in the cluster. The potential foraging area is a ½ mile radius circle around the cluster. In the cluster area pine basal area should be between 50 and 80 ft2/ac. The stand should be maintained with an open understory. Pesticides and sanitation cuts can be done to control insects or disease but the FWS must be notified if such cuts include a cavity tree or reduce basal area below the minimum.

Within the potential foraging zone, a foraging habitat of from 80 to 300 acres can be designated. The potential foraging zone is the entire ½ mile radius circle unless another cluster is less than 1 mile from the cluster. In cases where two clusters are closer than 1 mile the overlapping potential foraging zone is divided equally between the two clusters. The foraging habitat must contain 3000 ft^2 of pine basal area in trees over 10" DBH (Diameter at Breast Height). Stands in the foraging habitat must have from IO -80 ft^2/ac of pine basal area. They must also have an open understory as provided by frequent prescribed fire.

GIS analysis is most useful for RCW habitat management since the birds are non-migratory, territorial, and nest in easily identified living pines. Habitat requirements can be specified as specific numbers and sizes of pine trees in defined areas surrounding clusters of RCW cavity trees. GIS allows automatic mapping of the geometry of cluster areas and foraging zones. It can also combine these maps with data collected on the RCW trees or the cluster areas. It can also combine these maps with forest stand maps to determine data on foraging zones from cruise data. RCWFAT (Red-Cockaded Woodpecker Forage Analysis Tool) is an ARC-INFO AML program that will map cluster area and foraging habitat in accordance with FWS private landowner guidelines. The program runs on standard ARC-INFO 7.1.2 for the NT operating system. The program uses the same procedures to map cluster areas and foraging zones as presented as manual methods in Lipscomb and Williams (1995,1996)

METHODS

Data requirements for the program are a single ARC-INFO coverage with the locations of the cavity trees and an item evaluating their cavity status. RCWFAT also contains a report module that will report the total basal area and stems by basic management unit subtotaled by available foraging areas. To run the report module a second ARC-INFO coverage is needed. This coverage must have forest stand boundaries as polygons and the polygon attribute table needs at least two fields of specific cruise data. One field must be per/acre estimates of basal area in trees over IO DBH. The second field must be a per/acre estimate of the number of stems over 10" DBH.

The RCWFAT program consists of a number of program modules that allow a number of analysis options to be chosen from pop-up menus. There are modules that: segregates cavity trees into clusters, maps the clusters, calculates a cluster center, maps the potential foraging zones around cluster centers, allocates forage among clusters that closer than 1 mile apart. If a landowner has no knowledge of the biology of the bird, an automatic option maps cluster areas and foraging zones based on the geometry of the cavity trees. If the landowner knows which trees are used by specific groups of birds, a manual edit allows each cavity tree to be assigned to a specific cluster. If the landowner already has clusters mapped, a module will calculate foraging areas for these clusters.

In addition to maps of cluster area and potential foraging zone, the program's report module does an intersection of available foraging areas with stand boundaries to produce estimates of pine basal area and stems in the foraging zone of each cluster. It then creates a written report of the area,

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[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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pine basal area, and pine stems in each potential foraging area. A separate report is made for all stands outside of the foraging areas. In addition to written reports, it will also create tables of data from the stand polygon attribute table, with cluster identifiers, in tile formats for import into popular spreadsheet programs. More complete descriptions of how the program is structured and operates can be found in **Lipscomb** and Williams **(1998a,** b)

RESULTS

The main power of GIS is to associate map areas with tabular data and to combine separate maps to create new tabular data. Forage analysis uses the forage map and stand maps with cruise data to determine amount of forage available for each group of RCW. Although the program can be used for any landowner with RCW, the main value is for owners with denser populations. Figure 1 shows the 1993 distribution of RCW clusters on Hobcaw Forest in Georgetown County, SC. The guidelines require that if clusters are closer than 1 mile the overlapping foraging area must be allocated equally to each cluster. If few clusters overlap, the task is simple but if overlap many **(i.e** ten within one mile of cluster 8) the process is difficult and time consuming (fig. 2).

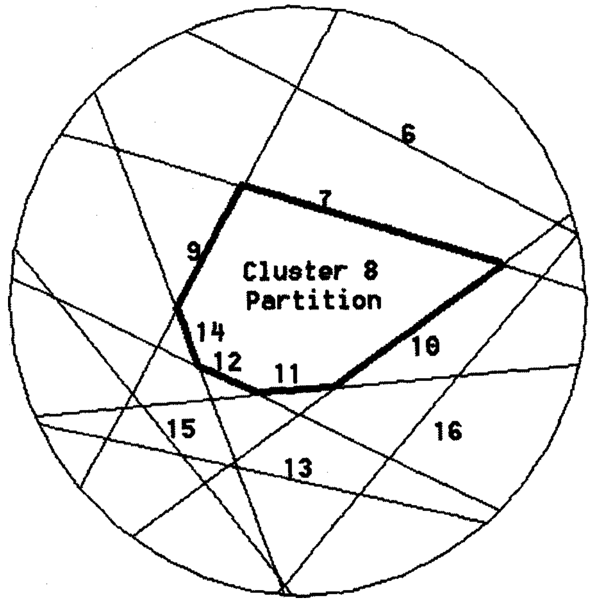

Figure 2-Foraging range of cluster 8 (circle), partition of range with overlapping clusters (numbered lines), and foraging partition allocated to cluster 8 (dark polygon).

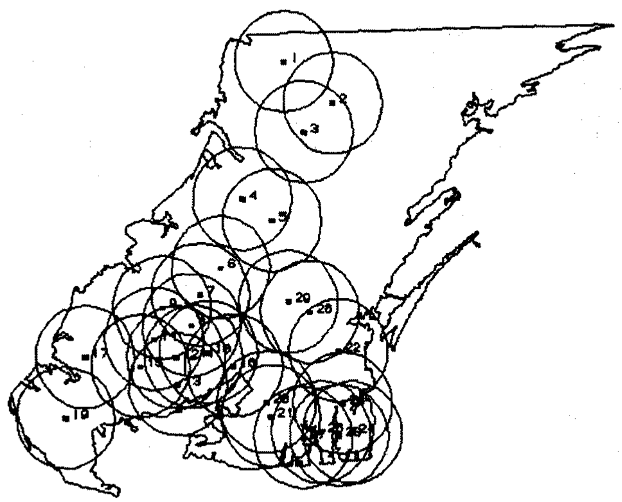

Figure l-Location of foraging ranges on Hobcaw Forest.

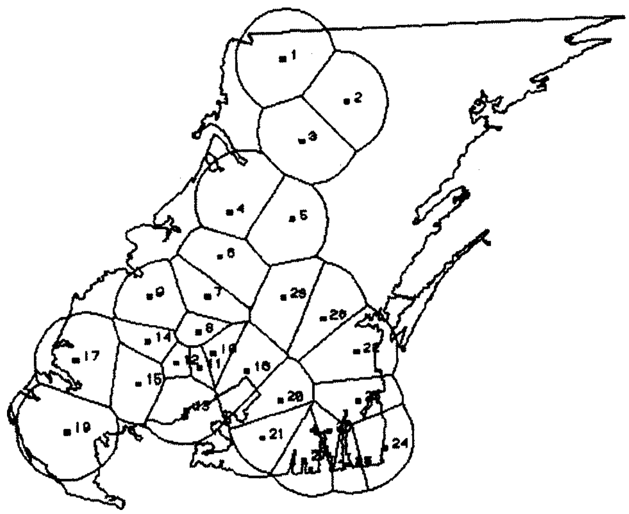

Figure Z-Final distribution of foraging partitions on Hobcaw Forest.

With the RCWFAT program the process of allocation is done automatically for each cluster. When the process is complete a map similar to figure 3 is produced. However, figure 3 is not only a map, but a complete ARC-INFO coverage. It can be combined with other coverages or it can displayed with images to allow management planning. For example, figure 4 displays cluster 2 from figure 3, with both potential foraging zone and cluster area. These coverages can overlay the forest stand map, allowing mapping of the portion of each stand within the potential foraging zones and cluster area. From the stand data tables the number of stems and basal area in each stand in the potential foraging zone can be computed. The ability to display these maps on aerial photographs allows a manager to examine gaps and stand characteristics that may limit usability of stands as part of the designated foraging zone. The ability to examine cluster areas with a picture of the stand also will assure that the program is assembling the correct trees in a cluster.

Mapping and designating cluster areas and potential foraging zones can be a routine part of forest management with ARC-INFO and this program. On a laptop computer maps can be made at a rate of one cluster per minute. A map can be produced whenever a stand treatment is planned, a new cavity tree is found, or a cavity tree dies.

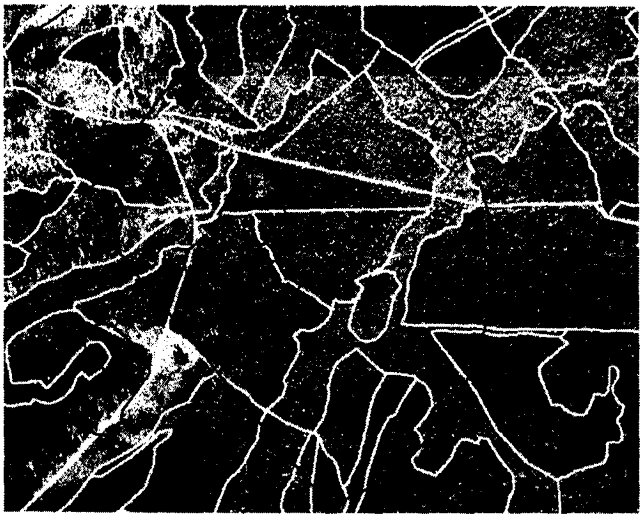

Figure 4—Cluster 2 foraging range and cluster area placed on aerial photo and stand coverage (white lines).

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