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Cover Photographs

Upper Left—Three year-old clonal loblolly pine (*Pinus taeda* L.) plantation in Berkeley, SC. Photo: Chris Maier, Southern Research Station, USDA Forest Service

Upper Right—Prescribed fire conducted every 2-3 years on Watershed #77, Santee Experimental Forest in South Carolina. The management is intended to control hardwood understory and maintain habitat for the Red Cockaded Woodpecker (*Picoides borealis*). The picture shows the loblolly pine (*Pinus taeda* L.) forest 4 weeks after burning. Photo: Julie Arnold, USDA Forest Service.

Lower Left—Development of thinning treatments to remove understory biomass was necessary in the over-stocked stands that developed in the lower coastal plain after Hurricane Hugo. This photo depicts a trial where the stand was thinned between rows, with biomass being concentrated in central point for processing into fuel. Photo: Watershed #79, Santee Experimental Forest in South Carolina. Photo: Julie Arnold, USDA Forest Service

Lower Right—Bottomland hardwoods are integral to the forested landscape of the southeastern coastal plain. The resultant mosaic of upland and wetlands provide valued goods and services that are highly influenced by hydrology. Long-term hydrologic research on the Santee Experimental Forest provides needed information to address contemporary issues, particularly those related to climate change and carbon cycling. Photo: Ground water well in a bottomland hardwood swamp, Fox Gulley Creek, Santee Experimental Forest in South Carolina; by Julie Arnold, USDA Forest Service.

Disclaimer

Pesticide Precautionary Statement

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

Caution: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife if they are not handled or applied properly. Use all herbicides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and their containers.

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Proceedings of the 16th Biennial Southern Silvicultural Research Conference

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John R. Butnor

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PREFACE

The 16th Biennial Southern Silvicultural Research Conference (BSSRC) was held February 15–17, 2011 in Charleston, South Carolina. The 16th BSSRC was the latest in a series of meetings designed to provide a forum for the exchange of research information among silviculturists, researchers, and managers. More than 260 people attended the conference with 189 oral and poster presentations given covering research in pine and hardwood silviculture, soil and water, physiology and genetics, carbon and bioenergy, fire and fuels, forest health, restoration, growth and yield, and forest economics. In addition, two field trips focused on state-of-the–art intensive management of loblolly pine and silvicultural research on the Francis Marion National Forest and the Santee Experimental Forest were provided.

We acknowledge and especially thank the conference sponsors and steering committee. The sponsors included North Carolina State University, ArborGen, Inc., the University of Florida, and the USDA Forest Service, Southern Research Station. The steering committee devoted numerous hours to reviewing abstracts, establishing the program for oral and poster presentations, and making all necessary arrangements for the conference. Steering committee members included:

Chris Maier (co-chair)
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Clemson University, Clemson, SC

An important feature of this conference was the awarding of student travel scholarships. Individuals were selected for this award based on giving a paper at the conference, recommendation from their institutional sponsor, and willingness to assist with audio-visual duties. We thank student scholarship chairs Mike Kane, Zakiya Leggett, and Geof Wang for organizing and selecting student scholarships.

We gratefully acknowledge Susan Moore and Kelly McCarter with the Forestry & Environmental Outreach Program (FEOP) at North Carolina State University for handling just about all of the meeting administrative activities including logistics, registration, lodging, and food at the Double Tree Hotel in Charleston, and field trip lunches and transportation. We thank student presentation awards chair Brian Lockhart, and all those who helped judge student presentations and posters. We also thank Phil Dougherty, Arborgen, Inc. and Carl Trettin, Southern Research Station for organizing and leading the field trips and Daniel McInnis, Pete Anderson, Bob Eaton, Tom Christensen, and Sandy Kelly from the Southern Research Station for general help during the meeting. Gary Kuhlmann and Maureen Merriman of the Southern Research Station, Technical Publications Team, Science Delivery Group provided excellent technical editing support for SRS authors and oversaw production of the proceedings publication. Pete Anderson, Joel Burley, Bob Eaton, Jason Jackson, Daniel McInnis, and Karen Sarsony graciously proof read the final copy of the proceedings prior to publication.

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The 86 papers published in these proceedings were submitted by the authors in electronic media. Limited editing was done to ensure a consistent format. Authors were responsible for content and accuracy of their individual papers.

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THE EFFECTS OF PLANTING DENSITY AND CULTURAL INTENSITY ON LOBLOLLY PINE CROWN CHARACTERISTICS AT AGE TWELVE

Madison Akers, Michael Kane, Robert Teskey, Richard Daniels, Dehai Zhao, and Santosh Subedi

Twelve-year old loblolly pine (*Pinus taeda* L.) stands were analyzed for the effects of planting density and cultural intensity on tree and crown attributes. Four study installations were located in the Piedmont and Upper Coastal Plain regions of the U.S. South. The treatments included six planting densities (740, 1480, 2220, 2960, 3700, 4440 trees per hectare) and two levels of culture (intensive and operational). The intensive cultural treatment included frequent fertilization and complete sustained chemical competition control. The operational cultural treatment included less frequent fertilization and early chemical competition control. Density and cultural treatments were combined to make a total of twelve plots per installation. Destructive sampling methods were used to obtain detailed tree and crown measurements. Trees planted at the lower densities (especially 740 and 1480 trees per hectare) had significantly (α=0.05) higher values for crown width, live crown length, foliar biomass, leaf area, and foliar nitrogen content at the tree level (Table 1). Greater individual crown size and nitrogen content at the lower densities corresponded with larger individual tree size (dbh and height). These attributes indicate that individual trees planted at lower densities are in better condition to respond to thinning. Specific leaf area (SLA) was measured as leaf area per unit leaf mass at the individual needle level. SLA increased significantly with increasing density, illustrating the effect of increased shading in the higher density stands. Surprisingly, foliar nitrogen concentration was the only crown measurement significantly affected by cultural regime. Trees grown under the intensive regime exhibited a higher percentage of nitrogen concentration in the crown. Even trees grown at the operational level, however, had foliar nitrogen percentages of at least 1.22 percent, above the critical level for loblolly pine (Allen 1987). The absence of a major cultural effect on crown attributes can most likely be attributed to the nature of the treatments, with even the operational cultural regime receiving considerable fertilization and competition control. Further research will include crown analysis by tree size to test for treatment effects on trees of a given dbh-class.

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Table 1—Mean sampled tree crown characteristics measured at age 12 for loblolly pine stands growing at different planting densities

Planting Density (trees ha^{-1})	Crown width (m tree^{-1})	Crown length (m tree^{-1})	Foliar biomass (g tree^{-1})	Leaf area (m^2 tree^{-1})	Foliar N content (g tree^{-1})
740	4.4 (a)	8.2 (a)	8507 (a)	91.5 (a)	117 (a)
1480	3.4 (b)	7.4 (b)	5228 (b)	58.1 (b)	76 (b)
2220	3.0 (c)	6.4 (cd)	3344 (cd)	36.7 (cd)	47 (c)
2960	2.7 (c)	6.6 (c)	3426 (c)	38.5 (c)	48 (c)
3700	2.7 (c)	5.9 (de)	2983 (ce)	33.1 (ce)	43 (cd)
4440	2.3 (d)	5.6 (e)	2303 (de)	26.0 (de)	34 (de)

Means in the same column with the same letters are not significantly different (Fisher's LSD multiple comparison test; α=0.05)

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EFFICACY AND NON-TARGET IMPACT OF MIDSTORY INJECTION IN BOTTOMLAND HARDWOODS

Derek K. Alkire, Andrew W. Ezell, Andrew B. Self, Stephen Demarais, and Bronson K. Strickland

ABSTRACT

The need for midstory control in bottomland hardwood regeneration work has been well documented. However, only a few research efforts have documented the efficacy of such efforts and the potential negative effects on non-target stems. This potential negative impact is extremely important in these stands where individual stem values are characteristically high. As part of an oak regeneration project, this study is designed to evaluate the efficacy of midstory control on target species as well as incidental damage to non-target stems. During this study, approximately 72,000 midstory stems were injected during August and September, 2009. These stems were located on 90 acres of bottomland hardwood stands within minor stream bottoms in northern Mississippi. All midstory stems except oaks which were ≥1 inch diameter at breast height (d.b.h.) received one hack per three inches d.b.h. and one ml of a 20 percent volume to volume Arsenal AC aqueous solution per hack. Ninety 0.025-acre plots will be evaluated in August 2010 to determine the effectiveness of the injection. Injected midstory stems within a plot will be recorded as dead or alive. All non-target stems on the plots will be evaluated for mortality or damage. In addition, any damage noted on non-target stems across the study areas outside the measurement plots will be recorded and reported. Results will be reported as percentages by species and diameter class. This information will be of great value to hardwood mangers using the wide spacing imazapyr injection method for control of undesirables.

INTRODUCTION

Bottomland hardwood sites are known to have some of the most productive forest soils, and species richness tends to be high on these sites. Due to high species richness and associated stand stratification, competition control is often essential to hardwood regeneration efforts. Midstory injection has long been recognized as a viable and cost effective method in controlling undesirable stems (Williston and others 1976). Peairs and others (2004) reported that midstory/understory control treatment increased regeneration of desirable hardwood species such as oaks. Lockhart and others reported that advanced cherrybark oak (*Quercus pagoda* Raf.) regeneration released from midstory competition were 76.2-103.6 cm taller than non-released seedlings nine years after treatment. A variety of chemicals can be used for hardwood midstory injection, including imazapyr (Arsenal AC®). Although injection effectiveness can vary by species, tree size, and season of application (Peevey 1971, Star 1973), imazapyr has been shown to be nearly 100 percent effective on a wide range of species such as black cherry (*Prunus serotina* Ehrh.), blackgum (*Nyssa sylvatica* Marsh.), red maple (*Acer rubrum* L.), American beech (*Fagus grandifolia* Ehrh.), and hickory (*Carya* spp.) (Miller 1992, Nelson and others 1993).

Potential non-target impact can be a concern when using herbicide treatments in hardwoods. A study in Ohio found that injecting tree-of-heaven (*Ailanthus altissima* Mill.) with imazapyr resulted in 100 percent control (Lewis and McCarthy 2008). However, 17.5 percent of non-injected tree-of-heaven stems within three meters were also killed. A similar study reported that untreated striped maples (*Acer pensylvanicum* L.) were killed on sites where the midstory was injected with imazapyr (Kochenderfer and Kochenderfer 2008). Graham and Bormann stated interspecific root grafts are rare, and concluded herbicide was likely absorbed from the soil, which is in agreement with what Kochenderfer and others (2011) found in West Virginia. That study found midstory injection utilizing imazapyr to be over 99 percent effective in controlling target midstory stems (Kochenderfer and others 2011); however, imazapyr treatments damaged several crop trees. Damage could have occurred because the injection crew was inexperienced and may have allowed herbicide to reach the soil (Kochenderfer and others 2011). Imazapyr does exhibit some soil activity (Anderson 2006) and can be absorbed by roots (USDA Forest Service 1989). The chemical has a half-life of 7-180 days in soil, and typically remains active for over 40 days (Michael and Neary 1990). Therefore, if sufficient quantities of imazapyr reach the soil, impacts to non-target stems may occur.

Past studies of midstory injection utilizing imazapyr have yielded conflicting results concerning both the efficacy of the treatment and the potential impacts to non-target stems.

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The objectives of this study were to 1) evaluate treatment efficacy of imazapyr on target stems, and 2) to determine if imazapyr affected non-target stems in southern bottomland hardwood stands.

METHODS

SITE DESCRIPTION

The study utilized six 6.07-ha sites characteristic of typical southern bottomland hardwood stands along river systems in Mississippi. Sites had overstories containing a prominent component of sawtimber size (DBH ≥ 27.9 cm) oaks and midstories dominated by shade tolerant species. Due to canopy closure and midstory competition, there was limited herbaceous ground cover. All sites contained soils predominantly from the Wilcox association which are fine, montmorillonitic, thermic Vertic Hapludals. Soil pH levels ranged from 4.5-5.2.

Sites one and two were located on the John W. Starr Memorial Forest owned by Mississippi State University. Site one was located at 33° 17' 34.25" N, 88° 55' 19.56" W in Winston County, MS. Site two was located at 33° 20' 41.33" N, 88° 55' 17.18" W in Oktibbeha County, MS.

Sites three and four were located on land owned and operated by C.A. Barge Timberlands LP. Site three was located at 33° 10' 12.64" N, 88° 49' 19.98" W in Noxubee County, MS. Site four was located at 33° 10' 26.47" N, 88° 41' 37.57" W in Noxubee County, MS.

Sites five and six were located on the Noxubee National Wildlife Refuge owned and operated by the United States Fish and Wildlife Service. Site five was located at 33° 16' 35.75" N, 88° 44' 25.79" W in Noxubee County, MS. Site six was located at 33° 16' 53.45" N, 88° 46' 30.98" W in Noxubee County, MS.

Oaks present in the overstory included cherrybark (*Quercus pagoda* Ell.), southern red (*Q. falcata* Michx.), Nuttall (*Q. texana* Buckl.), white (*Q. alba* L.), Shumard (*Q. shumardii* Buckl.), post (*Q. stellata* Wangenh.), water (*Q. nigra* L.), swamp chestnut (*Q. michauxii* Nutt.), overcup (*Q. lyrata* Walt.), and willow (*Q. phellos* L.). There were also small overstory components of sweetgum (*Liquidambar styraciflua* L.), American beech (*Fagus grandifolia* Ehrh.), black gum (*Nyssa sylvatica* Marsh.), yellow-poplar (*Liriodendron tulipifera* L.), sycamore (*Platanus occidentallis* L.), loblolly pine (*Pinus taeda* L.), baldcypress (*Taxodium distichum* (L.) Rich), and hickory (*Carya* spp.). Midstories consisted of species such as American hornbeam (*Carpinus caroliniana* Walt.), pawpaw (*Asimina triloba* (L.) Dunal), American holly (*Ilex opaca* Ait.), slippery elm (*Ulmus rubra* Muhl.), red mulberry (*Morus rubra* L.), red maple (*Acer rubrum* L.), sugarberry (*Celtis laevigata* Willd.), Eastern hophornbean (*Ostrya virginiana* Mill.), and winged elm (*Ulmus alata* Michx.).

METHODOLOGY

Approximately 72,000 midstory stems were injected in August 2009. Injections were made using hatchets and adjustable spray bottles utilizing the "hack and squirt" method. Each non-oak stem in the midstory ≥1 inch DBH received one hack per three inches diameter. One ml of a 20 percent volume to volume Arsenal AC® aqueous solution was applied per hack.

Efficacy of the injection treatments was evaluated in August 2010 on ninety 0.010-ha. plots. Each midstory stem within a plot was identified by species and diameter and recorded as injected or non-injected. Percent crown reduction was recorded for all stems using ocular estimation.

Crown reduction estimates could range between 0-100 percent, with zero percent indicating no impact and 100 percent indicating a dead tree. Percent crown reduction was also recorded for all overstory stems. In addition, damage to non-target stems outside measurement plots was recorded. Recorded data for damaged trees outside measurement plots included percent crown reduction, diameter, and species.

RESULTS

All sites exhibited similar responses. Therefore, the results related to species and tree size were combined across sites. Overall crown reduction for injected midstory stems on sample plots averaged 96.8 percent (Table 1) indicating that injected stems were effectively controlled.

Average crown reduction exceeded 91.8 percent for all species across all sites (Table 2). While 100 percent crown reduction was not achieved, remaining trees will likely die by the next growing season.

Non-target midstory stem injection impact was minimal. While injected midstory stems exhibited 96.8 percent crown reduction, crown reduction on non-injected stems averaged only 0.7 percent. Based on these observations, it is surmised that chemical root transfer was minimal. It is likely that crown reduction was due to natural senescence and/or dieback common in midstory/understory stems. The likely cause of any impacts to non-target stems (if any occurred) was the inexperience of the injection personnel. Failure to properly apply herbicide solutions, and keep it in the injection frill could have resulted in imazapyr reaching the soil causing non-target impact.

Non-target overstory stems exhibited little injection damage. Only three overstory stems were observed to be adversely affected. All stems were sweetgum which is highly susceptible to imazapyr. Only minor symptoms were observed and no lasting effects are expected. It is important to note that midstory sweetgum density was high where non-target damage occurred. Due to high stem density and numbers of stems injected; it is possible that the injection crew was responsible for herbicidal drip resulting in non-target damage. Also, these trees could have shared a common root system with injected stems. Root suckering is not common in southern hardwood species; however, both sweetgum and American beech (*Fagus grandifolia* Ehrh.) are species most often associated with this characteristic. While it is important to note that the damaged trees were in areas of high midstory density, high stem densities were characteristic of numerous other areas in the study which did not exhibit any overstory damage. Of the areas examined in this study, this was the only evidence of overstory damage noted. Additionally, this damage was in an area where a crew member was observed using poor injection technique. The lack of consistent non-target impact, considered in conjunction with undesirable injection work of one crew member, led to the assumption that damage was attributable to "operator error," not to herbicide translocation through root systems.

CONCLUSIONS

Midstory injection using imazapyr is very effective in controlling target stems. Crowns of injected stems were reduced by over 96 percent. Non-target impacts from the injection treatment were minimal, and were represented by only minor symptoms. Due to the lack of consistent non-target impact, root grafts were not considered a principal factor in herbicide transfer. Non-target stem damage can be attributed to an inexperienced injection crew. Injecting undesirable stems in hardwood stands using imazapyr was extremely effective, required substantially less labor than conventional injection (most trees receive only one hack), and resulted in virtually no damage to non-target stems. Although this is the first study to formally evaluate plots for non-target impact, hundreds of acres of hardwoods have been injected with imazapyr solutions with no observed non-target impact (Ezell and others 1999). In this study, many midstory sweetgum stems were missed during injection due to high stem density. These stems were excellent candidates to exhibit symptoms resulting from root graft transfer, however none were observed. Conducted properly, injection with imazapyr is a very effective tool for controlling undesirable stems in southern bottomland hardwoods.

ACKNOWLEDGMENTS

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Table 1—Percent crown reduction of injected midstory stems by site

Site	% Reduction
1	94.9
2	96.5
3	96.4
4	96.7
5	96.1
6	97.3
Overall	96.8

Table 2—Percent crown reduction of injected midstory stems by species

Species	% Reduction	N
American Hornbeam	100	302
Blackgum	99.8	21
Deciduous Holly	98	61
Green Ash	97.3	64
Hickory	95.2	470
Paw-Paw	99.8	45
Persimmon	97.5	2
Red Maple	92.3	108
Swamp Chestnut Oak	98.3	3
Sweet Gum	98.5	94
Winged Elm	91.8	214
Willow Oak	100	3

EXTENDING THE CAPABILITIES OF AN INDIVIDUAL TREE GROWTH SIMULATOR TO MODEL NON-TRADITIONAL LOBLOLLY PINE PLANTATION SYSTEMS FOR MULTIPLE PRODUCTS

Ralph L. Amateis and Harold E. Burkhart

ABSTRACT

Demand for traditional wood products from southern forests continues to increase even as demand for woody biomass for uses such as biofuels is on the rise. How to manage the plantation resource to meet demand for multiple products from a shrinking land base is of critical importance. Non-traditional plantation systems comprised of two populations planted on the same site and managed for multiple products may be an economical and environmentally attractive alternative. In order to examine the feasibility and profitability of these systems, growth and yield models flexible enough for such regimes will be needed. In this paper we describe how an individual tree growth and yield simulator for loblolly pine (PTAEDA) can be altered to accommodate two populations of loblolly pine trees planted at different densities and spacings on the same site and managed for alternative product objectives. Investigations underway suggest that the individual tree growth model architecture may be a suitable platform for modeling such stands.

INTRODUCTION

By the turn of the 21st century, plantation forestry was practiced across 32 million acres of land in the Southern United States (Fox et al. 2004). The methods of intensive plantation management currently available to managers, including genetically improved planting stock, mechanical and chemical control of competition, the use of fertilizers and the manipulation of stand density through thinning, have equipped them to increase production from less than 90 cubic feet per acre per year common in the 1950s and 1960s to over 400 cubic feet per acre per year today (Fox et al. 2004). The vast majority of these plantations have been established with one population at a specific planting density. While income is sometimes obtained from wood harvested at intermediate thinnings, these plantations generally are managed under the assumption of removing primarily pulpwood in thinnings and aiming at sawtimber at final harvest.

Growth and yield models are tools for making informed decisions about the management of plantations and for estimating the outcomes of those decisions on productivity. As such, most growth and yield models for southern pine plantations are developed at the stand level to model operational management practices that are made at the stand level. Growth data from trees measured on plots in operational stands or from research studies are expanded to per acre values and used to model the growth and development of the stand. Stand-level models for predicting unthinned stand yields were among the first growth and yield models to be developed (MacKinney and Chaiken 1939). Subsequently, size-class distribution models have been developed to distribute total yield across the diameter distribution at any specified age so that estimates by product can be obtained (Avery and Burkhart 2002). In recent years as plantation forestry has become more intensive, data from designed experiments have been used to construct response models for various silvicultural treatments such as thinning (Amateis 2000) and fertilization (Amateis et al. 2000). Component models are often assembled into decision support systems for making stand-level predictions and projections (Amateis et al. 1996). Due to the regularity of the growth and development of single-species even-aged plantations established at a uniform planting density, growth and yield models developed at the stand-level have generally been adequate for modeling the southern pine plantation resource.

NON-TRADITIONAL "FLEX" STANDS

Recently, interest has been growing in non-traditional even-aged plantations, sometimes called "flex" stands. Flex stands are comprised of two populations of trees planted on the same site and managed for alternative product objectives. One population may have genetic, growth or wood quality characteristics that warrant a different planting spacing than the other population. Trees from each population are mixed together on the landscape. Distances between rows and between trees within rows may vary for each population. This creates stands with a different number of trees per acre and different spatial patterns for each population.

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Management regimes may vary for each population. Some of the advantages of non-traditional flex stands over conventional plantations where only one population of trees is grown include:

1. Efficiently produce multiple products on the same site
2. Attractive for areas where markets for biomass and pulpwood are strong.
3. Permits herbicides and fertilizers to be focused on the crop tree component of the plantation.
4. Permits the deployment of expensive technology and genetic material across more acres.
5. Presents high-efficiency thinning opportunities with take-out rows of non-crop trees.

Currently there is no extant growth and yield model in the public domain for modeling flex stands. The dual-population nature and atypical spatial patterns characteristic of flex stands makes traditional stand-level growth and yield models cumbersome tools for estimating yields of these stands. A more useful approach for modeling flex stands may be the individual-tree distance dependent (IDD) modeling architecture. The modeling unit for the IDD modeling approach is the individual tree. Tree height and diameter growth models are developed from parameters associated with the site and characteristics associated with each tree and its neighbors. Tree mortality is a function of the site, the vigor of each tree, and the competitive pressure exerted on each tree from its neighbors. The spatial nature of the IDD framework makes it attractive for modeling the atypical spatial planting patterns associated with flex stands. The loblolly pine IDD model, PTAEDA (Daniels and Burkhart 1975), is a published model that appears promising for use with flex stands. The purpose of this paper is to suggest how PTAEDA can be modified to model flex plantations comprised of two populations of loblolly pine trees growing on the same site and managed for different product objectives.

METHODS AND RESULTS

The PTAEDA IDD model framework has been used for modeling the growth and development of loblolly pine plantations since the mid-1970s. The core individual tree growth equations comprising the PTAEDA simulator are composed of potential height and dbh increment equations modified by functions that take into account individual tree attributes and the competitive environment in which the trees grow. A stand-level equation expressing the potential height increment of all trees in the stand based on site index and a tree-level potential diameter increment equation based on how open grown trees of the same dbh and age grow are modified by a competition index (Hegyi 1974) that reflects the intra-specific competitive pressure exerted by neighboring trees. Trees are assigned coordinate locations on a x-y grid and annual growth is predicted. Suppression induced mortality occurs as the growth rate of less vigorous trees slows in relation to more vigorous neighbors. Over the past 35 years, the PTAEDA IDD simulator has evolved to keep pace with changes in loblolly pine plantation management. In the mid-1980s the core equations in the simulator were applied to a region-wide set of growth data collected from operational loblolly pine plantations established on cutover, site-prepared areas (Burkhart et al. 1987). Mid-rotation fertilization response functions (Hynynan et al. 1998) and juvenile growth response to early site preparation, fertilization and competition control treatments (Westfall et al. 2004) were fitted to appropriate data and incorporated into the simulator in the 1990s. Enhanced thinning and pruning algorithms were added during the same period.

The software has evolved over the same period as well. Originally coded in fortran and executed on large mainframe computers common in the 1970s, the fortran code was migrated to the DOS-based PC platform of the 1980s to make the simulator available to a broader base of users. In the 1990s the fortran code was converted to C and the simulator was made compatible with Windows-based operating systems gaining favor at the time. The current version (version 4.0) has enhanced graphical capabilities, a streamlined user interface, customizable merchandizing and output options, and an economic analysis package. It is fully compatible with the latest Windows-based computers.

In order for PTAEDA to be applied to the current generation of flex stands some additions and alterations to the software have been made:

1. A graphical tool was created and added to the user input options to allow a user to define a flex stand pattern. The pattern is the spatial arrangement of one or two populations (A or B) of loblolly pine in the stand. Any flex stand pattern that can be expressed with up to 5 rows and 5 trees within the row can be simulated. Distances between rows and distances between trees within each row can be set by the user. The determination of which rows and which trees within each row are assigned to population A and population B are made by the user. Once the flex pattern has been defined it is propogated within the simulator to create an entire stand.
2. Each population is defined by two attributes: site index and the percent of the trees of sawtimber and pulpwood quality. Edit boxes were created to accept these inputs from the user. In the simulator each tree is assigned to a population (either A or B) with an associated site index value and stem quality code (sawtimber or pulpwood quality).
3. An additional thinning algorithm was added to allow the removal of all population B trees.

Figure 1 shows an example flex stand pattern developed for two populations of loblolly pine. One row of population A is followed by two rows of population B. Inter-row distance between population A and adjacent row of population B is 8 feet. Inter-row distance between adjacent rows of population B is 4 feet. Twelve feet separate the trees in the population A rows and 5 feet separate the trees in the population B rows. In this example, population A and B trees would have exhibited site indexes of 80 and 70 feet (base 25), respectively. The percent of trees of sawtimber quality would be 80 and 50 for populations A and B, respectively. Figure 2 shows how this flex stand looks on a per unit area basis after it is propagated within the simulator.

By relaxing the single population and uniform spacing constraints of the original PTAEDA, a modified simulator was developed that can accommodate the dual population and non-uniform spacings associated with flex stands. Data from a few very high site index flex stands were available to test and debug the modified simulator. Preliminary results from projections of these stands to rotation age indicate:

1. The IDD modeling architecture looks promising for easily defining and modeling the growth and development of a wide range of flex stands.
2. Estimates of yields on moderate to good sites appeared reasonable. However, under prediction of yields at rotation for very high site index stands planted with elite genetics was also exhibited.

DISCUSSION

Evaluating the growth, development and ultimately the profitability of flex stands presents unique challenges. The use of two populations of trees with different growth or wood quality characteristics and planted at non-traditional spacing arrangements for different product objectives means that traditional even-aged stand-level growth and yield models may not provide adequate estimates of the productivity of the stand as a whole or of either individual population. An individual tree distance dependent (IDD) modeling system may prove tractable for such stands. In IDD systems where the individual tree is the modeling unit of interest, trees grow based on their individual genetic characteristics, their environment and the competitive forces around their individual growing space. Distributional assumptions common with stand-level models need not be applied to IDD systems. Instead, with IDD systems, individual tree attributes such as volume or weight are summed to obtain stand-level or diameter class-level estimates of yield. In an IDD simulator, management treatments such as weed control, fertilization, thinning and pruning can be applied to a particular population of trees in the stand. This makes it possible to evaluate the impact of management scenarios on specific portions of the stand as well as how those scenarios affect the stand as a whole.

The modifications to the PTAEDA software discussed above allow flex stands to be modeled within the framework of an IDD growth and yield model. Preliminary evaluation of the performance of the model suggests that reasonable predictions can be made for flex stands established on moderate to good sites. However, the core growth and yield equations within the simulator will need modification in order to properly represent the growth relationships associated with flex stands exhibiting very high site index values. In particular, growth relationships associated with genetically different populations must be understood and then modeled in order to properly extend the IDD system to the elite genotypes currently being deployed as flex stands. Investigations are now ongoing in the following areas:

1. There is some evidence that the simple diameter ratio, distance weighted competition index (Hegyi 1974) currently employed in PTAEDA may not be the best measure of competition for all populations at all ages of stand development. Additional measures of competition that include height may improve the predictive capability for some populations of loblolly pine deployed in flex stands.
2. The identification of competitors in IDD models is critical because the number and size of competitors determine the competition index associated with each tree. The variable radius plot methodology used in PTAEDA to identify competitors of subject trees is being tested against other methods of identifying competitors in order to find the best method for non-traditional spatial patterns.
3. Questions concerning competitive relationships between trees are also under investigation. For example, will trees in plantings of varietals compete more or less aggressively with each other than individuals planted in stands of varying genetic makeup? Do different genotypes use available growing space differently and, if so, how? Will some genotypes favor diameter growth over height growth compared to other genotypes and, if so, how can this disposition be accounted for in the competition index?

The outcome of these and other investigations will lead to a more robust simulator that should better reflect the growth dynamics in non-traditional flex stands.

The flex stand simulator discussed here was developed for one or two populations of loblolly pine. The populations are defined by different site indexes, planting densities, and stem quality characteristics. The system is flexible enough, however, to accommodate additional defining characteristics for each population, including different species, as long as the competitive relationships between the two populations can be quantified. For example, future versions of PTAEDA could accommodate flex stands comprised of pines and hardwoods growing together on the same site if the competitive relationships between the populations were known.

Relatively few operational flex stands comprised of two populations of loblolly pine have been established to date.

Those that do exist are very young (typically less than 8 years old). Many are mixtures of rows of mass control pollinated or varietals as the elite population managed for wood products on longer rotations inter-planted with rows of open pollinated material at close spacings for biomass or pulpwood production on short rotations. Thus, there is a paucity of data for developing, testing or calibrating models for these stands. As data from these stands becomes available, the work done here on the PTAEDA IDD framework and subsequent refinements to it will facilitate evaluation of the growth and development of the first generation of flex stands.

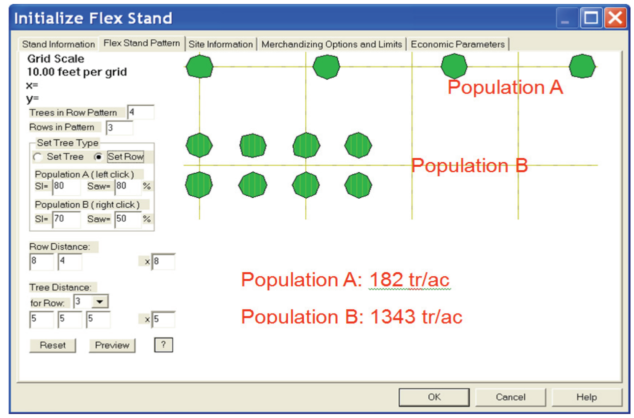

Figure 1—Example flex stand comprised of two populations (A and B) deployed as a row of population A followed by two rows of population B.

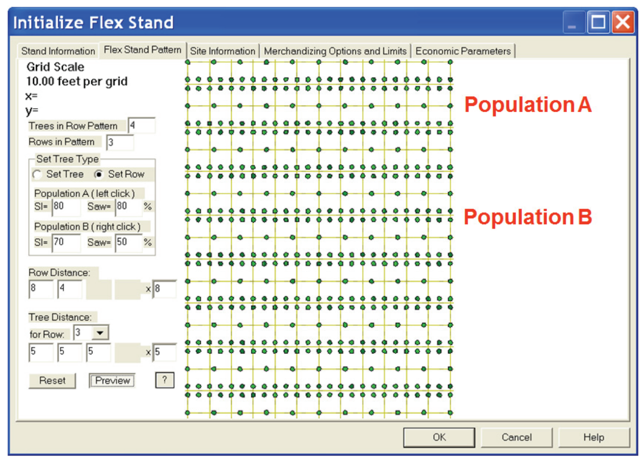

Figure 2—Example flex stand defined in Figure 1 shown fully deployed across the landscape at plantation establishment.

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LONGITUDINAL VARIATION IN WOOD SPECIFIC GRAVITY OF PLANTED LOBLOLLY PINE IN THE SOUTHERN UNITED STATES

Finto Antony, Laurence R. Schimleck, Richard F. Daniels, and Alexander Clark

Loblolly pine (*Pinus taeda* L.) is the most important plantation species grown in the southern United States, having more than half of the standing pine volume. Wood from loblolly pine is a principal source of raw material for the pulp and paper industry and is desirable for the production of lumber and composite wood products. The quality of wood produced from a loblolly pine tree is defined by its physical and mechanical properties. Of these, specific gravity (SG) is an important measure of wood quality (Panshin and de Zeeuw 1980), and varies both with tree height (Megraw 1985; Zobel and vanBuijtenen 1989) and with geographic locations (Clark and Daniels 2002; Jordan et al. 2008). The objectives of the present study were to model the regional and within tree variation in disk SG of loblolly pine.

The Wood Quality Consortium at the University of Georgia and the United States Department of Agriculture (USDA) Forest Service Southern Research Station sampled planted loblolly pine trees across its natural range to study the vertical variation in wood SG. Trees were sampled from 135 stands from six physiographic regions across the southeastern US. Regions sampled included: 1- southern Atlantic Coastal Plain, 2- northern Atlantic Coastal Plain, 3- Upper Coastal Plain, 4- Piedmont, 5- Gulf Coastal Plain and 6- Hilly Coastal region. A minimum of 12 plantations from each of the six physiographic regions were sampled. The stands selected for sampling included 20- to 25-year-old loblolly pine plantations planted at 1250 or more trees per hectare and with 625 trees per hectare or more after thinning. Only stands that were conventionally managed with no fertilization (except phosphorus at planting on phosphorus deficient sites) and no competition control were sampled. Three trees from each stand were felled and cross sectional disks of 3.8 cm thickness were collected from 0.15, 1.37 m and then 1.52 m intervals along the stem up to a diameter of 50 mm outside bark. Disk SG based on green volume and oven-dry weight was measured for each disk collected at different heights.

A semiparametric model, a flexible statistical approach to explain nonlinear trends, was proposed to explain the within tree (with tree height) and regional variation in disk SG. Based on the fitted model, disk SG follows a decreasing trend with relative height (Figure 1). Significant differences were observed among regions (p-value <0.0001). The mean trend in disk SG of trees from the southern Atlantic and Gulf Coastal Plain was observed to be higher than other physiographical regions (Upper Coastal, Hilly Coastal, northern Atlantic Coastal Plain and Piedmont). The lowest disk SG was observed for trees from the northern Atlantic Coastal Plain.

Our study suggests that the stem of loblolly pine can be divided into three zones based on the longitudinal variation of disk SG. Based on the first derivative of fitted semiparametric model for all regions, mean SG decreased rapidly from the base of the tree to a relative height ~0.1; SG then decreased at a decreasing rate between relative heights of ~0.1 - ~0.3; for relative heights >~0.3 SG decreases at constant rate. These findings agree with the three segmented classification of the stems of loblolly pine proposed by Burdon et al. (2004).

The mean trend of disk SG was highest for the southern Atlantic and Gulf Coastal Plain. The overall mean SG observed for these two regions was 0.46, which was higher than the mean disk SG observed for the other regions (0.42) (Table 1). The high SG of trees from southern Atlantic and Gulf Coastal Plain might be attributed to two major reasons: (1) reduced length of core wood formation and proportion of core wood formed in these two regions compared to other inland regions (Clark and Daniels 2002; Jordan et al. 2008); (2) high latewood percent in the rings of trees growing in these regions (~40 %) compared to other regions (~35 %). The proportion of latewood formed is highly correlated with summer precipitation, mean annual temperature and number of growing days. The trees growing in the southern Atlantic

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and Gulf Coastal Plains, on average, receive more summer precipitation, have a higher mean annual temperature and more growing days than the other regions (Clark and Daniels 2002).

Table 1—Mean stand attributes collected from six regions, standard deviation in parenthesis

Region	Age	DBH (cm)	Total Ht (m)	Disk SG
southern Atlantic	22.73 (1.82)	24.07 (4.58)	20.86 (2.50)	0.45 (0.06)
northern Atlantic	22.46 (1.61)	24.56 (3.74)	18.89 (2.48)	0.41 (0.05)
Upper Coastal	23.00 (1.46)	24.07 (4.87)	19.39 (3.08)	0.43 (0.05)
Piedmont	23.08 (2.01)	23.90 (4.54)	18.19 (2.11)	0.42 (0.05)
Gulf Coastal	23.22 (3.26)	21.16 (3.79)	19.54 (2.58)	0.46 (0.05)
Hilly Coastal	23.86 (3.58)	23.39 (4.12)	19.59 (2.75)	0.43 (0.05)

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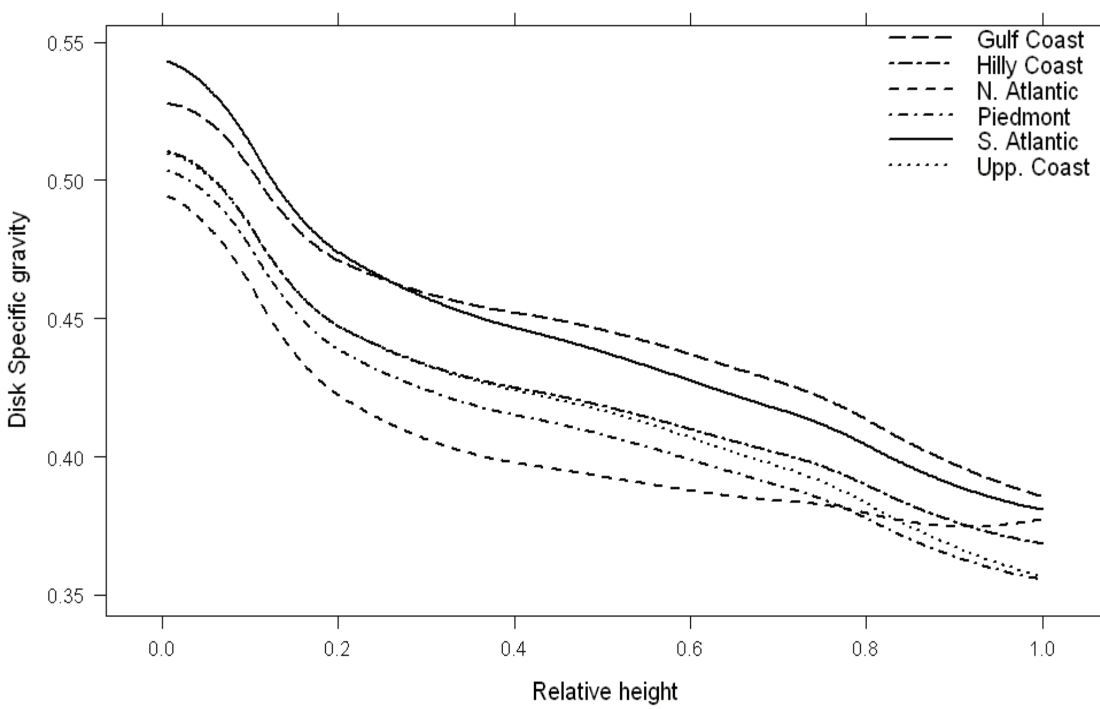

Figure 1—Predicted disk SG for six regions from fitted semiparametric model.

GENETIC EFFECTS ON STAND-LEVEL UNIFORMITY, AND ABOVE- AND BELOWGROUND DRY MASS PRODUCTION IN JUVENILE LOBLOLLY PINE

Michael J. Aspinwall, John S. King, Steven E. McKeand, and Bronson P. Bullock

Several decades of tree improvement operations have drastically increased loblolly pine plantation productivity in the southern U.S. (McKeand et al., 2003). This work has lead to the availability of a number of highly productive open-pollinated and full-sib families (McKeand et al., 2006). In addition, vegetative propagation (somatic embryogenesis) has also made it possible to clonally multiply elite genotypes (Bettinger et al., 2009). Open-pollinated, full-sib, and clonal trees contain varying amounts of inherent genetic variation which allows land managers to balance the gains and risks of deploying less genetically diverse, yet potentially more productive genotypes (Bridgwater et al., 2005). In many forest plantation species, deployment of clones has been suggested to result in more uniform plantation growth and development (DeBell and Harrington, 1997, Bettinger et al., 2009), and greater stand uniformity may lead to greater resource-use efficiency and enhanced productivity (Binkley et al., 2010, Ryan et al., 2010a). Clones have been suggested to show more uniform growth and development because they possess no tree-to-tree genetic variation (Zobel and Talbert, 1984). However, there are no known studies in loblolly pine and few other forest plantation species that have directly investigated the impact of genetic homogeneity on stand growth, development, and uniformity. Furthermore, genetic variation in stand uniformity and above- and belowground dry mass partitioning may ultimately impact stand resource capture and carbon (C) sequestration. Additionally, increases in C sequestration with genetically improved loblolly pine genotypes will be proportional to increases in volume or dry mass production (Ryan et al., 2010b). Therefore, with rising atmospheric CO_2 concentrations expected to continue, increases in above- and belowground dry mass production with improved loblolly pine genotypes could provide a potential means of increasing C sequestration and offsetting further fossil fuel emissions (Johnsen et al., 2001, Ryan et al., 2010b).

The goal of this study was to compare stand-level uniformity, dry mass production, and partitioning among several loblolly pine genotypes which possess varying amounts of inherent genetic variation. Our hypothesis was that less genetically diverse genotypes (clones) would show more uniform stand-level growth relative to more genetically diverse genotypes (full-sib and half-sib families). To examine genetic effects on stand uniformity and productivity, we grew ten different genotypes (3 open-pollinated families, 3 full-sib families, 3 clones, and 1 seed orchard mix variety) in a plantation setting for four years, at two different planting densities (~539 and 1077 trees ha^{-1}), and used allometric relationships to estimate standing dry mass and annual dry mass production. The study site was located at North Carolina State University's Hofmann Forest in Onslow County, North Carolina (34°49.4'N, 77°18.2'W).

In the low planting density treatment, age 3 total standing dry mass of the most productive genotype (5.8 Mg ha^{-1}) was 82% higher than that of the least productive genotype (3.2 Mg ha^{-1}) (Figure 1). In the high planting density treatment, age 3 total standing dry mass of the most productive genotype (11.4 Mg ha^{-1}) was 110% higher than that of the least productive genotype (5.4 Mg ha^{-1}) (Figure 1). Genetic differences in annual dry mass production were of a similar magnitude with peak rates during the third year as high as 4.2 and 8.2 Mg ha^{-1} yr^{-1} in the low and high planting density treatments, respectively. More genetically homogeneous genotypes did not show greater stand-level uniformity under operational management conditions. Over time, genotypes showed no consistent differences in the coefficient of variation (CV) for ground-level diameter; however, two full-sib and two half-sib families showed significantly lower CV's for total tree height than all three clones. Moreover, genotypes with lower CV's for height growth displayed greater stand-level dry mass production which supported the premise that greater stand uniformity will lead to enhanced productivity. Since uniformity and stand-level productivity of loblolly pine clones will be principally governed by environmental heterogeneity, our results highlight the need for silvicultural prescriptions that maximize site uniformity. In addition, our results demonstrate how the deployment of highly productive loblolly pine genotypes may provide a means of enhancing southern pine ecosystem sustainability by sequestering C in both harvestable aboveground biomass and woody belowground biomass.

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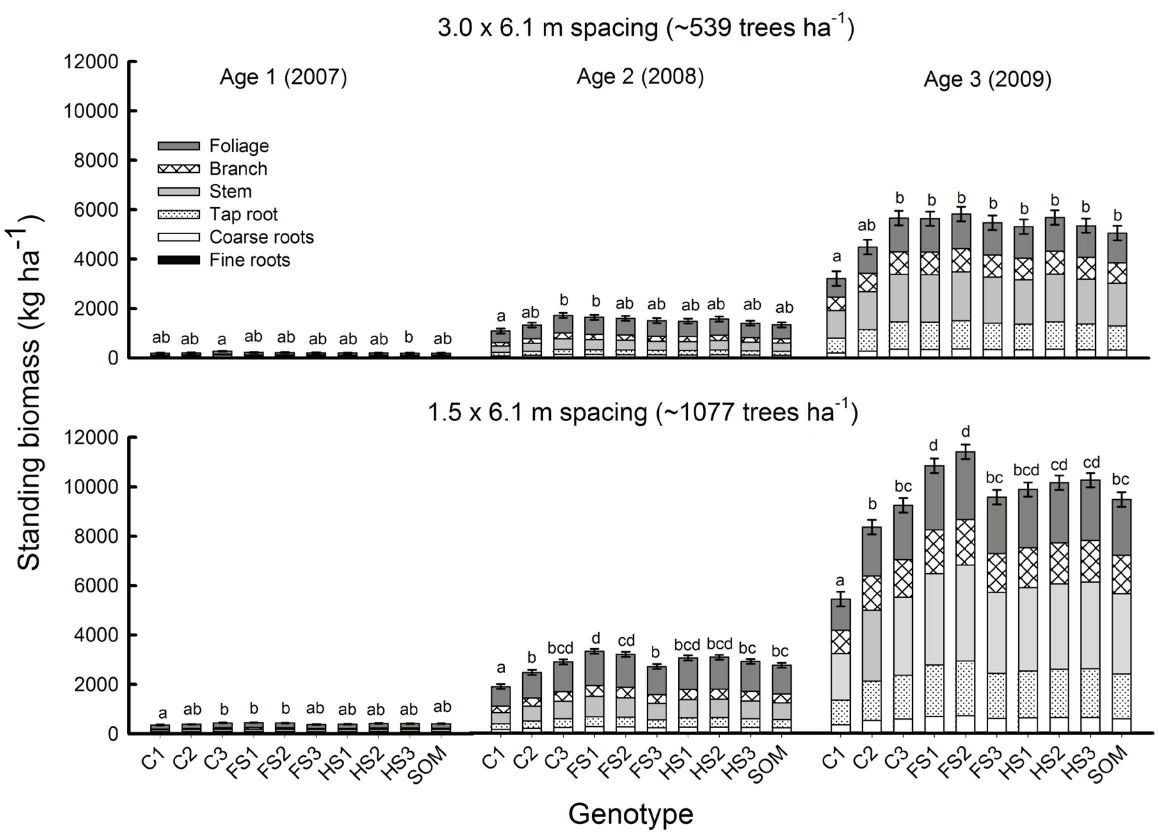

Figure 1—Estimates of component and total standing dry mass among different loblolly pine clones (C1, C2, C3), full-sib families (FS1, FS2, FS3), half-sib families (HS1, HS2, HS3), and one seed orchard mix (SOM) variety after three years of growth in the Hofmann Forest Genetics × Spacing × Thinning (GST) study on the lower Coastal Plain of North Carolina. Within each age group and spacing treatment, genotypes with the same letters are not significantly different at the P≤0.05 significance level.

A WATERSHED-BASED ENVIRONMENTAL AND REGULATORY DATA ANALYSIS SYSTEM FOR THE FOREST PRODUCTS INDUSTRY

John Beebe

A watershed-based data analysis system was created as a tool for forest product companies to better understand potential implications from environmental regulations. Also known as the Receiving Water Database (RWDB), this data system was designed with the purpose of assisting companies that own pulp and paper mills, wood product facilities, and commercial timberlands by assessing changes in water quality standards, aquatic life criteria, critical habitat designations, watershed-based permitting, and water resource management policies. Assessments using this database system have helped the industry as a whole by providing a unique enviro-regulatory perspective by combining environmental and regulatory information in a watershed-based GIS. The core of the hydrogeographical information is the interagency spatial product known as the National Hydrography Dataset or NHD, which allows for river and stream reach information to be analyzed in relationship to its drainage network.

One of the main functions of the data analysis system has been to support industry analysis and input into regulatory processes in areas where rivers and other surface waters have been identified as impacted from point and/or nonpoint sources. For example, the system played a key role for forest product companies operating in Florida by analyzing spatial information on water quality monitoring and nutrient ecoregions to address proposed numeric criteria for nitrogen and phosphorus, and the attainability of such criteria in different regions of the state (Figure 1). Another important use of the RWDB involved assessing the potential impact of nutrient loadings in areas where forest products and other industries operate, particularly in states with accelerated nutrient criteria development schedules. In response to similar regulatory initiatives, the tool has also been used in various regional and state analyses to advise forest product companies that may become involved in or need to respond to TMDL (Total Maximum Daily Load) development, especially for manufacturing facilities that are subject to changes in their water discharge permits.

In response to Gulf of Mexico hypoxia, another use of the tool involved an industry analysis of nutrients in the Mississippi River basin to estimate the proportion of industry loadings in watersheds relative to other sources. This analysis concluded that the majority of nutrients that enter the river were primarily from agriculture, while only a very small fraction were associated with the forest products industry. Other research using the RWDB involved an assessment of regulatory changes pertaining to aquatic life criteria by evaluating different forms of streamflow statistics to be used in a proposed water withdrawal policy. The analysis compared the frequency of critical flow levels for various river systems in the Southeast U.S., and demonstrated that low flow conditions in many areas were part of a normal, natural variation for many river systems in which industry facilities and commercial timberlands operate. Results from this analysis had important biological implications, and the conclusions were helpful in shaping policies that put water withdrawal permits on a more rational, scientific basis (NCASI 2009).

The system has also supported the establishment of water quality studies including one for an experimental watershed in Louisiana (Ice and others 2010, Xu and others 2008) which involved combining spatial information and research objectives for investigating dissolved oxygen patterns in response to silvicultural best management practices. The database has also been used to evaluate potential regulatory changes involving threatened and endangered species (including the Atlantic Sturgeon and the Altamaha Spinymussel), and the current system is being used in conjunction with an ongoing long-term receiving water study to evaluate biological conditions and adaptations of aquatic life in response to anthropogenic stressors. Periodic revisions to the framework of this database system have been and will continue to be made to make the tool a more efficient and comprehensive environmental data resource for the forest products industry.

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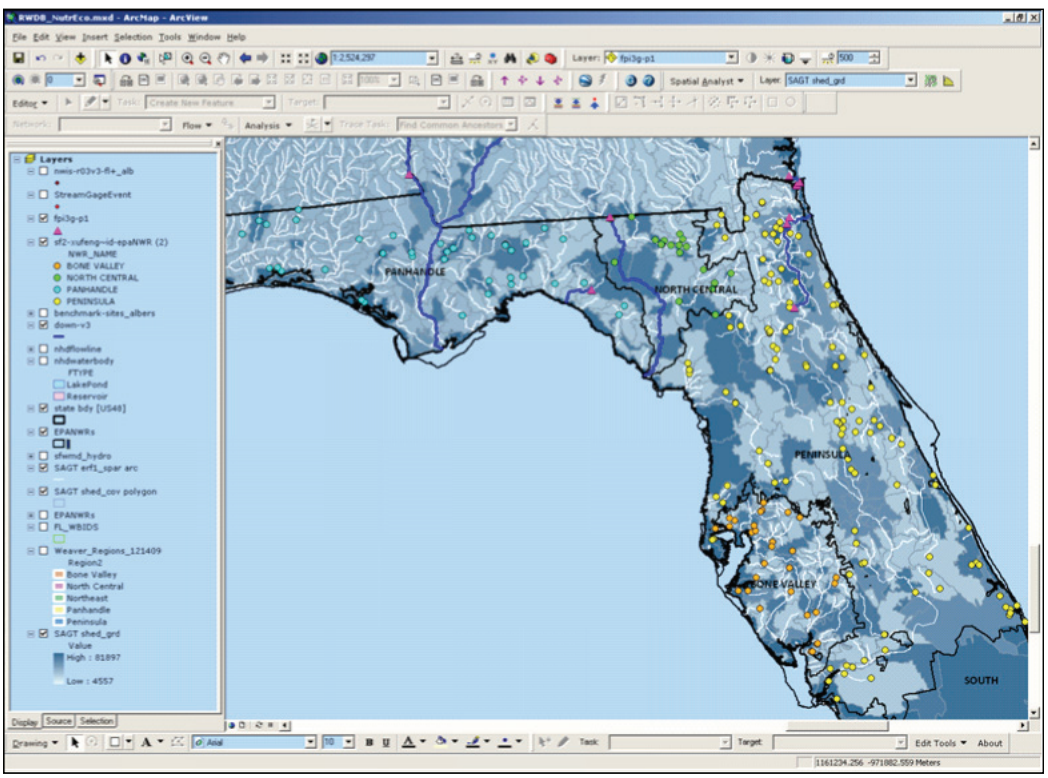

Figure 1—The watershed-based analysis system is designed to identify the industry's involvement in areas where waters that are subject to changes in water quality regulations. In this case the tool was used to evaluate water quality data in response to numeric nutrient criteria proposed for different ecoregions of the state.

EFFECTS OF SILVICULTURAL MANAGEMENT ON LOW GRADIENT STREAM WATER QUALITY IN LOUISIANA

John Beebe, George Ice, Y. Jun Xu, Abram DaSilva, and Richard Stich

Oxygen depletion in rivers and streams is among the top 5 impairment types most frequently cited in state water quality reports in the U.S., especially in the South. Such impairments require the development of Total Maximum Daily Loads (TMDLs) or other strategies to ameliorate low dissolved oxygen (DO) levels or high biochemical oxygen demand (BOD). TMDLs allocated to forested waterways in some states have called for reductions in BOD through appropriate harvesting and site preparation techniques. Specific silvicultural prescriptions for riparian areas following best management practice (BMP) guidelines can help mitigate elevated BOD levels in streams. However, recent surveys and research on streams in the South, including unimpaired waterbodies, have encountered naturally-occurring low DO concentrations that are already below state water quality standards (Ice and Sugden 2003).

As part of a larger study conducted by Louisiana State University (Xu and others 2008, Mason and others 2007), this body of research examined changes in DO for a low gradient stream in north-central Louisiana, the role of common silvicultural practices, and the effectiveness of BMPs in maintaining water quality. The DO component of this study employed a before-after-control-impact (BACI) design following Smith (2002), and monitoring water quality parameters at locations above and below a planned forest harvest unit. Water quality was monitored using instrumentation that collected data on DO, temperature, conductivity, and turbidity at 15-minute intervals. This allowed daily DO fluctuations over extended periods of time to be assessed. The clearcut harvest was conducted during the summer of 2007 following current forestry BMP guidelines, and more than 1 year of data was collected before harvest to serve as a baseline.

Water quality measurements taken upstream and downstream of the timber harvest both showed a similar annual pattern, with lower DO in summer months and higher DO in winter months. Measured concentrations of DO at a site located upstream of the harvest unit were below the state standard (3 milligrams per liter) 47 percent of the time, while DO concentrations downstream of the harvest unit were below the state standard 39 percent of the time. During the pre-harvest period DO levels at the upstream site were slightly lower than those at the downstream site. In the post-harvest period the difference increased significantly ($\rho<0.001$) with higher DO measured at the site downstream of the harvest unit. Despite there being no tributaries and only minor differences between upstream and downstream flow conditions, as documented herein by DaSilva and others (2011), these post-harvest observations were evident at various times, covering a range of seasons, in subsequent years. However, the difference in DO was most noticeable during winter when high surface runoff often occurred.

Daily monitoring data from the upstream and downstream locations also included water level measurements for estimating discharge and estimated mass loadings of BOD, inorganic carbon, dissolved organic carbon, and total organic carbon. The study of this low-gradient forested stream in Louisiana demonstrated pre-harvest DO concentrations are naturally low, but are still able to maintain stream conditions for supporting aquatic life (Klimesh and others 2011). In light of this, standards set by state agencies should reflect site-specific and/or seasonal conditions. Post-harvest results from this study, as well as those by researchers in other Southern states, also suggest silvicultural management practices have little or no impact on water quality when BMP guidelines are followed. Impairment determinations and TMDL allocations for existing impairments, therefore, should not only consider the demonstrated effectiveness of forest BMPs, but also the need to account for the natural conditions exhibited in many low gradient streams and other waterbodies in the South.

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HERBICIDE SITE PREPARATION AND RELEASE OPTIONS FOR EUCALYPTUS PLANTATION ESTABLISHMENT IN THE WESTERN GULF

Michael A. Blazier, John Johnson, Eric L. Taylor, and Brad Osbon

ABSTRACT

Cold-tolerant species of eucalyptus (*Eucalyptus* spp.) are increasingly grown in the Western Gulf region as short-rotation pulpwood feedstock. Operational chemical suppression of competing vegetation has been relatively costly and inefficient because it requires frequent applications of glyphosate applied via backpack sprayers. A series of studies were conducted in eucalyptus plantations in southwest Louisiana to identify herbicides that can be broadcast-applied by aircraft or ground equipment, providing effective competition suppression without damaging eucalyptus. A trial of 12 herbicide treatments indicated that oxyflurofen and sulfometuron methyl were viable alternatives to directed glyphosate for release treatments of first-year *Eucalyptus macarthurii* seedlings because both herbicides reduced competing vegetation and promoted *E. macarthurii* height growth better than directed glyphosate. Further testing of sulfometuron methyl as a release herbicide for first- and second-year *E. macarthurii* plantations revealed that rates in excess of 1.13 oz ai/acre damaged *E. macarthurii* seedlings. A trial of four pre-plant site preparation herbicide treatments revealed that first-year *E. macarthurii* seedlings planted in bedded and non-bedded plots were not significantly damaged by triclopyr, imazapyr, and hexazinone applied two months pre-planting.

INTRODUCTION

Paper mills that require hardwoods as raw material often have difficulty acquiring sufficient supplies of local trees when conditions are wet. Mills rely on hardwoods grown in moist bottomlands that cannot be harvested during wet periods to protect soil and water quality. When mills cannot obtain enough local trees, they must bring in chips by rail and/or barge at high expense. The emergence of new markets for small-diameter hardwoods as raw material for biofuels such as wood pellets is likely to exacerbate limitations on hardwood availability. To overcome these hardwood supply problems, forest managers need new options for quickly growing plantations of hardwoods, preferably on upland soils that provide a wider harvesting window (Blazier and others 2010).

Eucalyptus plantations have the potential to boost the hardwood production potential in portions of the southeastern U.S. Under proper management, eucalyptus grows rapidly, is resistant to disease and insects, and has wood properties highly desired for multiple uses. Eucalyptus has excellent fiber properties for paper, engineered and reconstituted wood products, and bio-based products. When pelletized and direct-fired in a power plant, eucalyptus has heat energy values that exceed many native tree species. Eucalyptus plantations can reach a harvestable size (up to 70 ft. in height and 7 inches in DBH) for pulpwood or biofuel in as little as 6 to 8 years. Under proper management, eucalyptus has the ability to produce 20 green tons per acre per year. This growth rate compares favorably to the commonly planted loblolly pine, which produces up to 8 tons per acre per year. Eucalyptus plantations can achieve these high growth rates on upland soils, which may provide the forest products industry with a greater supply of hardwood trees grown relatively close to paper and biofuel production facilities (Blazier and others 2010).

Eucalyptus is grown in many countries as a short-rotation pulpwood feedstock. As a result, much of the world's paper of hardwood origin contains eucalyptus. However, many eucalyptus species are intolerant of frost, or only tolerate light frosts down to about 27°F. This susceptibility to cold damage has historically restricted the viability of eucalyptus plantation management in much of the U.S. Tree breeding research has recently identified cold-resistant eucalyptus trees. These trees are tolerant of temperatures down to 17°F. This cold tolerance makes eucalyptus plantation management viable in southern portions of most states in the southeast U.S. As a result of the identification of cold-tolerant eucalyptus, the forest products industry is beginning to plant some eucalyptus plantations. For example, there were approximately 3,000 acres of eucalyptus plantations throughout southwest Louisiana and southeast Texas as of January 2010 (Blazier and others 2010).

A substantial limitation to establishment and productivity of eucalyptus plantations is competing vegetation. Eucalyptus is highly intolerant of competition, particularly early in the rotation (Adams and others 2003, Garau and others 2009).

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However, there are relatively few herbicides with labeling for eucalyptus species in the U.S. that can be broadcast over trees and provide broad-spectrum control. Forest managers have therefore relied heavily upon glyphosate for site preparation and release of eucalyptus plantations in the Western Gulf region. Release treatments with glyphosate have proven to be relatively inefficient and costly because it is often necessary to apply the glyphosate as a directed spray via backpack. Relatively few contract crews are available for such work, which results in large acreages to be covered per crew. With large acreages to cover, some tracts have poor suppression of competing vegetation because spraying is done before there is sufficient foliage for adequate efficacy of glyphosate. Other tracts have inadequate control of competing vegetation because spraying is done after the vegetation has grown too large for sufficient glyphosate efficacy. It is also necessary to spray sites three to four times per season to sufficiently control competing vegetation with glyphosate due to its lack of residual activity. This lack of residual activity also inhibits the effectiveness of pre-plant broadcast applications of glyphosate done for site preparation.

A more cost-effective and efficient alternative to directed spray of glyphosate would be herbicides with broad-spectrum control of competing vegetation that can be broadcast by ground or air over eucalyptus plantations without damaging eucalyptus. The objective of this series of trials was to identify the efficacy and eucalyptus tolerance of herbicides applied after planting as release treatments and prior to planting for site preparation.

METHODS

In 2008, a trial (RELEASE1) was established in a first-year *Eucalyptus macarthurii* (H. Deane and Maiden) plantation near Merryville, LA (30° 42' 52.57" N, 93° 31' 17.91" W). Soil at the site was classified as a Malbis fine sandy loam, which is a fine-loamy, siliceous, subactive, thermic Plinthic Paleudult with a pH range of 4.5 to 5.0 (USDA NRCS 2002). Dominant vegetation of the site included wooly croton (*Croton capitatus*), rosette grass (*Dichanthelium spp.*), and purple cudweed (*Gamochaeta purpurea*). The previous stand had been a slash pine (*Pinus elliotti* Engelm.) plantation that had a burning cycle during its rotation. In April 2008, the herbicide treatments listed in Table 1 (with the exception of the directed glyphosate treatment) were applied via a backpack-mounted, CO2-powered sprayer with a KLC9 tip mounted atop a 15 ft. spray boom to simulate aerial broadcast of herbicide. Directed glyphosate treatments consisted of a 5 percent solution of glyphosate applied via hand-pump backpack sprayer in April, June, and August 2008. Three replications of each treatment were applied in a completely randomized design to plots that were 30 ft. wide and 100 ft. long. By June 2008 competing vegetation had returned to all plots, so all treatments were re-applied. At 5,10, and 15 weeks after the April 2008 application, ground coverage and tree condition were assessed. Ground coverage was determined as the proportion of ground covered by living vegetation within a 1-ft^2 quadrat at four random locations per plot. Tree condition score was measured by assigning a qualitative score of 1 to 9 to ten trees in the center of each plot. The scores, which accounted for increasing levels of damage severity, were: 1=no apparent damage, 2=chlorotic leaves, 3=dead leaves in upper stem, 4=dead leaves in lower stem, 5=tip dieback, second flush, 6=tip dieback, 7=dieback to bottom of tree with resprouting, 8=dieback to bottom of tree with no resprouting, 9=dead. Tree survival and total height was measured immediately prior to treatment, in October 2008, and December 2009. Height growth 1 and 2 years after treatment was calculated as the difference between the October 2008 and December 2009 height measurements and the April 2008 height measurements.

As of October 2008 it was apparent that sulfometuron methyl was an effective herbicide in the RELEASE1 trial, so follow-up trials (RELEASE2 and RELEASE3) were conducted to further elucidate *E. macarthurii* tolerance of sulfometuron. The RELEASE2 trial was established in a first-year *E. macarthurii* plantation, and the RELEASE3 trial was established in a second-year *E. macarthurii* plantation. Both trials were established near Merryville, LA (30° 44' 23.34" N, 93° 30' 16.49" W). Soil at the sites for both trials was classified as a Kolin silt loam, which is a fine-silty, siliceous, active, thermic Glossaquic Paleudalf with a pH range of 4.5 to 5.0 (USDA NRCS 2002). In April 2009, the treatments listed in Tables 2 and 3 were applied for the RELEASE2 and RELEASE3 trials, respectively. Previous stand conditions, application protocol, experimental design, and plot size of the RELEASE2 and RELEASE3 trials were identical to those of the RELEASE1 trial. For the RELEASE2 and RELEASE3 trials, ground coverage was assessed in June 2009 and tree condition was measured in June and October 2009 using the same protocol as in the RELEASE1 trial. Tree height was measured immediately prior to treatment and in December 2009 for the RELEASE2 and RELEASE3 trials as well.

In 2008, a trial (PREP) was established at the same location as the RELEASE2 and RELEASE3 trials to determine the effects of several herbicides applied prior to planting on eucalyptus survival, condition, and growth. The PREP trial also explored the influence of bedding after herbicide application on eucalyptus survival, condition, and growth. Herbicide treatments, listed in Table 4, were applied in August 2008. Previous stand conditions, application protocol, and plot size of the PREP trial were identical to those of the trials described above. Bedding was done in appropriate plots in September 2008 with a skidder-drawn bedding plow. Three replications of all bedding and herbicide treatment combinations were conducted. *Eucalyptus macarthurii* seedlings were planted in all plots in October 2008. In December 2009, survival, tree condition, total height, and groundline diameter were measured.

All treatment effects were analyzed for variance (ANOVA) at an alpha of 0.05 using the MIXED procedure of the SAS System (SAS Institute, Inc. 2006). When an ANOVA indicated significant treatment effects, treatment means were calculated and separated by the DIFF option of the LSMEANS procedure. The DIFF option provided multiple comparisons of treatment means by invoking t-tests to determine significant differences between all possible treatment combinations. All variables for the RELEASE1, RELEASE2, and RELEASE3 trials were analyzed with a model that had herbicide treatment as a fixed effect. All variables for the PREP trial were analyzed with a model that had herbicide treatment, bedding treatment, and all possible combinations of the herbicide and bedding treatments as fixed effects.

RESULTS AND DISCUSSION

Ground coverage differed among treatments of the RELEASE1 trial at only five weeks post-treatment (Table 1). Ground coverage in response to oxyflurofen applied at 0.89 pt ai/acre was the lowest among all treatments. Among other treatments, both rates of sulfometuron methyl, the lower rate of oxyflurofen, the lower rate of quizalofop, and sulfosulfuron had lower ground coverage than the unsprayed control. Each of these herbicides, particularly oxyflurofen and sulfometuron methyl, are formulated for control of a relatively broad array of broadleaf and grass competition and residual activity in soil. Interestingly, ground coverage of the directed glyphosate treatment (which was included in this trial because it was analogous to operational spray treatments) was similar to the control even five weeks after treatment. This result is likely due to glyphosate's lack of residual soil activity, which permitted re-establishment of vegetation. However, by ten weeks after treatment the effects of all herbicides on ground coverage had subsided as indicated by the similarities in ground coverage among all treatments.

None of the herbicides and rates tested in the RELEASE1 trial significantly affected tree survival and condition score (data not shown). However, differences among the treatments in tree height growth were observed (Table 1). At one and two years post-treatment, trees treated with the higher rates of oxyflurofen and sulfometuron methyl tested had the greatest height growth among treatments. The relatively low ground coverage observed five weeks post-treatment for these treatments as well suggests that the better suppression of competing vegetation of these treatments led to improvements in tree height growth as late as two years post-treatment.

Although oxyflurofen and sulfometuron methyl were the most effective herbicides in the RELEASE1 trial, sulfometuron methyl is a substantially cheaper herbicide. As a result, the RELEASE2 trial was developed to determine first-year eucalyptus tolerance to a wider array of sulfometuron methyl rates. Ground coverage of all sulfometuron methyl rates was similarly lower than that of the control, so there was no appreciable benefit to applying rates greater than 0.38 oz ai/acre in terms of increased control of competing vegetation at this site (Table 2). Applying a rate as high as 1.50 oz ai/acre induced damage to the eucalyptus trees, as evidenced by the higher damage scores of this treatment relative to most others as of June 2009. In the RELEASE2 trial, sulfometuron methyl applied at rates lower than and greater than 1.13 oz ai/acre was associated with eucalyptus height growth lower than directed glyphosate. These results suggest that competition control of a single application of sulfometuron methyl at rates lower than 1.13 oz ai/acre did not adequately control competition through the growing season as well as the multiple applications of glyphosate and that the significant increase in eucalyptus damage caused by a single application at 1.50 oz ai/acre was substantial enough to reduce height growth.

The RELEASE3 trial was developed to determine second-year eucalyptus tolerance to a wider array of sulfometuron methyl rates because operational experience has shown that competition control through at least the second year of the rotation is needed for sufficient *E. macarthurii* growth. All sulfometuron methyl rates tested in this trial significantly reduced competition, as shown by the lower ground coverage of all rates relative to the control (Table 3). However, all rates tested were high enough to induce *E. macarthruii* damage as evidenced by the greater October 2009 tree condition scores and lower tree height growth of all sulfometuron treatments relative to the control. The damage of *E. macarthurii* in the RELEASE3 trial, in which all rates tested were 1.50 oz ai/acre and greater, is similar to the increased damage observed in response to the 1.50 oz ai/acre rate in the RELEASE2 trial. Thus, *E. macarthurii* was damaged by sulfometuron methyl rates as high as 1.50 oz ai/acre at this site irrespective of whether the plantations were in the first or second year of the rotation.

Tree height, survival, and condition scores did not differ among treatments in the PREP trial. Groundline diameter of the imazapyr treatment was greater than that of all other treatments in both non-bedded and bedded plots (Table 4). These results suggest that *E. macarthurii* at this site was tolerant of the herbicides tested even when they were applied within two months of planting to simulate a "worst-case" management scenario and that imazapyr promoted tree growth better than the other herbicides tested. The imazapyr result was unexpected because although imazapyr is highly effective for relatively long competition suppression it has relatively long residual activity in soil. The lack of damage from imazapyr may have been due to the formulation of Chopper Gen2 imazapyr product. Chopper Gen2 is formulated to enter plants more readily than conventional imazapyr herbicides, so if it was more rapidly absorbed by vegetation there was less potential for the herbicide to enter and remain in soil. Bedding significantly improved seedling survival across all herbicide treatments, with average survival of bedded and non-bedded plots being 83.7 and 50.5 percent, respectively. Survival benefits of bedding in the PREP trial are similar to those reported for *Eucalyptus tereticomis* in previous studies (Chamshama and Hall 1987).

CONCLUSIONS

Oxyflurofen and sulfometuron methyl were viable alternatives to directed glyphosate for release treatments of first-year *E. macarthurii* seedlings at this study site because both herbicides reduced competing vegetation and promoted *E. macarthurii* height growth better than directed glyphosate. However, applying sulfometuron methyl at these sites in excess of 1.13 oz ai/acre damaged *E. macarthurii* seedlings. Triclopyr, hexazinone, and imazapyr did not damage *E. macarthurii* seedlings irrespective of whether plots were bedded or non-bedded at this site even though the herbicides were applied only two months before the site was planted. There was also modest evidence that the imazapyr formulation tested led to greater seedling groundline diameters relative to triclopyr and hexazinone. It must be stressed that although these trials provide information useful for *E. macarthurii* plantations managed on similar loamy soils, these trials were conducted on a single soil type with a single eucalyptus species. Before broader inferences can be made, it is essential to conduct similar tests over a greater array of soil types and eucalyptus species.

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Table 1—Proportion of ground covered in live vegetation 5, 10, and 15 weeks after treatment (WAT) and tree height growth 1 and 2 years after treatment (YAT) in response to herbicides applied to a newly planted Eucalyptus macarthurii plantation in April 2008

	Ground Coverage (%)			Tree Height Growth (ft)	
Treatment	5 WAT	10 WAT	15 WAT	1 YAT	2 YAT
Control	20.0 a	11.8 a	57.5 a	1.63 cde	4.22 de
Directed glyphosate	21.3 a	12.3 a	52.9 a	1.15 e	5.22 cde
Sulfometuron 0.38 oz ai/ac	9.6 cde	5.9 a	33.3 a	1.59 cde	4.98 cde
Sulfometuron 0.94 oz ai/ac	11.7 bcde	9.9 a	55.8 a	2.37 ab	8.04 a
Oxyflurofen 0.45 pt ai/ac	7.9 de	18.1 a	48.8 a	1.64 cde	5.51 cd
Oxyflurofen 0.89 pt ai/ac	2.9 f	4.3 a	37.3 a	2.77 a	7.59 ab
Clopyralid 0.12 pt ai/ac	19.2 abc	10.9 a	47.5 a	1.99 bcd	4.84 cde
Clopyralid 0.28 pt ai/ac	13.8 abcd	13.7 a	57.5 a	2.17 abc	6.26 bc
Quizalofop 1.24 oz ai/ac	10.8 bcde	9.0 a	47.1 a	1.90 bcd	4.92 cde
Quizalofop 2.06 oz ai/ac	15.0 abc	8.9 a	40.4 a	1.52 de	3.77 e
Fluazifop 3.9 oz ai/ac	16.7 ab	8.3 a	43.8 a	1.87 bcd	4.86 cde
Sulfosulfuron 0.98 oz ai/ac	9.6 e	10.7 a	52.1 a	1.75 cde	5.97 bc

NOTE: Glyphosate applied as Accord, sulfometuron applied as Oust XP, oxyflurofen applied as Goal 2XL, clopyralid applied as Transline, quizalofop at 1.24 oz ai/ac applied as Targa, quizalofop at 2.06 oz ai/ac applied as Assure II, fluazifop applied as Fusilade, and sulfosulfuron applied as Outrider. Within each column, means followed by different letters differ significantly at $P < 0.05$.

Table 2—Proportion of ground covered in live vegetation in June 2009, tree condition score, and tree height growth from April to October 2009 in response to herbicides applied to a newly planted Eucalyptus macarthurii plantation in April 2009

Treatment	Ground Coverage (%)	Tree Condition Score		Tree Height Growth (ft.)
		June 2009	October 2009	
Control	16.5 a	1.00 b	1.92 a	1.34 d
Directed glyphosate	4.1 b	1.14 ab	1.25 a	2.95 a
Sulfometuron 0.38 oz ai/ac	5.0 b	1.00 b	1.34 a	2.28 bc
Sulfometuron 0.75 oz ai/ac	6.6 b	1.00 b	1.14 a	1.80 cd
Sulfometuron 1.13 oz ai/ac	4.6 b	1.09 b	1.59 a	2.50 ab
Sulfometuron 1.50 oz ai/ac	1.9 b	1.43 a	1.62 a	1.87 cd

NOTE: Glyphosate applied as Accord and sulfometuron applied as Oust XP. Tree condition scores were defined as 1=no apparent damage, 2=chlorotic leaves, 3=dead leaves in upper stem, 4=dead leaves in lower stem, 5=tip dieback, second flush, 6=tip dieback, 7=dieback to bottom of tree with resprouting, 8=dieback to bottom of tree with no resprouting, and 9=dead. Within each column, means followed by different letters differ significantly at $P < 0.05$.

Table 3—Proportion of ground covered in live vegetation in June 2009, tree condition score, and tree height growth from April to October 2009 in response to herbicides applied to a second-year Eucalyptus macarthurii plantation in April 2009

Treatment	Ground Coverage (%)	Tree Condition Score		Tree Height Growth (ft.)
		June 2009	October 2009	
Control	38.3 a	1.19 a	1.94 b	5.10 a
Sulfometuron 1.50 oz ai/ac	8.3 c	1.13 a	2.87 a	3.96 b
Sulfometuron 2.25 oz ai/ac	10.8 bc	1.07 a	2.30 a	3.42 bc
Sulfometuron 3.00 oz ai/ac	21.3 b	1.38 a	2.62 a	2.56 c

NOTE: Sulfometuron applied as Oust XP. Tree condition scores were defined as 1=no apparent damage, 2=chlorotic leaves, 3=dead leaves in upper stem, 4=dead leaves in lower stem, 5=tip dieback, second flush, 6=tip dieback, 7=dieback to bottom of tree with resprouting, 8=dieback to bottom of tree with no resprouting, and 9=dead. Within each column, means followed by different letters differ significantly at $P < 0.05$.

Table 4—Groundline diameter (in inches) in response to herbicide and bedding treatments conducted prior to planting of Eucalyptus macarthurii in southwest Louisiana

Treatment	Non-bedded	Bedded
Control	0.30 b	0.34 b
Triclopyr 1.2 oz ai/acre	0.35 b	0.46 b
Imazapyr 8.5 oz ai/acre	0.60 a	0.55 a
Hexazinone 1 qt ai/acre	0.31 b	0.42 b

NOTE: Triclopyr applied as Garlon4, imazapyr applied as Chopper Gen2, and hexazinone applied as Velpar L. Within each column, means followed by different letters differ significantly at $P < 0.05$.

SHORT-TERM CHANGES IN LOBLOLLY PINE WATER CONDUCTANCE AND PHOTOSYNTHETIC CAPACITY FROM FERTILIZER SOURCE AND STRAW HARVESTING

Michael A. Blazier, Keith Ellum, and Hal O. Liechty

ABSTRACT

Organic matter removal associated with intensive straw harvesting in loblolly pine (*Pinus taeda* L.) plantations has the potential to alter tree water regimes and photosynthetic capacity. Fertilization done to remedy nutrient removals from straw harvesting, as well as the type of fertilizer, likewise has potential to change water regimes and photosynthetic capacity of these plantations. In 2008 and 2009, conductance, light-saturated photosynthesis, and intrinsic water use efficiency were measured seasonally in a loblolly pine plantation in north central Louisiana in response to: (1) a non-raked, non-fertilized control treatment, (2) annual straw raking for seven years, (3) annual straw raking for seven years and five years of inorganic fertilizer application, and (4) annual straw raking for seven years and five years of organic fertilizer (poultry litter) application. Precipitation was comparable to or exceeded regional averages throughout the study period. Conductance in spring was greater in response to poultry litter application than to all other treatments. Both fertilization treatments were associated with lower photosynthetic capacity in summer relative to the control treatment. No differences in intrinsic water use efficiency were observed in response to treatments.

INTRODUCTION

Pine straw is commonly used in the southeast U.S. as a landscaping material in residential, urban, and industrial settings (Minogue and others 2007). Pine straw production supplements income from conventional forest products (Minogue and others 2007, Wolfe and others 2005). Pine straw is a large component of the forest floor in loblolly pine plantations (Kinerson and others 1977), and the presence of this organic matter in part determines soil water availability and temperature (Attiwill and Adams 1993). Blazier and others (2008) found that soil available water holding capacity was reduced by annual pine straw harvesting. Excessive removal of organic matter without soil amendment in plantations in which pine straw is frequently harvested could potentially reduce tree water uptake and use as well.

Nutrient amendments are often used in southern pine plantations to replenish macro- and micronutrients removed by pine straw raking (Morris and others 1992). Both inorganic and organic fertilizers such as poultry litter have been used to supply nutrients and increase productivity of southern plantations in which pine straw is harvested (Blazier and others 2008, Chastain and others 2007). Poultry litter is a by-product of poultry production and consists of chicken manure, feed waste, and bedding materials such as rice hulls, peanut hulls, or pine shavings. Amending southern pine plantations with poultry litter may prove beneficial in replacing not only nutrients but also organic matter removed during pine straw raking. The additional organic matter added to the soil may benefit growth by increasing porosity and reducing the impacts of compaction, thereby improving water availability to the trees (Blazier and others 2008).

Both nutrient and water regimes in loblolly pine plantations are important to productivity and tree growth (Green and Mitchell 1992, Samuelson and others 2008). Removal of organic matter in stands in which pine straw is harvested and subsequent fertilization with inorganic or organic fertilizer may alter the water regimes as well as photosynthetic capacity of loblolly pine that govern its productivity. Understanding of the effects of straw raking and fertilizer source on the water regimes and photosynthetic capacity of loblolly pine is needed to develop ecologically sustainable management practices, but research on these issues is limited. The objectives of this study were to determine the effects of annual straw harvesting, fertilization, and fertilizer source on stomatal water conductance, photosynthetic capacity, and intrinsic water use efficiency of loblolly pine.

METHODS

The study site was located at the LSU AgCenter Calhoun Research Station in north central Louisiana (32° 30’ 48” N, 92° 20’ 53” W). The study was established in two loblolly pine plantations located within 0.5 km of each other. The

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plantations were planted in winter 1990 at a spacing of 4.9 m x 1.8 m. Prior to tree establishment the two areas had been managed as a bermudagrass (*Cynodon spp*.) pasture. In 2000, the stands were thinned to 618 trees/ha. The soil mapping unit at this study site is an Ora-Savannah association (Matthews and others 1974). This association is composed of loamy soils that are nearly level to gently sloping, medium acid to very strongly acid, and low in natural fertility. These soil series are primarily classified as fine loamy, mixed, siliceous, thermic, Typic Fragiudults (Matthews and others 1974). The climate in Ouachita Parish is mild, humid subtropical with high rainfall occurring in the winter and spring followed by dry weather in the summer and autumn. Average annual temperature is 21° C, and average rainfall is 128 cm (Matthews and others 1974). Ice storms passed through Ouachita Parish in December 1998 and January 2001, with minimal damage occurring in the study stands.

The study design was a randomized complete block design with a one-way treatment structure and four levels of pine straw harvesting and fertilizer regime treatments. The four treatment regimes were replicated twice within a 1-ha block in each stand, with stand as the blocking factor. Treatments were applied to 0.08-ha plots which were separated by a 3-m buffer to ensure independence of treatments. The regime treatments were: (1) a control treatment of no straw raking and no fertilization (CONTROL), (2) pine straw raking without fertilization (RAKE), (3) pine straw raking with annual application of diammonium phosphate and urea (RAKE-IN), and (4) pine straw raking with an annual application of poultry litter (RAKE-PL).

Pine straw raking began in fall 2000, with straw harvests occurring annually thereafter. Pine straw was collected in February, August, and November each year by tractor-drawn hay rakes and balers operated by a commercial pine straw harvest contractor. Understory vegetation in raked plots was controlled with glyphosate applied once in August 2003 at a rate of 1.2 L active ingredient/ha. All coarse and fine woody debris and vegetative matter was removed and windrowed by hand prior to raking but left on site. Average annual production was 173 bales/ha, with an average bale weight of 11.3 kg. Fertilizer applications in the RAKE-IN and RAKE-PL treatments began in April 2003 and were conducted annually thereafter. For the RAKE-IN treatment, 308 kg/ha of urea and 280 kg/ha of diammonium phosphate were applied each spring. The fertilizers applied for the RAKE-IN treatment supplied N and P at 193 kg/ha/year and 129 kg/ha/year, respectively. For the RAKE-PL treatment it was assumed that the poultry litter had N and P concentrations of 3 percent, and dry litter was applied at a rate of 7.7 Mg/ha in order to provide N and P equivalent to that of the RAKE-IN treatment.

Gas exchange was measured to determine light-saturated photosynthesis (Amax) and stomatal conductance (Gs). Measurements were taken on needles from the upper, mid, and lower branch positions of the crown seasonally: summer (August 2008), late fall (December 2008), winter (February 2009), and spring (May 2009). Dominant trees with well-developed crowns and absent of disease, insect, drought, or ice damage were selected for sampling. Branches from one tree from each plot were excised with a 12-gauge shotgun. The same trees were sampled each season. Measurements were taken in an open-system configuration with a CI-340 Photosynthesis System (CID Inc., Camas, WA, USA). The cuvette of the analyzer was operated under ambient CO_2 concentrations, and saturating light (photosynthetically active radiation of 1800 μmol/m^2/s) was applied so that photosynthesis was maximized throughout the measurement period. When branches were detached, they were placed upright in a container of water at ambient temperature and measured within 5 minutes to optimize accuracy during measurement (Blazier and others 2004). Nine needles (three fascicles) from the first flush of current-year foliage were placed into the leaf chamber of the gas analyzer. The CI-340 Photosynthesis System calculated Amax and Gs based on the gas exchange parameters (relative humidity, air temperature, leaf temperature, and atmospheric pressure) directly measured with the instrument. Intrinsic water use efficiency (WUE) was then calculated by dividing Amax by Gs (Cregg and others 2000).

During the study period, daily precipitation was measured by a tipping-bucket rain gauge located at the Calhoun Research Station as part of the Louisiana Agriclimatic Information System. Daily precipitation was summed for each month from July 2008 through June 2009. The historical monthly potential evapotranspiration (PET) for the Calhoun Research Station was developed from 30-year monthly averages of air temperature and day length collected at the station (Thornthwaite 1948).

To characterize the influence of the treatments on tree nutrition, foliage samples were collected from the upper-mid portion of tree crowns in December 2007 from three dominant or codominant trees of good form and vigor per plot using a 12-gauge shotgun. Ten needle fascicles were taken from the first flush of current-year foliage in the excised branches. All sampled fascicles were pooled for each plot, so each plot was represented by one composite sample. Concentrations of N, P, K, S, B, Ca, Cu, Fe, Mg, Mn, and Zn were then analyzed. Nitrogen was analyzed by dry combustion (Nelson and Sommers 1996) with a Leco CN analyzer (Leco, Inc., St. Joseph, MI, USA). All other nutrients in the foliage samples were determined by nitric acid digestion followed by analysis with ICP spectrometry (Zarcinas and others 1987) on a Thermo-Jarrell Enviro II (Thermo-Jarrell Ash, Inc., Franklin, MA).

All gas exchange variables (Amax, Gs, WUE) were analyzed with the SAS System program using a repeated measures mixed model (PROC MIXED; SAS Inc.) that included block, season, and the interaction of block and season as random effects and treatment, crown position, and the interaction of treatment and crown position as fixed effects. An autoregressive correlation structure was used for the repeated measures analysis. All nutrient variables were analyzed with a model that contained block, treatment, and the interaction of block and treatment as fixed effects. When an ANOVA indicated significant treatment effects, treatment means were calculated using the LSMEANS procedure and separated by the DIFF and SLICE options. The DIFF option provided multiple comparisons of treatment means by invoking t-tests to determine significant differences between all possible treatment combinations. The SLICE option, which was used to investigate treatment main effects when significant 2-way interactions were found, provided t-tests of treatment means in which the effect of one treatment was evaluated at each level of another treatment. An alpha of 0.10 was used for all data analyses.

RESULTS AND DISCUSSION

Significant season x treatment interactions were found in the analyses of Amax and Gs (Table 1). In August 2008, Amax of the CONTROL and RAKE treatments were greater than those of both fertilization treatments. Among all foliage nutrients tested, only S and P were affected by treatments (Table 2). The RAKE-PL treatment had greater P concentrations than the unfertilized treatments. Interestingly both fertilizer treatments had greater S than the non-fertilized treatments, and the RAKE-PL treatment led to greater loblolly pine foliage S concentrations than the RAKE-IN treatment. Foliage S concentrations of the CONTROL treatment were below foliage S critical values, so the site was likely deficient in S (Allen 1987, Jokela and others 1991). Increased foliage S of the RAKE-IN treatment may have been due to increased uptake capacity as a result of the N and P applied as part of this treatment regime. Increased foliage S of the RAKE-PL treatment was likely because of the S supplied by the poultry litter as well as improved uptake capacity as a consequence of the other nutrients supplied by the poultry litter. The increases in tree foliage S nutrition as a result of the fertilizer treatments may have contributed to the short-term lower Amax of the trees observed in August 2008, because studies of S-enriched plants have revealed reductions in net photosynthesis (Black and Unsworth 1979).

Stomatal conductance of the RAKE-PL treatment in May 2009 was greater than that of all other treatments (Table 1). Similar increases in Gs during the spring with poultry litter additions were found by Tyler and others (1993) in outdoor container- grown *Hemerocallis* spp. in North Carolina. Tyler and others (1993) found that Gs increased with rate of poultry litter application and the greater Gs was attributed to increased soil water-holding capacity, available water, and nutrients with the addition of poultry litter. In a concurrent study at the Calhoun study site, Ellum (2010) found that the RAKE-PL treatment had higher soil organic matter concentrations than all other treatments. This increased organic matter may have contributed to the greater Gs observed in response to this treatment in May 2009. This effect of poultry litter on Gs was likely most pronounced in May 2009 among all sampling periods because litter had been applied two weeks before measurement occurred. Intrinsic WUE was unaffected by treatments, which was likely due to the sufficient precipitation of the study period. In all months of sampling, precipitation exceeded PET (Figure 1).

CONCLUSIONS

During a study period characterized by sufficient precipitation, there were no persistent effects of straw raking on Amax, Gs, and WUE. Lower Amax in fertilized treatments than in non-fertilized treatments was observed in summer. In a measurement period within two weeks of poultry litter application, greater Gs was found in response to litter application. The short-term increase in Gs in response to litter application was likely due to water retention by the litter.

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Table 1—Light-saturated photosynthetic rate (Amax) and stomatal conductance (Gs) of loblolly pine in north central Louisiana in response to no fertilization and no raking of pine straw (CONTROL), annual pine straw raking initiated in 2000 (RAKE), annual pine straw raking initiated in 2000 and annual application of urea and diammonium phosphate initiated in 2003 (RAKE-IN), and annual pine straw raking initiated in 2000 and annual application of poultry litter initiated in 2003 (RAKE-PL). For each variable, means within each column differ at $P < 0.10$.

Treatment	Date			
	August 2008	December 2008	February 2009	May 2009
Amax (μmol/m²/s)				
CONTROL	4.58 a	1.88 a	0.43 a	2.37 a
RAKE	3.97 a	1.05 a	1.81 a	1.83 a
RAKE-IN	1.99 b	0.70 a	0.78 a	1.64 a
RAKE-PL	1.73 b	2.07 a	1.43 a	2.66 a
Gs (mmol/m²/s)				
CONTROL	0.44 a	0.22 a	1.37 a	1.00 b
RAKE	0.14 a	0.03 a	0.85 a	0.35 b
RAKE-IN	0.33 a	0.09 a	1.70 a	0.38 b
RAKE-PL	0.11 a	0.46 a	0.85 a	2.99 a

Table 2—Foliar nutrient concentrations of loblolly pine in north central Louisiana in response to no fertilization and no raking of pine straw (CONTROL), annual pine straw raking initiated in 2000 (RAKE), annual pine straw raking initiated in 2000 and annual application of urea and diammonium phosphate initiated in 2003 (RAKE-IN), and annual pine straw raking initiated in 2000 and annual application of poultry litter initiated in 2003 (RAKE-PL). For each nutrient, means within each row differ at P < 0.10

Nutrient	Treatment			
(mg/kg)	CONTROL	RAKE	RAKE-IN	RAKE-PL
N	14633 a	14470 a	18850 a	19413 a
P	1260 b	1303 b	1375 ab	1443 a
K	3528 a	3467 a	3755 a	3895 a
S	985 c	1048 c	1158 b	1255 a
Ca	1630 a	1588 a	1653 a	2055 a
Mg	803 a	973 a	745 a	855 a
B	11 a	14 a	14 a	21 a
Cu	3 a	3 a	4 a	3 a
Fe	37 a	37 a	37 a	35 a
Mn	365 a	315 a	369 a	406 a
Zn	32 a	37 a	32 a	41 a

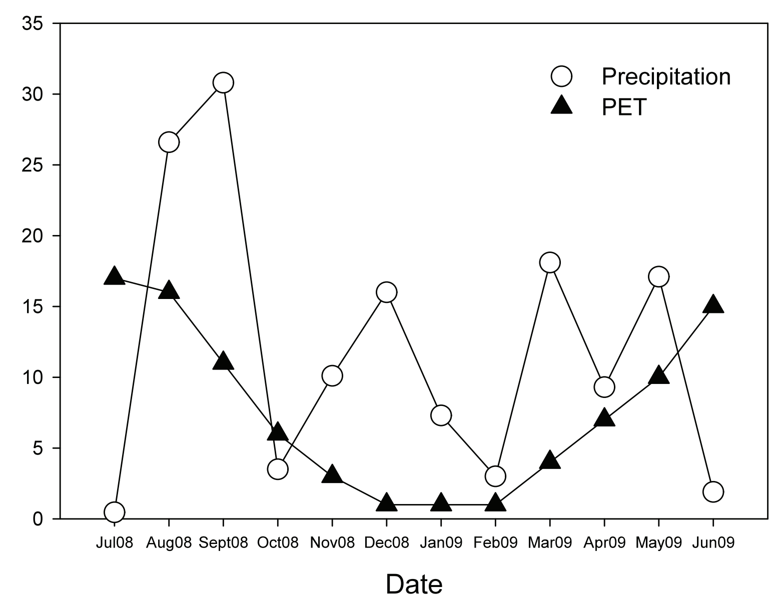

Figure 1—Average monthly precipitation at the LSU AgCenter Calhoun Research Station during the study period and Thornthwaite potential evapotranspiration based on 30-year climatic data collected at the station.

AGE STRUCTURE OF A SOUTHERN PINE STAND FOLLOWING 72 YEARS OF UNEVEN-AGED SILVICULTURE

Don C. Bragg

Work on uneven-aged silviculture in southern pine stands on the Crossett Experimental Forest (CEF) began in the 1930s, when a number of 16.2-ha compartments were placed into a series of demonstration projects and studies (Reynolds 1980). Two of these compartments, the Good and Poor Farm Forestry Forties, have been maintained continuously in this silvicultural regime since 1937. However, for all of the long history of the CEF, we have not systematically aged the loblolly (*Pinus taeda*) and shortleaf (*Pinus echinata*) pine-dominated Farm Forestry Forties. Rather, we have accepted decades of continuous sawtimber production as de facto evidence of uneven-aged structure.

Because a functional uneven-aged forest requires more than the simple appearance of multiple age classes (Smith and others 1997), measurements were undertaken in 2009 to document the age structure of the Farm Forestry Forties. This paper reports on the Poor Forty, a parcel originally designated as “poor” because of its low initial pine stocking, not site quality (Reynolds 1980). Five pines were randomly selected (4 overstory and 1 seedling/sapling) for sampling on each of 25 plots systematically established in this stand. An increment borer was used to core trees at least 6 cm in diameter at breast height (d.b.h.); cores were taken at 50.8 cm above ground line, and were then dried, mounted, sanded, and ring-counted (no cross-dating was done, so these are only approximations of actual age). For pines less than 6 cm d.b.h., trees were felled, and a 50.8-cm long bolt was sawn from the base of the stem, starting at groundline. Ring counts were taken at both ends of this bolt, allowing for the estimation of how long it took pines to grow from 0 to 50.8 cm in height. This value (on average, approximately 2 years) was then added to the ring counts of the larger trees to provide a final age estimate.

Of the 125 pines aged, 119 were loblolly (95.2 percent). Pines as young as 4 years old were sampled, with diameters as low as 0.5 cm d.b.h. (Figure 1). Pine reproduction is present in this stand, clustered around canopy openings (gaps) and on substrates that were favorable shortly after they formed (most recently, following a timber harvest in 2002-2003). Only 7 (5.6 percent) pines were over 72 years old, with the oldest one having an estimated age of 86 years (Figure 1). This stand is managed under a prescription that greatly reduces the number of pines greater than 50 cm d.b.h., and therefore limits the abundance of older trees.

Not surprisingly, the Poor Forty has a diffuse age distribution that reflects 30 annual harvests from 1938 to 1968 and 7 periodic harvests since 1969 (Table 1). In addition to old pines, two other deficiencies in the Poor Forty age class data are notable—the first arises from the lack of pines 30 to 40 years old, a likely consequence of inadequate timber harvesting which limited pine regeneration during the temporary closure of the CEF in the 1970s. The second is apparent over the last 5 years, attributable to a recent lack of pine recruitment.

Similar to uneven-aged forests dominated by shade-tolerant species, there was only a moderate relationship between d.b.h. and age (Figure 1). Small-diameter (less than 10 cm d.b.h.) pines varied the least in their age range, followed by intermediate size classes (10 to 25 cm d.b.h.), and then the largest trees. The oldest individual, an 86-year-old, 41.2 cm d.b.h. loblolly pine, was noticeably older than most other stems in the 40 to 42 cm range—the 5 other pines in this class had the following ring counts: 47, 52, 62, 63, and 67 years.

Though not as well-structured as an idealized uneven-aged stand would be, it is quite apparent from these data that the pine component of the Poor Farm Forestry Forty on the Crossett Experimental Forest is composed of multiple size classes of spatially intermingled individuals. This textbook definition (see Baker and others 1996) arose from decades of selection harvests, and given the current size and age structure of this stand, should be sustainable well into the future.

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Table 1—Age class structure from the uneven-aged, loblolly pine-dominated Poor Farm Forestry Forty on the Crossett Experimental Forest in Arkansas

Age class	Count	Fraction of total	Cumulative total
-- years --	-- trees --	-- % --	-- % --
0 - 4	1	0.8	0.8
5 - 9	14	11.2	12.0
10 - 14	8	6.4	18.4
15 - 19	13	10.4	28.8
20 - 24	13	10.4	39.2
25 - 29	5	4.0	43.2
30 - 34	3	2.4	45.6
35 - 39	4	3.2	48.8
40 - 44	3	2.4	51.2
45 - 49	6	4.8	56.0
50 - 54	9	7.2	63.2
55 - 59	16	12.8	76.0
60 - 64	13	10.4	86.4
65 - 69	9	7.2	93.6
70 - 74	4	3.2	96.8
75 - 79	3	2.4	99.2
80 - 84	0	0.0	99.2
>84	1	0.8	100.0
TOTALS	125	100.0	100.0

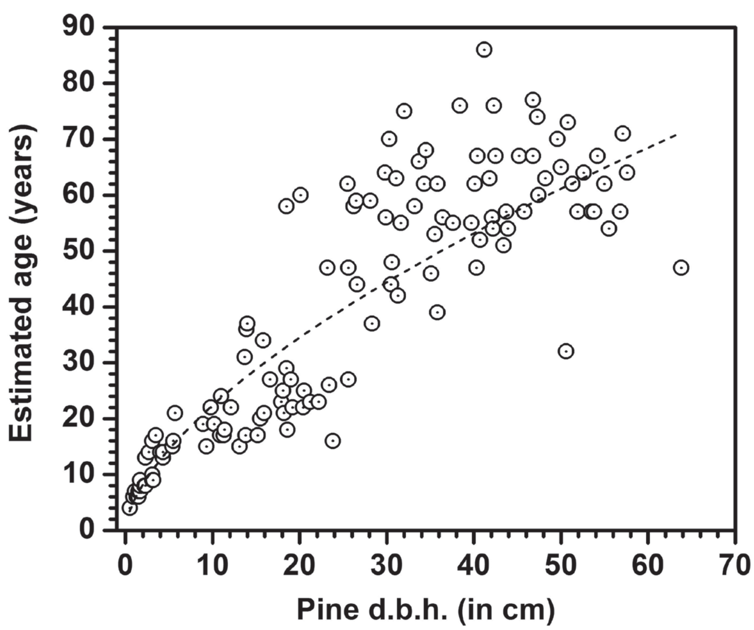

Figure 1—Relationship between estimated age and d.b.h. from the Poor Farm Forestry Forty on the Crossett Experimental Forest. The dashed line was fit using ordinary least squares nonlinear regression (estimated age = $5.313 d.b.h.^{0.6244}$, pseudo-R^2 = 0.8675).

APICAL BUD TOUGHNESS TESTS AND TREE SWAY MOVEMENTS TO EXAMINE CROWN ABRASION: PRELIMINARY RESULTS

Tyler Brannon and Wayne Clatterbuck

ABSTRACT

Apical bud toughness differences were examined for several species to determine if crown abrasion affects shoot growth of determinate and indeterminate species during stand development. Determinate buds will set and harden after initial shoot elongation in the spring, while the indeterminate shoots form leaves from the apical meristem continuously based on the resources that are available at the time of growth. These growth differences can influence which species' buds are abraded or broken upon impact with adjoining crowns affecting crown growth. Shoot and bud toughness by species and shoot growth form were evaluated using a pendulum impact tester. Crown movement was assessed by using 3-axial accelerometers in outer most extreme points of crowns. Accelerometers automatically logged the movement of branches in the tree crown over a period of time and are evaluated with local wind data. By using both the crown sway information and associated bud and branch toughness models, evidence is provided to suggest that crown friction and abrasion are contributors to crown and stand development patterns in mixed species stands, often allowing species with determinate shoot growth to stratify above trees with indeterminate growth.

INTRODUCTION

Crown abrasion is the physical loss of terminal buds and branches when tree crowns overlap during wind sway (Rudnicki and others 2001). Crown abrasion could be affecting stand development, crown differentiation, and crown dynamics. Clatterbuck and Hodges (1988) observed an even-age stand of sweetgum (*Liquidambar styraciflua*) and oak (*Quercus* spp.) where sweetgum quickly captured the site, but around age 20 to 25 the oaks were able to stratify above the sweetgum. Crowns of surrounding sweetgums recede from the crown of the oak, possibly caused by abrasion. Crown abrasion has been studied in coniferous forests (Meng and others 2006, Rudnicki and others 2003). In Costa Rica, abrasion has also been observed in black mangrove (*Avicennia germinans*) forests (Putz and others 1984). Tarbox and Reed (1924) found crown abrasion led to reduced yields in overstocked pine plantations. Mechanical abrasion by neighboring trees is hypothesized as a factor influencing suppression of shoot extensions (Oliver and Larson 1996). Quantitative data of this phenomenon is limited to pine (*Pinus* spp.).

Tree throw, stem break and root break are well known disturbances that can occur from wind events (Mayer 1987). Mechanical abrasion may be a more persistent and subtle form of disturbance from wind events. Mechanical abrasion is the physical shearing of crowns during wind sway. As trees grow in height, their limbs grow longer and sway farther (Oliver and Larson 1996). No tree can survive a powerful wind event without some damage (Mayer 1987).

Tree crowns create carbohydrates from converting sunlight, CO_2 and H_2O, which are used by all parts of the tree. The amount of crown is dynamically related to the growth of the tree because production of photosynthate dictates shape and size of all other parts of a tree (Holland and Rolfe 1997). Crowns are one of the most easily impacted components of a tree by environmental conditions. Crown expansion is limited when crown abrasion occurs, which can impact crown size and photosynthate production.

Oliver and Larson (1996) hypothesized that one species' terminal branches could be severed by tougher branches of another species. Terminal buds have different growth forms that could be influencing abrasion in mixed species stands. Preformed growth form (determinate) and the sustained growth form (indeterminate) are the two growth forms of interest. Preformed shoots contain all the leaf primordial and internodes that that will expand during the flush of the growing seasons. Sustained growth trees will form leaves from the apical meristem continuously depending on the resources that are available at the time of growth (Kozlowski and Pallardy 1997).

Lockhart and others (2006) found when cherrybark oak (*Quercus pagoda* Raf.) were at or above the height of neighboring sweetgums, the sweetgum branches were often damaged, especially terminal branches. The sweetgums

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with damaged terminal branches grew more laterally. This resulted in sweetgum crowns receding from cherrybark oak crowns. Subsequently, most of the neighboring cherrybark oaks' growth was in height, allowing cherrybark oaks to stratify above sweetgum. Lockhart and others (2006) suggests that crown abrasion is the major component allowing this to occur.

The primary objective of this study was to evaluate different quantitative methods that might be used in assessing how crown abrasion occurs and how it impacts stand development. Two components of crown abrasion were assessed: (a) toughness of the bud and twig of various growth forms and (b) how the branches move in the wind. In order to evaluate these two components, the following were investigated:

1) Use a pendulum impact tester to determine bud toughness.

2) Measure and compare crown movement during the dormant season using accelerometers.

Standard methodologies for studying crown abrasion are not yet developed, therefore, new techniques were investigated to evaluate crown abrasion and their impacts on stand development. A pendulum impact tester was used to evaluate bud toughness, which is the amount of energy a material can absorb before fracture. A pendulum impact tester was selected over other testing methods due to its consistency in testing, and its similarities to colliding branches that are perpendicular. Rudicki and others (2001) used clinometers to measure bole displacement in lodgepole pine (*Pinus contorta*). This work inspired the use of accelerometers to measure gravitational force on crown edge and to 2-dimensionally map movement of a branch.

MATERIALS AND METHODS

APICAL BUD TOUGHNESS

Apical bud toughness was tested on several species on a Tinius Olsen Model 92T Impact Tester. The impact tester is a pendulum that swings through and strikes the sample. The amount of energy that is absorbed into the sample is given in Joules. Buds are braced with a block of wood to ensure the break occurs at the bud collar. If samples are not braced, the sample would not break anywhere because the vice holding the sample was too low.

Species with preformed bud growth and species with sustained bud growth were sampled in the dormant season. Samples were collected and broken within hours to ensure natural wood moisture content. Notes were made if samples had more than one terminal bud that was broken.

TREE SWAY MOVEMENTS

The study area is located at the East Tennessee Nursery near Delano, Tennessee. Data were collected in 2011 in a Nuttall oak (*Quercus texana*) tree that was planted in the spring of 1993. The trees in the stand averaged 40 feet tall with live crown starting at 9 feet, and branches expanded 16 feet from the stem. One tree in the southwestern corner was selected to place tri-axis accelerometers because of its exposure to prevailing wind, crown symmetry, and accessibility.

The accelerometers were placed about 20 feet into the crown in each cardinal direction. The 4 accelerometers were placed about 2 feet from the end of the branches to ensure that movement was not influenced by the weight of the device. Accelerometers record gravitational force on each axis (X, Y and Z) and were set to record at +/- 4 g's. They also record at 10 hertz, resulting in data recording 10 times a second. Data were collected during various windstorm events during the dormant season.

An anemometer was used to record local wind data near the stand. The anemometer was placed 9 feet high and recorded average wind speed and top wind gust. The device was set to record once every minute while accelerometer data were being recorded. All wind speeds were recorded in miles per hour.

RESULTS AND DISCUSSION

Preliminary data suggest differences in bud toughness between preformed and sustained bud growth forms. Mockernut hickory (*Carya tomentosa)* has a preformed bud growth form, while red maple (*Acer rubrum*) has a sustained bud growth form (Table 1). Tests show that mockernut hickory has an average bud collar diameter of 0.18 inches. Red maple has a bud collar diameter of 0.09 inches. Mockernut hickory required an average of 0.182 Joules to cause failure at the bud/stem matrix. Red maple buds fractured on average around 0.014 Joules. The energy required for mockernut hickory bud failure was about 1:1. This ratio for red maple was about 1:6.

If these two species were to collide during a wind event in a mixed species stand, the hickory would be able to withstand more energy than the red maple, resulting in the red maple being abraded. A smaller hickory growing alongside and below a red maple may be able to abrade the maple enough to increase growing space for itself. The increased growing space could result in more space and leaf area for the hickory, allowing growth to accelerate. The recession of the red maple crown is a continuous process as the mockernut hickory crown potentially stratifies above the red maple crown.

Structure of these species buds vary. Some species, such as hickory, will have a single terminal bud. Other species, such as oak, can have several terminal buds emanating from the same point. When buds were broken using the impact tester, we were careful to only break the largest terminal buds that were dominant on the terminal shoot. This could cause the species of oak to appear more fragile than they actually are. An advantage of several terminal buds would be the protection of inner buds that are surrounded by outer buds. The presence of several buds allows the tree to continue terminal growth even if one or more of the outer terminal buds are damaged. Species such as sweetgum would not have this ability.

Preliminary data suggest that preformed bud growth may be able to abrade sustained bud growth. Although Nuttall oak (*Quercus texana)*, a preformed growth species, has a lower amount of energy required to cause bud fracture than many of the sustained growth species, Nuttall oak has more than one terminal bud on each branch tip. More terminal buds could increase the likelihood of that branch continuing terminal growth, even if one or more buds are damaged. A damaged bud of sustained growth would result in the apical dominance to be reverted back to a lower bud, causing growth to be hindered.

Preliminary crown movement indicates that the most acceleration occurs on the Z and X axis. The Y axis does not display much acceleration because accelerometers were not placed high enough to experience movement from the bole (Figure 1). As expected, acceleration increased as wind speed increased. Almost no acceleration was recorded up to a 15 mph (miles per hour) wind speed. Winds around 40 mph caused accelerations up to 2g's, twice as much gravitational force as one experiences from the earth. These recordings can be expected to be larger farther out on the tip of the branch, as the accelerometer had to be placed 2 feet from the tip to avoid influence from weight.

Even-aged monoculture hardwood stands generally do not stratify to the extent mixed species stands can. If crown abrasion is a factor that influences crown dynamics, then data suggest that monocultures of a single species would be evenly matched on terminal bud toughness. The intra-species competition would lead to no "winners," resulting in a lack of stratification and lateral damage that is equally distributed throughout the canopy.

FUTURE CONSIDERATIONS

Mixed species stands could experience crown abrasion. Crown abrasion could be playing a critical role in stratification of slower, hardier species such as oaks into the upper canopy. Further investigation using these methods during the growing season will help us better understand species bud toughness and crown movement as branches become heavier with more leaf mass. Branch analysis will be conducted to study abrasion in pure and mixed, overstocked stands.

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Table 1—Bud toughness test results by species using a pendulum impact test with average bud collar diameter (inches) and energy needed to fracture the bud as the variables. The ratio provided is the energy required for a break to bud collar diameter. Tests were conducted during the dormant season. Asterisk (*) is considered preformed bud growth form

Species	*n*	Bud Collar Diameter (inches)	Energy to Break (Joules)	Ratio Energy:Diameter
		Inches	Joules	%
*Carya tomentosa**	177	0.183	0.184	101%
*Quercus alba**	77	0.116	0.049	42%
*Quercus texana**	75	0.091	0.017	19%
Platanus occidentalis	78	0.163	0.053	33%
Liriodendron tulipifera	180	0.115	0.045	40%
Liquidambar styraciflua	80	0.109	0.037	34%
Acer rubrum	77	0.090	0.014	15%

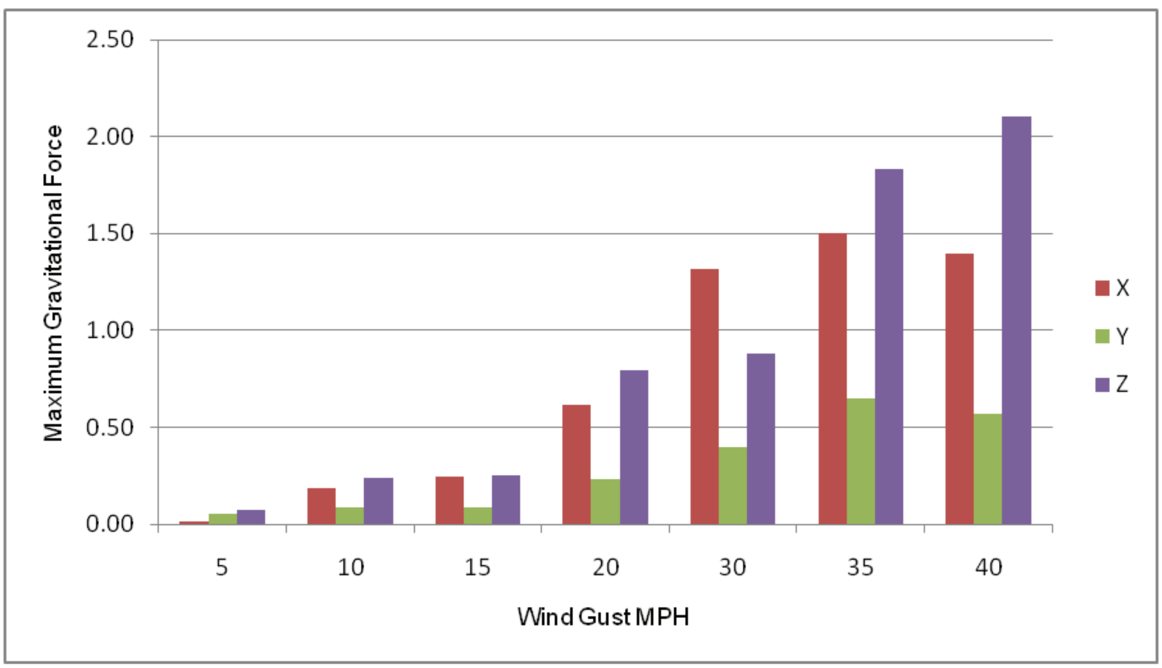

Figure 1—Gravitational force of branch movement as a function of wind speed. Maximum force was recorded from all accelerometers at the time of the wind events.

CANOPY ACCESSION PATTERNS OF TABLE MOUNTAIN AND PITCH PINES DURING THE 19TH AND 20TH CENTURIES

Patrick H. Brose and Thomas A Waldrop

ABSTRACT

A dendrochronology study was conducted in three upland yellow pine stands in Georgia to determine whether the individual Table Mountain (*Pinus pungens*) and pitch (*P. rigida*) pines originated in sunny gaps or shaded understories, whether they grew uninterrupted into the canopy or were assisted by one or more releases, and whether these strategies changed through time. From the three stands, 169 increment cores of the two pine species were obtained and analyzed for radial growth patterns using standard dendrochronological procedures. In the 1800s, approximately 80 percent of the pitch and Table Mountain pines originated in gaps with small gaps + release being the most common strategy. After 1900, large gaps without a followup release became the most common strategy. Many of these gaps were associated with known fires, hurricanes, or chestnut blight. Approximately 20 percent of both species originated in shaded understories, but more than half of these ascended to the canopy via one or more canopy releases. These canopy ascension strategies illustrate the importance of gaps in the dual fire – canopy disturbance regime and provide insight for managers seeking to maintain this rare forest type.

INTRODUCTION

Upland Yellow Pine (UYP) stands are a rare forest type of the Appalachian Mountains. These uncommon stands consist of one to four native hard pine species of the sub-genus Diploxolon [pitch (*Pinus rigida*), shortleaf (*P. echinata*), Table Mountian (*P. pungens*), and Virginia (*P. virginiana*)] dominating the canopy while several xeric hardwood and heath shrub species, especially chestnut oak (*Quercus montana*) and mountain laurel (*Kalmia latifolia*), occupy the midstory and understory strata, respectively. UYP stands occur from central Pennsylvania to northern Georgia on thin, dry soils of south- and west-facing ridges and upper slopes between 1,000 and 4,000 feet (Williams 1998, Zobel 1969). Many of the current UYP stands are even-aged and mature because they originated during or immediately after the extensive forest clearing and wildfire era of the early 1900s (Brose and Waldrop 2006a, Lafon and Grissino-Mayer 2007). Presently, UYP stands are declining in abundance and extent (Welch and others 2000). This decline is undesirable to land managers for beta-diversity reasons beacuse UYP stands constitute an unusual conifer community in an otherwise hardwood-dominated forest landscape.

The existence of UYP stands is strongly associated with fire because the principal oak and pine species possess a variety of traits such as cone serotiny, dormant basal buds, precocious fruiting, and thick bark that allow them to survive fire and exploit the post-fire environment (Della-Bianca 1990, Little and Garrett 1990, McQuilkin 1990). Because of this relationship, the vast majority of UYP research has focused on fire. However, canopy gaps caused by storms, ice accretion, and insect/disease outbreaks are also likely important disturbances in the ecology of UYP stands. Unfortunately, not much research has been done along these lines. Whitney and Johnson (1984) and Lafon and Kutac (2003) examined the effects of ice storm and southern bark beetle (*Dendroctonus frontalis*) outbreaks in UYP stands in southwestern Virginia. The former finding increased pine regeneration after ice storms while the latter found the opposite unless fire was an accompanying disturbance.

Dendrochronology can be used to examine the role of canopy gaps in stand dynamics by determining how individual trees originated and ascended to the canopy. Rentch and others (2003) used this method in studying old-growth white oaks in Ohio, Pennsylvania, and West Virginia. They found three distinct canopy ascension patterns: gap origin with and without release and understory origin with release. In this study, we use radial growth analysis of individual Table Mountain and pitch pines found in three UYP stands in northern Georgia to determine whether they originated in gaps or understories and whether they grew uninterrupted into the canopy or experienced one or more release events. Understanding how pitch and Table Mountain pines originated and grew into the canopy will help forest managers maintain or restore this rare forest type.

METHODS

STUDY SITES

This study was conducted in three UYP stands located on the Chattahoochee National Forest in northern Georgia.

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The stands were situated on the tops and upper side slopes of south- and west-facing ridges in the vicinity of Rabun Bald. Elevations varied from 3,200 to 3,600 feet and soils were well drained sandy or silt loams formed in place by weathering of gneiss, sandstone, and schist parent material (Carson and Green 1981). Consequently, they were moderately fertile and strongly acidic. Climate was warm, humid, and continental with average monthly high temperatures ranging from 25°F in January to 85°F in July. Mean annual precipitation ranged from 53 to 73 inches distributed evenly throughout the year.

Composition, structure, and size of the UYP stands also were quite similar among the study sites. In general, they were 10 to 30 acres each and consisted of 10 to 20 woody species distributed in three distinct strata. The main canopy was 50 to 65 feet tall, broken and patchy, and consisted almost exclusively of Table Mountain pine, pitch pine, and chestnut oak. A ubiquitous midstory stratum (10 to 40 feet tall) was present. It generally lacked a pine component, being comprised almost exclusively of chestnut oak and several other hardwood species such as blackgum (*Nyssa sylvatica*), red maple (*Acer rubrum*), scarlet oak (*Q. coccinea*), and sourwood (*Oxydendrum arboretum*). Together, the main and sub canopies contained approximately 400 to 500 stems and 130 to 175 square feet of basal area per acre. The understory stratum (3 to 10 feet tall) varied from absent to impenetrably dense. When present, it was dominated by ericaceous shrubs, especially mountain laurel, and lacked hardwood and pine seedlings as well as herbaceous plants.

SAMPLING PROCEDURES

At each stand, twelve 0.05-acre rectangular plots were randomly selected from those of a previous study (Waldrop and Brose 1999, Welch and others 2000). In each plot, up to five pines were randomly selected and an increment core was extracted from the bole of each tree at a height of 1 foot above the ground. The cores were air-dried for several weeks, mounted, and sanded with increasingly finer sandpaper (120-, 220-, 320-, and 400-grit) to expose the annual rings (Speer 2010). The cores were skeleton plotted to identify signature years for cross-dating to recognize false or missing rings (Speer 2010). After proper ages were verified for these cores, their annual rings were measured to the nearest 0.002 mm with a Unislide "TA" Tree-Ring Measurement System1 (Velmex Inc. Bloomfield, NY). The COFECHA 2.1 quality assurance program (Grissino-Mayer 2001, Speer 2010) in the International Tree-Ring Data Bank Program Library was used to verify the accuracy of the dating. After dating and measuring, each core was examined for major and moderate releases using the JOLTS program (Holmes 1999) in the International Tree-Ring Data Bank Program Library. A major release is defined as a ≥100 percent increase in average growth lasting at least 15 years and a moderate release as a ≥50 percent increase lasting 10 to 15 years (Lorimer and Frelich 1989). These correspond to large canopy-level disturbances that release residual trees from competition until crown closure occurs again.

Finally, each core was categorized by origin (large gap, small gap with and without release, or understory shade with and without release) using criteria established by Rentch et al. (2003). Seedlings originating in large gaps exhibit initial radial growth of 2 to 3 mm/year for 2 to 3 years until their root systems are well established. Then, growth accelerates until the gap closes from the bottom (canopy closure). At this time, the seedling has grown into a dominant sapling and subsequent radial growth slowly diminishes through time as the tree ages. Seedlings originating in small gaps show the same initial growth pattern, but this pattern is truncated because the gap quickly closes from the sides. The seedling becomes an intermediate or weak co-dominant tree with reduced radial growth relative to those growing in full sunlight. Seedlings originating in understory shade have initial radial growth rates that are less than 1 mm/year and do not exhibit any growth acceleration. They become suppressed saplings if they survive. Both small-gap and understory seedlings are susceptible to major and moderate releases. See Figure 1 for examples of these radial growth patterns. Because these criteria were developed for oaks, we verified their appropriateness for pine by comparing the oak patterns to those of pines known to have originated in gaps or understory shade. The initial growth patterns were identical for both species groups and therefore appropriate for pine.

STATISTICAL ANALYSIS

Because the sites had nearly identical age structures (Brose and others 2002), we combined the cores from all three sites to increase sample size. Then, we created a 2x5 contingency table by categorizing the cores by species (pitch or Table Mountain) and origin type (large gap, small gap with and without release, or understory with or without release). We also created a 2x5 contingency table for each species by origin type and period of origin (1800s or 1900s) because of the differences in the disturbance regimes between those two centuries (Brose and Waldrop 2006b). On each contingency table, we used Chi-square analysis (Zar 1999) to test whether the cores were distributed as expected among the different categories. Alpha was 0.05 for all comparisons.

[1]The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or Forest Service of any product or service to the exclusion of others that may be suitable.

RESULTS

A total of 62 pitch pines and 107 Table Mountain pines yielded sound cores that were suitable for the study (Table 1). Chi-square analysis of the species x origin type contingency table produced a value of 17.65, indicating that the samples were not distributed as expected among the five origin classes and two species. Among the five origin categories, more Table Mountain pine started in large gaps (56) than in the other four types combined. After large gaps, the other four origin classes were ranked as small gaps + release (26), small gaps with no release and understory + release (9 each), and understory with no release (7). Pitch pine distribution was more equitable among the five origin classes with the small gap + release having the most stems (20) followed by large gap (13), small gap with no release (11), understory + release (10), and understory with no release (8).

Overall, the Table Mountain pine samples were equitably distributed between the 1800s and 1900s (Table 2). However, within each period, the samples were not equitably distributed among the five origin types. Before 1900, 42 of the 52 Table Mountain pines originated in gaps and half of these started in small gaps and experienced at least one canopy release. After 1900, 47 of 55 Table Mountain pines originated in gaps, but 85 percent of these started in large gaps. These tendencies toward small gaps before 1900 and large gaps after 1900 resulted in a significant X2 value of 22.623.

The distribution of the pitch pine samples among the origin periods and origin types did not produce a significant X2 value (Table 3). Like Table Mountain pine, the 62 pitch pine samples were about evenly split between the 1800s and 1900s. Pitch pine also showed the same within-period trend of originating in small gaps before 1900 and in large gaps after 1900. However, the collective differences between observed and expected values for the origin period and origin type combinations were not large enough to produce a statistically significant X2 value at the alpha level of 0.05.

DISCUSSION

Perpetuation of any forest community requires that the keystone tree species successfully recruit to the canopy and that they successfully produce seedlings that are able to do likewise in due time. The disturbance regime is a critical part of this perpetuation process because there is an affinity between the silvics of the principal species and the characteristics of the disturbance regime. Drastic changes to the disturbance regime can promote the keystone species to become more dominant even to the point of forming natural monocultures. Or, the keystone species may fail to reproduce and recruit and the forest community changes to another forest type or vegetative association. Both scenarios are evident in the UYP stands used in this study. Understanding the relationships between the regeneration/recruitment of pitch and Table Mountain pine and gap formation via disturbances will help forest managers sustain this rare forest type throughout the Appalachian Mountains.

Before 1900, both pine species clearly preferred sunny gaps to shady understories for regeneration; about 78 percent of all stems originated in gaps. Many of these gaps were likely small in size because 70 percent of the gap-origin pines experienced extended periods of suppression beginning a few years after germination, suggesting the gap closed over them before they reached the canopy. That suppression ended for the majority of these pines; their growth chronologies show one or more moderate or major canopy releases that allowed them to grow into the canopy and become dominant or strong co-dominant trees. A few pines never experienced a canopy release and became weak co-dominant or strong intermediate stems. These releases were either direct canopy disturbances such as a storm event or caused indirectly by a surface fire that resulted in delayed tree mortality. For example, the middle graph on Figure 1 shows a Table Mountain pine that originated in the late 1800s. It was quickly suppressed, but was released in the late 1920s. This release corresponds to the arrival of the chestnut blight in the area (Keever 1953), and these stands had a sizeable component of American chestnut.

Large gaps also played an important role in these UYP stands before 1900 for Table Mountain pine, but not pitch pine. Of the 42 gap-origin Table Mountain pines, 16 germinated in gaps large enough for them to grow unaided into canopy dominants. Generally, pines using this canopy accession strategy originated after a fire. For example, the upper graph of Figure 1 is of a dominant Table Mountain pine that originated about 1875. Fire scars found in the vicinity of this tree indicate a fire occurred there in 1872. This difference in large gap utilization between the two species is understandable given their silvics. Table Mountain pine has serotinous cones so the vast majority of its seeds are released after a fire, while pitch pine cones open annually resulting in continuous rather than episodic seed fall (Williams and Johnson 1992).

A few pines of both species originated in understory shade for they showed suppressed growth from the beginning. About half of these eventually experienced one or more moderate or major releases that allowed them to persist. The bottom graph in Figure 1 shows a pitch pine with this canopy accession pattern. It originated about 1840 and grew slowly for 30 years, becoming a small sapling. The sapling escaped or survived the 1872 fire, but the resultant gap released the sapling, resulting in accelerated growth. By 1900, the gap had closed, but a hurricane passed through the area in 1902 and this storm apparently formed another gap. The pine then grew into a dominant canopy position.

The other half of the understory-origin pines showed no evidence of any moderate or major releases in their growth chronologies. All of these were canopy intermediate trees. Many were as old as nearby pines, but substantially smaller.

The limited occurrence of these understory-origin pitch and Table Mountain pines suggests an important concept relative to stand conditions in the 1800s. Modern UYP stands are not regenerating and have not done so for decades due to the proliferation of mountain laurel in their understories (Brose and Waldrop 2010). The ability of pitch and Table Mountain pines to germinate and persist as suppressed seedlings in the 1800s may indicate that the forest floor was less dense and the light levels were sufficient for their survival. The periodic occurrence of surface fires in the 1800s and their absence for much of the 1900s is the most likely explanation for the presence of understory-origin pines in the past and their absence now.

In the 1900s, regeneration and recruitment in large gaps became the modus operandi for Table Mountain pine and, to a lesser degree, pitch pine. In the 20th century, nearly 73 percent of all Table Mountain pines and 41 percent of all pitch pines originated in large gaps and grew uninhibited into the canopy. The remaining pines of both species germinated in a mix of small gaps and understory environments with a majority of these attaining the canopy via one or more canopy releases. This shift in regeneration/recruitment strategy from a mix of gap types in the 1800s to primarily large gaps in the 1900s is a result of the increase in severe disturbances during the first half of the 20th century (Brose and Waldrop 2006b). Besides the chestnut blight, these stands experienced several fires and hurricanes between 1900 and 1950. Many of these disturbances were severe, creating large gaps that were ideal habitats for both pine species to regenerate and ascend into the canopy. Conversely, disturbances and gaps became scarce in the second half of the 20th century, and regeneration/recruitment of the pines diminished and then ceased altogether.

CONCLUSIONS

In the 1800s, periodic surface fires maintained open understories in UYP stands that allowed pitch and Table Mountain pines to regenerate, persist as seedlings and saplings, and eventually ascend into the main canopy through small gaps created by canopy disturbances. In the early 1900s, fires and canopy disturbances such as chestnut blight became more severe, creating large gaps. In these large gaps, Table Mountain pine was especially successful at regenerating and recruiting to the canopy without needing further releases. Since the mid-to-late 1900s, pine regeneration and canopy recruitment has virtually ceased, corresponding to the advent of fire control as well as a decline in tropical storms passing through the region. Forest managers desiring to regenerate or maintain UYP stands should strive to recreate the dual disturbance regime of the 1800s and early 1900s via prescribed burning and other management techniques.

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Table 1—Distribution of the 169 sampled trees by species and origin type. Numbers in parentheses are the expected values for each species and origin type combination

Species	Pitch pine	Table Mountain pine	Total
Large Gap	13 (25)	56 (44)	69
Small Gap	11 (7)	9 (13)	20
Small Gap + release	20 (18)	26 (28)	46
Understory	8 (5)	7 (10)	15
Understory + release	10 (7)	9 (12)	19
Total	62	107	169

Comparison of pine species by origin type (test statistic: X2 = 17.65, critical value = 9.488, α = 0.05, df = 4)

Table 2—Distribution of the 107 sampled Table Mountain pines by origin period and origin type. Numbers in parentheses are the expected values for each origin type and origin period combination

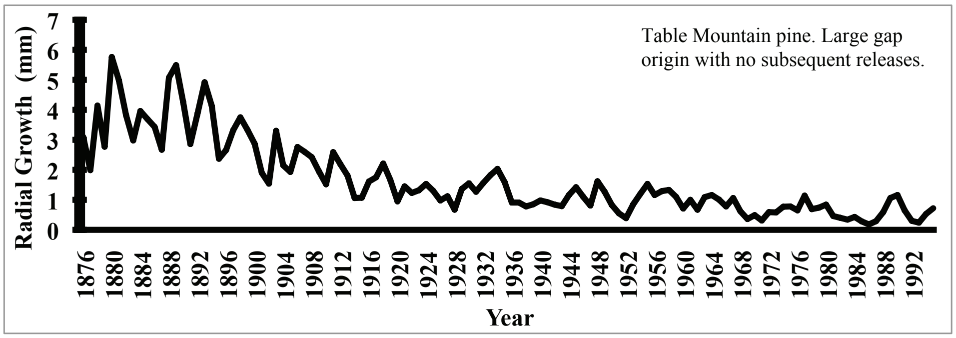
	Origin Period		
Origin Type	before 1900	after 1900	Total
Large Gap	16 (27)	40 (29)	56
Small Gap	5 (3)	2 (4)	7
Small Gap + release	21 (13)	5 (13)	26
Understory	6 (4)	3 (5)	9
Understory + release	4 (4)	5 (5)	9
Total	52	55	107

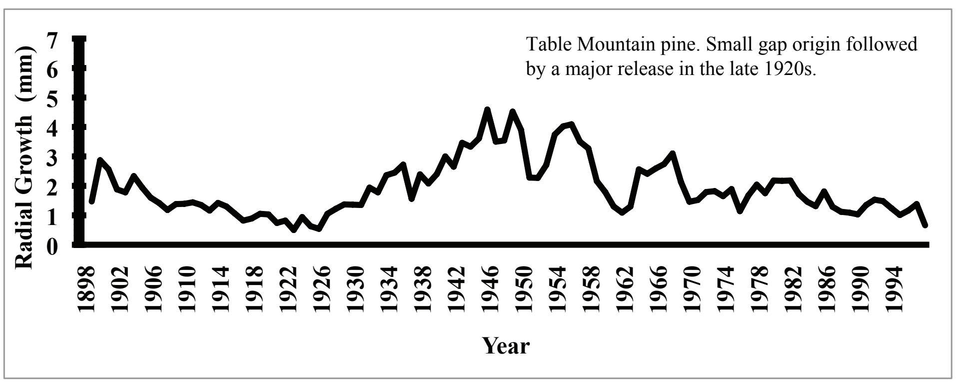
Comparison of origin type by origin period (test statistic: X2 = 22.623, critical value = 9.488, α = 0.05, df = 4)

Table 3—Distribution of the 62 sampled pitch pines by origin period and origin type. Numbers in parentheses are the expected values for each origin type and origin period combination

	Origin Period		
Origin Type	before 1900	after 1900	Total
Large Gap	4 (7)	9 (6)	13
Small Gap	6 (6)	5 (5)	11
Small Gap + release	14 (11)	6 (9)	20
Understory	4 (5)	4 (3)	8
Understory + release	7 (6)	3 (4)	10
Total	35	27	62

Comparison of origin type by origin period (test statistic: X2 = 5.55, critical value = 9.488, α = 0.05, df = 4)





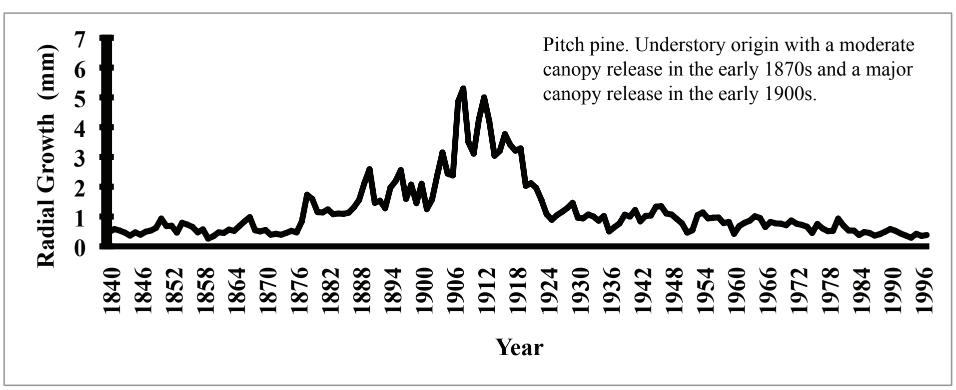


Figure 1—Examples of canopy accession patterns (large gap, small gap + release, and understory + release) of dominant pitch and Table Mountain pines growing in northern Georgia. Note that the horizontal axes are different scales for the three graphs.

EXPLORING GENETIC DIVERSITY, PHYSIOLOGIC EXPRESSION AND CARBON DYNAMICS IN LONGLEAF PINE: A NEW STUDY INSTALLATION AT THE HARRISON EXPERIMENTAL FOREST

John R. Butnor, Kurt H. Johnsen, and C. Dana Nelson

In 1960, an experiment was established on the Harrison Experimental Forest in southeast Mississippi to compare productivity and wood properties of planted longleaf (*Pinus palustris*), loblolly (*Pinus taeda*), and slash (*Pinus elliotii*) pines under different management intensities: cultivation, cultivation plus three levels of NPK fertilizer and a control (Smith and Schmidtling 1970). Key findings over the years demonstrate that longleaf pine lagged in productivity the early years, but eventually surpassed loblolly and slash pine:

- Age 9, intensive culture increased productivity of all species; loblolly pine had greater height and volume than longleaf or slash pine (Schmidtling, 1973). Yield differences between species in the highest fertilizer treatment were considerable: loblolly 41 Mg ha^{-1}, slash 29 Mg ha^{-1}, longleaf 12 Mg ha^{-1}.

- Age 25, longleaf had surpassed both slash and loblolly pine in height in the control plots, characterized by low nutrient availability. At the highest level of management intensity loblolly was still >2 m taller than the other species (Schmidtling, 1986).

- Age 39, longleaf pine attained similar height as loblolly pine, though it lagged behind slash pine in height and diameter growth

- Age 45, Hurricane Katrina impacted the site; longleaf pine suffered the least mortality, followed by slash and loblolly pine respectively (7 percent, 15 percent, 26 percent) (Johnsen and others, 2009). In 2006, after hurricane Katrina, mean basal area across all treatments was 23 m^2 ha^{-1} for longleaf pine and 19.3 m^2 ha^{-1} for slash pine and 12.4 m^2 ha^{-1} for loblolly pine.

Hurricane Katrina (August 2005) left the experiment heavily damaged, especially the loblolly plots, limiting the experiment's usefulness for future comparisons between pine species. We saw this as an opportunity for continuing longleaf pine research on the site with a new experimental design and study installation. While there is strong region-wide interest in restoring longleaf pine to enhance forest resilience to climate change and extreme climate events, little is known about the level of variability among and within regional seed sources and how this might affect adaptive traits. The goal of the new design is to better understand genetic control of physiologic traits that enhance survivorship and productivity at a hurricane prone site with relatively low native soil fertility.

The new installation will compare four longleaf pine sources originating from similar latitudes from Texas to South Carolina under three planting densities (750, 1330, 2200 trees per hectare) using a completely randomized design replicated four times for a total of 12 plots. Within each plot, there will be four genetic source split-plots: Region 8 improved TX source, Region 8 improved south MS/south AL source, Region 8 improved SC source, and unimproved local source (i.e., control, representing genetic quality of original planting). The tested genetic sources define a west-to-east transect covering the full range of south coastal longleaf pine. Each genetic source, excluding the control, represents one generation of genetic improvement as completed by the Region 8 tree improvement program. Physiologic differences among and within sources will be analyzed along with differences in height, diameter, stem taper and carbon allocation to specific components (foliage, branches, stems, roots) across the planting density gradient. Allelic states of several genes will be related to survival and performance traits to determine which genes affect which traits and to measure and monitor the resident genetic diversity in these sources as the stand matures. Experiments such as this will inform development of genetic guidelines for restoring resilient longleaf pine ecosystems.

The original experiment has been invaluable for comparing long-term productivity and carbon dynamics among three species of planted pines, and the study continues to have

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demonstration and research value. Instead of simply harvesting the entire site and starting over, a novel plan which includes retaining some of the original plots and moving them to uneven age management with thinning was devised. Natural regeneration of longleaf pine is most successful in large gaps in the canopy. We propose to install each of the new measurement plots in 55 m by 55 m gaps created by clear cutting (Figure 1). Some of the original longleaf pine plots have accrued exceptional basal area over the past 50 years, with a few plots approaching 45 m^2 ha^{-1}. Eleven of these plots will be thinned to 23 m^2 ha^{-1} to continue studying them under relatively high density (Figure 1). The rest of the original planting will be thinned to 14 m^2 ha^{-1}. Prescribed fire will be continued on a 2 year cycle.

Several goals are achieved with this new experimental design: 1) creation of a new longleaf pine planting density x genetic source study, 2) restoration of a longleaf pine ecosystem with fire and planting, 3) enhanced aesthetics and habitat with gap layout, 4) unique opportunity to study longleaf genetics and physiology at the Harrison Experimental Forest in a multi-age stand, and 5) initiation of a powerful experimental design for genetically mapping quantitative traits in longleaf pine. Thinning and harvesting are planned for summer 2011, site preparation in fall 2011, followed by planting during the 2011-2012 winter season.

This new study is made possible by a close partnership with the DeSoto Ranger District of the DeSoto National Forest. Without their assistance with prescribed burning, timber sale administration, site preparation, and advice on land use policy and regulations this project would not be possible. Special thanks to Ronald Smith, District Ranger, James Mordica, Ecosystem Restoration Coordinator, and Larry Lott for serving as an onsite liaison between the SRS and the district personnel.

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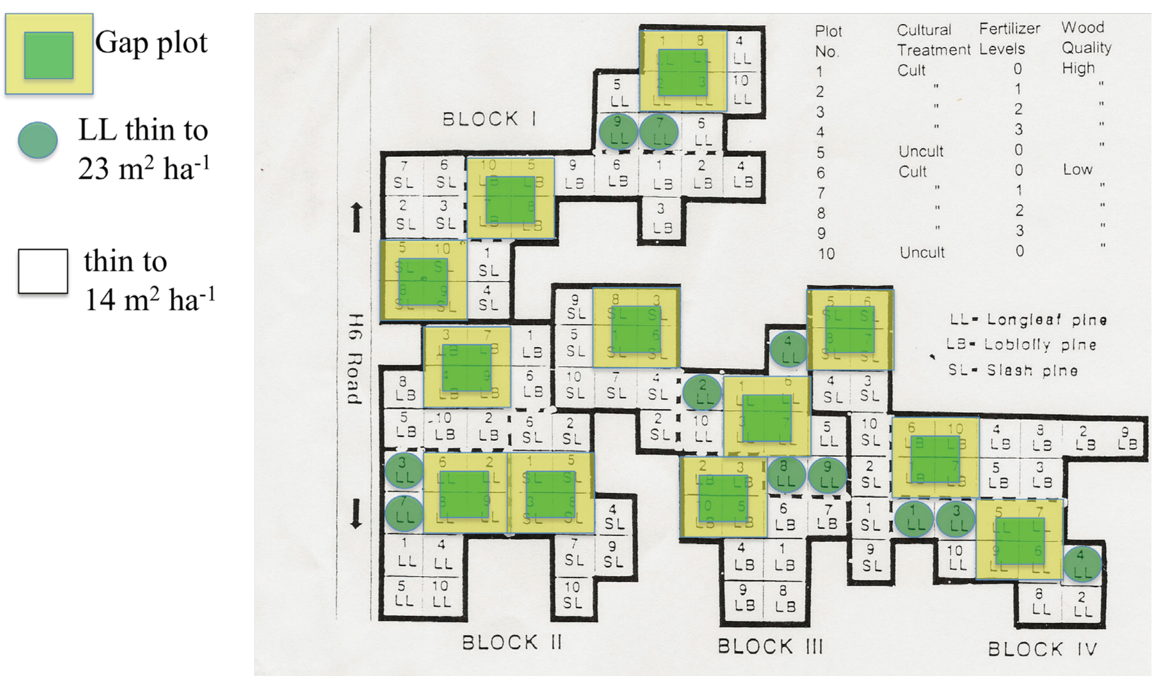

Figure 1—Map showing the location of 12 new gap plots created by combining 4 adjacent plots from the original experiment. A 5 tree buffer (yellow) will surround the new measurement area (green). The buffer area will be thinned to 14 m^2 ha^{-1}, while a 55 m by 55 m area will be clear cut to create the new measurement plot. The location of 11 longleaf plots which will be thinned to 23 m^2 ha^{-1} are marked with a green circle, all other plots will be thinned to 14 m^2 ha^{-1}.

LONGER BLACK WILLOW CUTTINGS RESULT IN BETTER INITITAL HEIGHT AND DIAMETER GROWTH IN BIOMASS PLANTATIONS

Jake C. Camp, Randall J. Rousseau and Emile S. Gardiner

ABSTRACT

Black willow (*Salix nigra* Marsh.) has the potential to be a viable plantation species for biomass production on heavy clay soils throughout the southern United States. The most favorable planting stock for woody biomass plantations is dormant unrooted cuttings, because they are easy to plant and use of clonal material allows for advancing genetic improvement. The purpose of this study was to determine the optimal cutting size and planting depth for maximum survival and growth of unrooted black willow cuttings. A test using three cutting lengths (9, 15, 21 inches), four cutting diameters (⅜, ½, ¾, 1 inches), and three planting depths that left 2, 5, and 8 inches of exposed unrooted cuttings was established in 2009, and survival and growth were measured for two growing seasons. Second-year survival exceeded 99 percent across all treatment combinations and was not influenced by any of the experimental factors. Total height differed among cutting length and cutting diameter. The 21 inch cuttings produced stems with the greatest heights and diameters two growing seasons after planting, but the largest cutting diameters did not produce the same effect. Our results indicate that cutting length had a stronger influence than either cutting diameter or planting depth on black willow height and diameter growth during the first two growing seasons after planting.

INTRODUCTION

Short rotation woody crops (SRWCs) are characterized by fast growing tree species, grown in plantation culture under a greatly reduced timeframe for either pulp or biomass production. This type of plantation system has attained significant acreage in Europe, and will become increasingly important in the United States as renewable energy demands turn to woody biomass as a source of biofuel feedstock. Black willow (*Salix nigra* Marsh.), a species native to North America, possesses a range of silvical qualities that demonstrate high potential for culture in SRWC plantations. These characteristics include extremely fast growth, ease of vegetative reproduction via stem cuttings, and ability to grow on extremely wet sites not typically favorable to other SRWC species. In spite of its extraordinary biomass production potential for biofuel feedstock, there is little information to support black willow establishment and management techniques in a plantation setting.

Black willow is among other SRWC species, e.g. cottonwood (*Populus* spp.) and sycamore (*Platanus* sp.), naturally found on alluvial sites (Morgenson 1992). However, black willow is more flood tolerant than these other species and grows on soils that are at best only marginal for row crop production as well as other commercially viable tree species.

Considerable work on willow biomass production has been conducted in the northeastern United States using a number of shrub willow species (Abrahamson et al. 2002). The same research effort has not extended into the southern region of the country where black willow is the predominant willow species. Research from the northeast indicates vegetative propagation with unrooted cuttings is the most economical and efficient method of establishing willow plantations (Abrahamson et al. 2002). Additionally, work on poplar, a closely related genus, indicates larger cuttings exhibit best survival and growth, and cuttings harvested distally from the terminal showed best rooting (Morgenson 1992). Dickmann (1992) noted that cutting diameter influenced poplar survival and growth.

Research on black willow is needed in the southeast region of the United States to support development of its potential as a viable biomass feedstock species. Plantation establishment using unrooted cuttings must be understood to optimize survival and growth in production settings. The purpose of this study was to determine the optimal cutting size and planting depth of unrooted black willow cuttings for maximizing survival and growth. Results from this research are expected to aide future studies and allow more focused research on other aspects of black willow silviculture. In addition, this study will provide landowners with knowledge of planting stock requirements for establishing dedicated bioenergy plantations using black willow.

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MATERIALS AND METHODS

The study was established in March 2009 at the Mississippi Agricultural and Forestry Experiment Station in Stoneville, MS. The site was a former agricultural field in the Lower Mississippi Alluvial Valley (LMAV), with soils in the Bosket and Commerce series. The Bosket series are fine sandy loams and the Commerce series are silty clay loams; both are poorly drained with a water table depth of around 20 inches and less than 2 percent slope. Annual rainfall for the site averages 55 inches with a long growing season.

Dormant black willow whips were collected from a single geographic source, which included a small area in southwest Oktibbeha County, MS. The whips were harvested, in December 2008, from only one geographic source to minimize genetic variation and allow for full expression of treatment effects. Whips were cut to the appropriate length, grouped into the appropriate sizes, and stored at 34 °F until planted. The planting site was prepared by disking and sub-soiling to a depth of 16 inches on 10 foot centers to break any possible pans. Cuttings were hand planted at 6 x 10 ft spacing. A broadcast application of Goal 2XL (oxyfluorfen), at 48 ounces to the acre, was used prior to black willow bud break to reduce herbaceous competition early in the first growing season. Mechanical practices controlled competing vegetation during the remainder of the first growing season. Canopy closure reduced competing vegetation during the second growing season minimizing the need for mechanical weed control. No silvicultural applications were conducted in the second growing season.

The experiment was established as an incomplete 3 x 4 x 3 factorial according to a randomized block design. There were 3 levels of cutting length (9, 15, 21 inches), 4 levels of cutting diameter (⅜, ½, ¾, and 1 inch), and 3 levels of planting depth that left 2, 5, and 8 inches of exposed cutting. There was an incomplete set of 32 treatment combinations, because the combination of the 9 inch cutting with 8 inches of exposed cutting was not practical. Thus, the four treatment combinations of 9 inch cuttings, planted 1 inch deep, for each of the 4 different cutting diameters were omitted from the experiment. All treatment combinations were assigned in plots of 4 cuttings, and plots were replicated in each of 4 blocks. A total of 512 cuttings were planted for this study, plots were surrounded by two buffer rows of planted cuttings. All sample stems were measured in December 2009 and 2010. Measurements included height to the nearest tenth of a foot and diameter, one foot above the cutting, to the nearest hundredth of an inch. Statistical analyses tested for treatment effects on height and diameter by plot means basis at an alpha level of 0.05. Means from significant effects were separated with Fisher's LSD in tables 1, 2, and 3.

RESULTS

The objective of this study was to determine the optimal cutting length, cutting diameter, and planting depth for maximizing survival and growth of black willow unrooted cuttings. Survival, height, and diameter were measured for two consecutive years in this experiment. For all treatments, shoot height averaged 8.9 feet for the first year and 15.9 feet for the second. Mean shoot diameters were approximately 1 inch for the first year and 1.79 inches for the second. Survival was high across the study and did not differ by treatment. Only two trees died in the first year and none in the second, resulting in a survival percentage of 99.6 percent in both years. Results indicate the longest cuttings exhibited the most vigorous shoot height and diameter growth (Table 1). On average, 21 in. cuttings developed shoots almost 4 percent taller and 7.5 percent larger in diameter than 9 in. cuttings. Cutting diameter also influenced height and diameter growth of shoots, but growth trends relative to this factor did not follow any logical sequence (Table 2). The smallest diameter cutting (3/8 inches) produced the greatest height and diameter growth for both years, but was not followed by the next level of cutting diameter (1/2 inches). Two years after plantation establishment, planting depth had little impact on black willow shoot growth (Table 3).Shoot height was did not differ among planting depths, while shoot diameter increased about 3 percent for shoots that developed from cuttings with the greatest amount of exposed material.

DISCUSSION

This study was conducted to determine the optimal dimensions for maximizing survival and growth of unrooted cuttings of black willow grown as a short rotation renewable energy crop. Results were analyzed to determine the most favorable size of vegetative planting stock along with its planting depth for survival and growth enhancement. An understanding of how size of vegetative planting material influences survival and shoot growth will enable development of plantation establishment protocols for advanced experimentation on other aspects of plantation production, such as genetic screening trials. It was hypothesized that long cuttings with large diameters would exhibit the greatest survival and shoot growth.

Cutting length was the most influential factor on black willow shoot height and diameter growth in this study, with the longest cuttings showing the greatest growth. This finding may relate to the amount of root mass that developed on the rooting zone of longer cuttings. Our personal observations indicate black willow will root along the entire length of the below-ground portion of the cutting. One limitation of this study is that we only measured trees over a two year study period. Our results indicate that initial differences due to cutting length may be decreasing over time. Additional years of measurements may demonstrate that longer cuttings only benefit shoot growth in the first few years of plantation establishment. Shorter cuttings may prove to be just as tall in 3 to 5 years, which is harvesting age for other willow biomass crops (Abrahamson et al. 2002).

We cannot explain why cutting diameter was not a more influential factor on black willow shoot growth. Our results indicated that the smallest cutting diameters yielded the tallest shoots, but we did not observe a linear trend of stem growth among treatment levels. While small diameter cuttings exhibited good shoot growth, cuttings of very small diameter could easily break during planting.

As with cutting diameter, we expected planting depth to have more of an influence on shoot growth than observed in this study. It is likely that a greater response would have been observed on a site with lower soil moisture availability. The practical limitation on planting depth is that the longer a cutting is, the more energy and time it takes to plant. Deeper planting depths would increase planting cost. On sites with less annual rainfall, deeper planting depths would likely be required to keep survival high. It is hypothesized that on less mesic sites survival would decrease.

CONCLUSIONS

This study demonstrates relatively long black willow cuttings developed shoots that were taller and with a larger diameter than relatively short cuttings. In contrast, cutting diameter and planting depth did not influence growth to the same extent. Furthermore, cutting dimension did not impact black willow survival. The recommendation from this study is to plant longer cuttings for increased height growth in biomass plantations of black willow. Results from this study indicate that height growth of black willow can be maximized with cuttings that are 21 inches long, 3/8 inches in diameter, and planted to leave 8 inches of exposed material above the ground. Future measurement of this study will reveal if our findings are maintained over longer periods of plantation development. Additionally, we plan future work to evaluate optimization of cutting size with horizontal and vertical planting techniques to minimize planting cost.

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Table 1—Mean height and diameter of black willow shoots by cutting length treatment levels 1 and 2 years after planting

Cutting Length (in)	Year 1		Year 2	
	Height (ft)*	Diameter (in)	Height (ft)	Diameter (in)
9	8.5 a	0.92 a	15.8 a	1.74 a
15	8.9 b	1.00 b	16.1 b	1.81 a
21	9.5 c	1.09 c	16.4 c	1.87 b

* Significant differences (p<.05) are indicated by different letters following the means in a column.

Table 2—Mean height and diameter of black willow shoots by cutting diameter treatment levels 1 and 2 years after planting

Cutting Diameter (in)	Year 1		Year 2	
	Height (ft)*	Diameter (in)	Height (ft)	Diameter (in)
3/8	9.2 a	1.06 a	16.4 a	1.90 a
1/2	8.9 b	0.97 b	15.9 b	1.75 a
3/4	9.0ab	1.02 ab	16.0 b	1.80 b
1	8.9 b	1.00 b	16.0 b	1.78 b

* Significant differences (p<.05) are indicated by different letters following the means in a column.

Table 3—Mean height and diameter of black willow shoots relative to amount of exposed cutting material above ground 1 and 2 years after planting

Exposed Material (in)	Year 1		Year 2	
	Height (ft)*	Diameter (in)	Height (ft)	Diameter (in)
2	8.9 b	1.00 a	16.0 a	1.79 b
5	9.1 ab	1.02 a	16.1 a	1.80 ab
8	9.1 a	1.03 a	16.2 a	1.85 a

* Significant differences (p < .05) are indicated by different letters following the means in a column.

HERPETOFAUNAL RESPONSE TO OAK-REGENERATING SILVICULTURAL PRACTICES IN THE MID-CUMBERLAND PLATEAU OF SOUTHERN TENNESSEE

Andrew W. Cantrell, Yong Wang, Callie J. Schweitzer, and Cathryn H. Greenberg

ABSTRACT

Silviculture treatments can alter landscapes, which in return can affect wildlife communities. This research examined how microhabitat differed short-term (1-2 years after disturbance) between two different oak-regenerating shelterwood treatments, a midstory-reduction (oak-shelterwood) and a first-harvested basal area removal (shelterwood), in comparison to undisturbed controls. Mechanisms responsible for influencing herpetofaunal communities were examined in the oak-hickory hardwood forests of the mid-Cumberland Plateau in Grundy County of Southern TN. Herpetofauna were captured using drift fences equipped with pitfall and box funnel traps, and microhabitat variables were collected at each trap location. Shelterwood stands had a higher amount of slash, slash pile volume, and woody and herbaceous vegetation than other stand types. Oak-shelterwood and control stands had higher litter depth, litter cover, and presence of overstory than shelterwood stands. Eastern fence lizards, eastern five-lined skinks, Fowler's toads and broad-headed skinks were all significantly more abundant in stands that received manipulation in comparison to control stands.

INTRODUCTION

Herpetofauna are important components of biological diversity, and play an ecological role as predators and prey. Understanding herpetofaunal responses to forest management practices that alter habitat conditions is important because many species have specific habitat requirements. Many herpetofaunal species use structural features of forests, ranging from the tree canopy to the forest floor, as habitat. Complex vegetation structure, such as multiple tree strata (canopy, understory, and shrub layers) and dead standing trees, also provides habitat and foraging sources for many wildlife species (Lanham and Guynn 1996). Changes in the availability of these forest features may affect the density and species composition of wildlife communities and individual species (Felix and others 2009, Wang and others 2006). Forest management techniques that affect forest structure, microhabitat, and microclimate have the potential to affect plant and animal community composition and abundance. Wildlife response to forest disturbance may vary with the type and intensity of disturbance, the forest type, and across their geographic range. Understanding vertebrate community responses to changes in forest conditions is important in predicting impacts of forest management.

The USDA Forest Service Southern Research Station, Upland Hardwood Ecology and Management Research Work Unit 4157 implemented a regional oak study (ROS) (Greenberg and others 2008, Keyser and others 2008) with partners to address how three recommended, but not widely tested, oak regeneration treatments affect oak and other hardwood species regeneration and wildlife communities across three areas within the southern Central Hardwood Region of the USA. In the ROS, effects of the following forest management treatments are being examined: 1) Shelterwood with prescribed fire (SW), 2) Oak-Shelterwood (OSW), and 3) Prescribed fire. All 3 regeneration prescriptions will have any residual trees removed 11 years after initial implementation. Studying herpetofaunal response to these treatments is one of many components of this multidisciplinary research. The herpetofaunal study examined how these disturbances affected herpetofaunal species abundance, and the mechanisms (e.g. microhabitat features) possibly responsible for influencing such communities. This study examined the short-term differences detected in microhabitat variables among SW, OSW, and control stands, and the variation of herpetofauna in relationship to treatments and habitat conditions.

STUDY SITE DESCRIPTION

The study site was located on the mid-Cumberland Plateau of southern Tennessee. This research was conducted in Grundy County, TN on property owned by Stevenson Land Company. The elevation of the site is approximately 390 m to 550 m above sea level. The forest stands are located on the eastern escarpment of Burrow's Cove, drained by Laurel

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Creek; stands are located to the north and south of Mill Hollow. Braun (1950) classified the area as being in the cliff section of mixed mesophytic forest region. The forest stands on average had a basal area (BA) of 22.5 m^2/ha and 164 stems/ha (SPHA), and they are composed of 27 different hardwood species, having yellow poplar (*Liriodendron tulipfera*), sugar maple (*Acer saccharum*), white oak (*Quercus alba*), pignut hickory (*Carya glabra*), and northern red oak (*Quercus rubra*) as their dominant overstory trees (unpublished data, Callie J. Schweitzer).

EXPERIMENTAL DESIGN

The field experiment followed the guidelines of Greenberg and others (2008) which adopted a completely randomized design with 3 oak regenerating treatment types and 1 control, each replicated 5 times for a total of 20 experiment stands (approximately 5 ha each). Treatment units were selected by the USDA Forest Service researchers following guidelines that all treatment units have mature closed canopy stands with trees >70 years old without major anthropogenic or natural disturbances within the last 15-20 years.

The prescribed burns were not implemented during the course of this study. However, since data were collected within these unaltered stands, they were considered control stands during statistical analyses. Two out of the five SW treatments were not harvested prior to the completion of field sampling and are omitted from statistical analyses. These modifications resulted in 18 experimental stands: 10 controls, 5 OSW, and 3 SW.

SILVICULTURE TREATMENTS

Shelterwood harvest method—The SW harvest prescription followed the guidelines of Brose and others (1999). The treatment entailed harvesting of timber with a 30-40 percent basal area (BA) retention. Residual trees were based on species, diameter and quality. Trees were harvested by chainsaw felling and grapple skidding along pre-designated trails, leaving removed limbs and branches within the stands. Treatments were implemented in the fall and winter of 2008.

Oak-shelterwood method—The OSW treatment followed the guidelines of Loftis (1990). This treatment used a Garlon 3A herbicide, with the main active ingredient being Trichlopyr. Herbicide was induced into competing mid-story trees with ≥ 5 cm and ≤ 25 cm diameter at breast height (DBH) by the hack-and-squirt method. The initial treatment implementation in fall/winter of 2008 was not effective for undetermined reasons and was repeated in the fall/winter of 2009.

MATERIALS AND METHODS

MICROHABITAT

Microhabitat data were collected along line transects located at each herpetofauna sampling drift fence. At each fence two 10-m transects were installed. Transects originated 2 m from the middle of the fence to eliminate any disturbance caused by drift fence installation. Direction of the first transect was randomly determined by azimuth degree compass bearing, and the second transect used the polar opposite of the first transect on the opposite side of the fence. Variables recorded along transects included: litter depth, percent ground cover, volume of coarse woody debris (CWD) and slash, and forest stratification. Litter depth was recorded every 2 m along each transect using a ruler to the nearest millimeter. Percent ground cover was recorded every 5 m along each transect using 0.5 x 0.5 m sampling plots. Percent ground cover categories included leaf litter, bare ground, CWD, slash, rock, and herbaceous and woody vegetation. Percent cover of each category was recorded as cover within or directly above the sampling plots up to 2 m. Forest strata were visually assessed at each 5 m interval. The forest strata was assigned one of the following categories modified from Sutton (2010): 1) ground cover (≤ 2 m); 2) understory (> 2 m – ≤ 4 m); 3) midstory (> 4 m – < overstory); and 4) overstory (the main forest canopy). Volumes of CWD and slash piles were also assessed. Length and diameter at transect contact was recorded for all CWD ≥ 10 cm in diameter at the transect intercept point. Volume of CWD was calculated using the formula given by Van Wagner (1968). The volume of slash piles was roughly estimated; slash was measured if any portion of a mound intersected with the transect based on diagrams given by Hardy (1996). Canopy cover was collected at the center of each drift fence using a hand-held spherical densiometer during mid-summer when the canopy foliage was full.

HERPETOFAUNAL TRAPPING

The herpetofaunal community was assessed from mid-May until the end of September in 2010 via drift fences with pitfall and double funnel box traps, a commonly used technique to capture terrestrial reptile and amphibian species (Dodd 1991). In each unit four drift fences of 7.6 m long aluminum flashing were installed by excavating trenches approximately 15.2 cm deep and 15.2 cm wide and secured using wooden stakes. Two drift fences were installed at the lower slope region (bottom 1/3 of the stand) and the other two drift fences were installed at the upper slope region (top 1/3 of the stand). A pitfall trap (a 19 L bucket) was installed into the ground at each end of the drift fence. Each drift fence also had a funnel box trap at the center along each side of the fence. Traps were opened continuously except for a few days at the end of August and beginning of September. All traps were checked four to six days a week. Each time a single drift fence was checked it was recorded as being a single trap night.

STATISTICAL ANALYSIS

Species and microhabitat data were analyzed using general linear model analysis of variance (ANOVA) for a completely randomized design to determine if there were any differences among treatment types. Post-hoc Tukey multiple range tests (HSD) were used to identify differences between specific treatments if ANOVA tests were significant. Principal component analysis (PCA) was used to simplify microhabitat variables into components, which allowed the interpretation of possible relationships among microhabitat variables. A constrained ordination technique, canonical correspondence analysis (CCA), was used to explore the relationship between herpetofaunal species and microhabitat variables (McGarigal and others 2000). Microhabitat variables represented by vectors in CCA that did not show a strong relationship with either axis were excluded. Species with < 10 captures were excluded from CCA and ANOVA analyses. All tests were performed with $\alpha = 0.1$.

RESULTS

MICROHABITAT

Several microhabitat variables differed among treatments in 2010 (Table 1). Canopy cover was the only variable significantly different among all three treatment types, which averaged 92 percent for control stands, 86 percent for OSW stands, and 67 percent for SW stands. Oak-shelterwood and control stands had higher litter depth, litter cover and presence of overstory than SW stands. Shelterwood stands had a higher amount of slash, slash pile volume, and woody and herbaceous vegetation than control and OSW treatment stands. Shelterwood stands had more bare ground than OSW and control stands. Understory and midstory structure was reduced in SW and OSW treatments compared to control stands.

Principal component analysis extracted 5 separate components (eigenvalue >1) that accounted for 74.2 percent of total habitat variance (Table 2). Component one was positively related to canopy cover, overstory structure, litter depth, and ground litter cover, and negatively related to the amount of slash, ground cover, and woody and herbaceous vegetation covers. Component two was positively related to canopy cover and understory and midstory vegetation cover, and negatively related to ground cover vegetation. Component three was positively related to slash and slash pile volume, and the amount of bare ground, and negatively correlated with litter depth. Component four was positively related to the presence and volume of CWD, but negatively related to the amount of ground cover vegetation. The last component, component five, was positively related to the rock coverage and negatively related to the litter depth.

HERPETOFAUNA

There were 96 days of trapping during the 2010 field season, which resulted in 6,912 trap nights. A total of 4,108 individuals of 28 species were captured. American toads (*Anaxyrus americanus*) made up 84.6 percent of the individuals captured. The abundance of four hereptofaunal species differed among treatments. Eastern fence lizards (*Sceloporus undulatus*), Eastern five-lined skinks (*Plestiodon fasciatus*), and Fowler's toads (*Anaxyrus fowleri*) were more abundant in SW stands than oak-shelterwood and control stands (Table 3). Broad-headed skinks (*Plestiodon laticeps*) were more abundant in OSW stands (Table 3).

MICROHABITAT AND HERPETOFAUNAL RELATIONSHIP

For amphibians, CCA eigenvalues accounted for 84.9 percent of total variance of species-environment relationship (Figure 1). Axis 1 was positively correlated to the percent cover of rock and bare ground, and negatively related to litter cover and presence of overstory; the second axis was positively related to the covers of woody vegetation, slash, and overall ground cover, and negatively related to the mid and upper story vegetations, slash pile volume, litter depth, and CWD volume. Eastern spadefoot toads (*Scaphiopus holbrookii*) had a strong positive relationship with high coverage of herbaceous vegetation, and slash. Other species such as southern leopard frogs (*Lithobates sphenocephala*), pickerel frogs (*Lithobates palustris*), American toads, and Fowler's toads appeared to be habitat generalists and occurred at the center of the CCA plot. Eastern red spotted newts (*Notophthalmus v.viridescens*) occurred more often in sites with high rock coverage, whereas green frogs (*Lithobates clamitans*) occurred more often at sites with more bare ground. Cave salamanders (*Eurycea lucifuga*) appeared to have a strong association with the second axis, and occurred at sites with high ground cover.

For reptiles, CCA eigenvalues accounted for 88.9 percent of total variance for species-environment relationship (Figure 2). Axis 1 represented a gradient from higher percentage of bare ground, CWD, and volume of slash, and negatively related to canopy cover, litter cover and depth, and understory. Axis 2 represented a gradient from higher percentage of rock, presence of overstory, and CWD volume, and was negatively related to woody vegetation, presence of ground cover and midstory. Most reptile species appeared to be habitat specialists and were associated with specific microhabitat features. For example, eastern fence lizards had strong positive relationship with the first axis, characterized by habitats with more slash piles and increased bare ground, whereas broad-headed skinks had a strong negative association with the first axis, with more litter cover and understory. Copperheads (*Agkistrodon contortrix*) and eastern five-lined skinks were associated with sites that had a higher presence of overstory and litter depth. Species such as the midwest worm snake (*Carphophis a. helenae*) and eastern garter snake (*Thamnophis s. sirtalis*) were not strongly associated with any of the tested microhabitat variables.

DISCUSSION

This study examined herpetofaunal response to the habitat changes created by different forest management prescriptions for oak regeneration. Only the first phase of each SW was implemented and studied, however each created uniquely different microhabitat characteristics. Only the SW treatment involved a commercial harvest, which resulted in a 42 percent reduction in overstory basal area. The OSW treatment did not alter the overstory basal area but did change the composition and structure of the midstory.

Several reptile species were more abundant in SW stands compared to OSW and control stands. This can be attributed to the subsequent changes in forest canopy cover. The opening of the forest canopy increased the amount of light available for thermal regulation by reptiles. This coincides with findings by Felix (2007) who also found an overall increase in reptilian species richness and abundance in response to canopy removal. Results of this study indicated that abundance of most amphibians was either unchanged or increased in disturbed forest habitats. This may be due to several factors, including the increased heterogeneity and complexity within these stands.

Canonical correspondence analysis showed the habitat associations of reptile and amphibian species regardless of the treatment by examining habitats associated with specific trapping locations. Most species in this study were habitat specialists and were associated with specific habitat features. The gradients demonstrated in CCA also helped verify the microhabitat conditions presented by PCA and ANOVA. For example, in the CCA conducted using reptiles and habitat associations, high canopy cover, litter cover, and litter depth were correlated, and were associated with control stands in ANOVA. These associations are also seen in PCA. These same variables using CCA were inversely related to percent coverage of woody, herbaceous, and slash covers, which corresponded to ANOVA results showing these variables to be more abundant in SW treatment stands.

CONCLUSIONS

Results from this study showed that several microhabitat features in both the SW and OSW silviculture treatments differed from control stands in the short-term. These differences, either directly or indirectly, influenced the composition and abundance of herpetofaunal communities. The SW and OSW method created openings in the canopy and changes in the vertical structure of vegetation that likely resulted in more woody and herbaceous vegetation ground cover. The SW method resulted in more open areas, less canopy cover, and increased light availability. These increases were beneficial for species that depend on sunlight for thermoregulation. The SW treatment removed both the midstory and overstory, which resulted in less litter cover and litter depth due to a decrease in the source. However, litter cover and depth will likely increase over time as the vegetation responds, regeneration occurs, and the system inputs leaves and twigs as part of the deciduous vegetation process. Shelterwood stands also had higher amounts of CWD and slash on the forest floor, which provided cover not found in the other treatments. All of these factors contributed to increased complexity and heterogeneity of the forest floor environment and microenvironments, providing increased habitat diversity that appeared to benefit some reptile and amphibian species and subsequently change species abundance compared to OSW and control stands.

These findings give forest resource managers and private land owners in the region the knowledge of how herpetofauna respond to these two forest management practices compared to no management in the short-term. Results suggest that these two active management practices for oak regeneration do not adversely affect reptiles or amphibian populations, and may benefit some of these species. However, the scale and intensity of such operations combined with differences in geographic locations should be considered. It should also be considered that these results are indicative of only one-year of response data, and responses over longer temporal and broader spatial scales should be investigated.

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Table 1—Comparison of microhabitat variables for three management treatments in Grundy County, TN, 2010. ANOVA (F) test was followed with post-hoc Tukey tests. Means in the same row (Means ± Standard Deviation) with different superscript letters indicate significant difference (Tukey p<0.1)

Variable	Control	Oak-Shelterwood	Shelterwood	F	P
Canopy Cover %	92.3 ± 3.02^{a}	86.1 ± 5.18^{b}	67.4 ± 9.91^{c}	101.12	0.000
Litter Depth (cm)	3.2 ± 1.15^{a}	3.4 ± 1.14^{a}	2.2 ± 0.77^{b}	4.61	0.013
Litter Cover %	62.5 ± 12.54^{a}	60.2 ± 8.85^{a}	23.3 ± 9.89^{b}	58.95	0.000
Bare Ground Cover %	0.9 ± 1.77^{ab}	0.7 ± 0.91^{b}	2.3 ± 2.38^{a}	3.386	0.040
Slash %	4.0 ± 2.07^{b}	4.0 ± 1.74^{b}	7.9 ± 4.28^{a}	12.31	0.000
Slash Pile Volume (m^3/ha)	0.0 ± 0.00^{b}	0.0 ± 0.00^{b}	87.61 ± 98.3^{a}	24.91	0.000
Woody Vegetation %	13.0 ± 8.5^{b}	14.4 ± 9.18^{b}	30.2 ± 11.92^{a}	16.25	0.000
Herbaceous Vegetation%	8.9 ± 8.13^{b}	9.9 ± 6.79^{b}	24.1 ± 10.45^{a}	16.55	0.000
Understory	0.6 ± 0.31^{a}	0.1 ± 0.2^{b}	0.2 ± 0.19^{b}	23.58	0.000
Midstory	0.7 ± 0.23^{a}	0.2 ± 0.18^{b}	0.4 ± 0.29^{b}	37.87	0.000
Overstory	01.0 ± 0.13^{a}	1.0 ± 0.05^{a}	0.8 ± 0.18^{b}	10.28	0.000

Table 2—Component loadings based on principal component analysis for microhabitat variables in Grundy County, TN, 2010

	Component				
Variable	PC1	PC2	PC3	PC4	PC5
Litter %	.85	.29	-.16	-.09	-.20
Overstory	.78	-.23	-.24	-.10	-.05
Woody %	-.81	-.18	-.02	-.25	-.04
Canopy Cover %	.76	.44	-.30	-.15	.04
Herbaceous %	-.74	-.27	-.05	.14	-.15
Slash %	-.49	.06	.48	.02	.20
Ground Cover %	-.45	-.42	-.11	-.52	.11
Understory	.13	.90	-.14	-.04	.06
Midstory	.18	.82	.02	-.02	-.27
CWD %	-.02	-.04	.27	.73	-.09
CWD Volume (m^3/ha)	-.17	-.08	-.12	.80	.15
Slash Piles Volume (m^3/ha)	-.40	-.25	.65	.18	.16
Bare Ground %	.03	-.05	.92	.09	-.07
Litter Depth (cm)	.42	-.13	-.40	.27	-.48
Rock %	.08	-.18	.01	.07	.89
Percent of Variance	26.52	14.73	13.01	11.2	8.57
Cumulative Percent	26.52	41.25	54.26	65.46	74.0

Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization

Table 3—Herpetofaunal response to three different forest management practices at Burrow Cove in Grundy County, TN, 2010. ANOVA (F) test was followed with post-hoc Tukey tests. Means in the same row (Means ± Standard Deviation). Different superscript letters indicate significant difference (Tukey p<0.1)

Species	Scientific Name	Control	Oak-Shelterwood	Shelterwood	F	P
Eastern Five-Lined Skink	*Plestiodon fasciatus*	0.6±0.76 [b]	0.8±1.03 [b]	1.8±0.98 [a]	4.951	0.013
Eastern Fence Lizard	*Sceloporus undulatus*	0.1 ±0.31 [b]	0.5±0.53 [b]	4.3±3.78 [a]	18.569	0.000
Broadheaded Skink	*Plestiodon laticeps*	0.2±0.52 [b]	1.2±1.81 [a]	0.7±0.82 [b]	2.923	0.068
Fowler's Toad	*Anaxyrus fowleri*	0.6±0.68[b]	1.3±1.57[ab]	1.8±1.17[a]	3.615	0.038

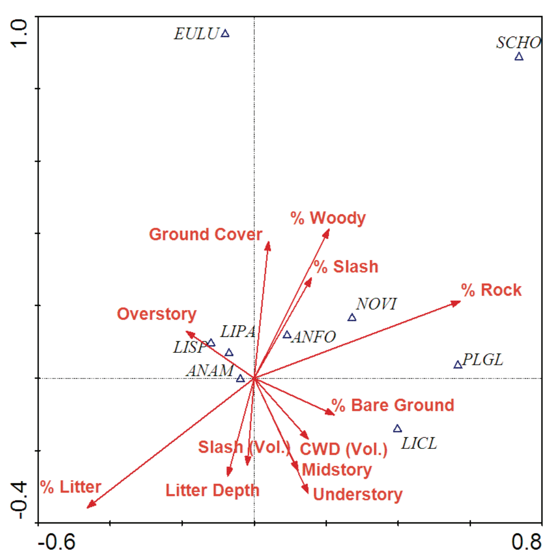

Figure 1—Canonical correspondence analysis ordination plot representing the relationship between amphibian species and microhabitat variables at Burrow Cove in Grundy County, TN, 2010. Four-lettered abbreviations accompanied with triangles represent the Garrison code of species scientific names and arrowed lines represent microhabitat variables.

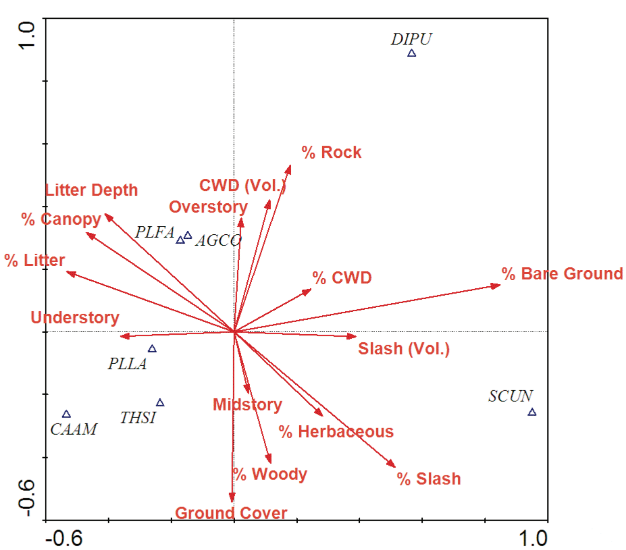

Figure 2—Canonical correspondence analysis ordination plot representing the relationship between reptile species and microhabitat variables at Burrow Cove in Grundy County, TN, 2010. Four-lettered abbreviations accompanied with triangles represent the Garrison code of species scientific names and arrowed lines represent microhabitat variables.

USE OF THE WEIBULL FUNCTION TO PREDICT FUTURE DIAMETER DISTRIBUTIONS FROM CURRENT PLOT DATA

Quang V. Cao

ABSTRACT

The Weibull function has been widely used to characterize diameter distributions in forest stands. The future diameter distribution of a forest stand can be predicted by use of a Weibull probability density function from current inventory data for that stand. The parameter recovery approach has been used to "recover" the Weibull parameters from diameter moments or percentiles. The Moment method involves arithmetic or quadratic mean diameter, and diameter variance, whereas the Percentile method includes diameter percentiles. The Hybrid method is a combination of both methods, requiring both diameter moments and percentiles. Results based on data from loblolly pine plantations showed that the three methods involving the predicted quadratic mean diameter performed better than the rest, and that the two methods involving the predicted 31st and 63rd percentiles performed the poorest.

INTRODUCTION

The Weibull function was introduced by Bailey and Dell (1973) to model diameter distributions in forest stands. It has since become popular because it is flexible enough to fit shapes commonly found in both uneven-aged and even-aged stands, and also because the calculation of proportions of trees in diameter classes is straightforward. The parameter recovery approach (Hyink and Moser 1983) has been found to perform better than the parameter prediction approach, in which the Weibull parameters are predicted directly. In the parameter recovery approach, the Weibull parameters are "recovered" from diameter moments (arithmetic and quadratic diameters, and diameter variance), diameter percentiles (e.g. 25th, 50th, 31st, 63rd, or 95th), or a combination of both.

The objective of this study was to evaluate ten parameter recovery methods to predict the parameters of Weibull functions that modeled diameter distributions of a future stand. The Weibull parameters were recovered from future stand attributes, which were predicted from current stand attributes by use of regression.

DATA

Data were from the Southwide Seed Source Study, which involved 15 loblolly pine (*Pinus taeda* L.) seed sources planted at 13 locations across 10 southern states (Wells and Wakeley 1966). Seedlings were planted at a 6 ft x 6 ft spacing. Each plot of size 0.04 acre consisted of 49 trees measured four times at ages 10, 15 or 16, 20 or 22, and 25 or 27. A subset (100 plots) of the original data was randomly selected as the fit data set, to be used for fitting the models. Furthermore, only one growing period was randomly chosen from each plot. The fit data set therefore contained growth periods from age 10 to age 15 (33 plots), from age 15 to age 20 (33 plots), and from age 20 to age 25 (34 plots). Another 100 plots were randomly selected from the remaining original data in the same manner to form a validation data set. Table 1 shows summary statistics for stand attributes at the end of each growth period for the fit and validation data sets.

METHODS

The Weibull probability density function (pdf), used in this study to characterize diameter distribution, has the following form:

$$f(x) = \left(\frac{c}{b}\right)\left(\frac{x-a}{b}\right)^{c-1} \exp\left(-\left[\frac{x-a}{c}\right]^{c}\right)$$

where a, b, and c are the location, scale, and shape parameters, respectively, and x is tree diameter at breast height.

PARAMETER RECOVERY METHODS

The Weibull location parameter (a) must be smaller than the predicted minimum diameter in the stand ($\hat{D}_0$). We set $a = 0.5\,\hat{D}_0$ since Frazier (1981) found that this gave best results in terms of goodness-of-fit. The other Weibull parameters,

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b and c, were recovered from the moments of the diameter distribution (Moment method), the diameter percentiles (Percentile method), or a combination of both (Hybrid method). The following parameter recovery methods were evaluated:

Moment methods
- Method 1 ($\hat{\bar{D}}$ and $\hat{D}\,\mathrm{var}$)
- Method 2 ($\hat{D}q$ and $\hat{D}\,\mathrm{var}$)

Percentile methods
- Method 3 ($\hat{D}_{31}$ and $\hat{D}_{63}$)
- Method 4 ($\hat{D}_{50}$ and $\hat{D}_{95}$)
- Method 5 ($\hat{D}_{25}$, $\hat{D}_{50}$, and $\hat{D}_{95}$)
- Method 6 ($\hat{D}_{31}$, $\hat{D}_{50}$, and $\hat{D}_{63}$)

Hybrid methods
- Method 7 ($\hat{\bar{D}}$ and $\hat{D}_{95}$)
- Method 8 ($\hat{D}q$ and $\hat{D}_{95}$)
- Method 9 ($\hat{D}q$, $\hat{D}_{25}$, and $\hat{D}_{95}$)
- Method 10 ($\hat{D}q$, $\hat{D}_{25}$, $\hat{D}_{50}$, and $\hat{D}_{95}$)

The symbols $\hat{\bar{D}}$, $\hat{D}q$, $\hat{D}\,\mathrm{var}$, $\hat{D}_{25}$, $\hat{D}_{31}$, $\hat{D}_{50}$, $\hat{D}_{63}$, and $\hat{D}_{95}$ denote predicted values of average diameter, quadratic mean diameter, diameter variance, and the 25th, 31st, 50th, 63rd, and 95th diameter percentiles, respectively. In method 10 (Bailey et al. 1989), the a parameter was computed from

$$a = \frac{\hat{D}_0 n^{1/3} - \hat{D}_{50}}{n^{1/3} - 1}$$

where n is number of trees in the plot. Systems of equations for the ten methods are shown in Table 2.

EVALUATION

The error index (Reynolds et al. 1988), used to evaluate how well each method performed for the validation data, is defined as:

$$EI = \frac{1}{m} \sum_i \sum_k \left| n_{ik} - \hat{n}_{ik} \right|$$

where n_{ik} and $\hat{n}_{ik}$ are, respectively, the observed and predicted number of trees/ha in diameter class k for the i^{th} plot, and m is the number of plots. The smaller the error index, the better the distribution fits the data.

RESULTS AND DISCUSSION

The future stand survival was predicted from:

$$\hat{N} = N_0 \left(\frac{A}{A_0}\right)^{1.30125-1} \exp\left(-0.01958\left(A^{1.30125} - A_0^{1.30125}\right)\right)$$

; $R^2 = 0.5775$, where $\hat{N}$ is the predicted future stand survival, N_0 is the current number of trees/ha, A and A_0 are future and current stand age, respectively.

The diameter moments and percentiles were simultaneously predicted by use of seemingly unrelated regression (SUR). The equations used were of the following general form:

$$\hat{y} = y_0\{1 + \exp[b_1 + b_2 RS_0 + b_3 \ln(Hd_0) + b_4 \ln(N_0)]\}$$

where $\hat{y}$ is the predicted future moment/percentile, y_0 is the current moment/percentile, $RS_0 = [(10000/N_0)^{0.5}]/Hd_0$ is the current relative spacing, and Hd_0 is the current dominant height. The parameter estimates obtained from the fit data are presented in Table 3.

Table 4 shows the error index computed for each method from the validation data. The methods formed three groups based on their error index results, with some overlaps in between. The first group (methods 2, 9, and 10) produced the best results by scoring the lowest error indices. This group consisted of three methods, all of which involved $\hat{D}q$. These results showed that $\hat{D}q$ seemed to be a better central measure of the Weibull distribution than either $\hat{\bar{D}}$ or $\hat{D}_{50}$. An exception was method 8 ($\hat{D}q$ and $\hat{D}_{95}$), which was ranked 8th among ten methods.

The lowest-ranked group (methods 3 and 6) produced the highest values of error index, i.e. poorest fit. Both of these methods involved $\hat{D}_{31}$ and $\hat{D}_{63}$, suggesting that these two percentiles should not be used in recovering the Weibull parameters.

CONCLUSIONS

The analyses shown in this study revealed that the predicted quadratic mean diameter played an important role in recovering parameters of the Weibull that characterized the future diameter distribution of loblolly pine plantations. On the other hand, both methods involving the predicted 31st and 63rd percentiles performed the poorest among all methods. Method 2 ($\hat{D}q$ and $\hat{D}\,\mathrm{var}$) produced the lowest error index and should be considered as a parameter recovery method for other data sets.

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Table 1—Means (and standard deviations) of stand attributes at the end of each growth period for the fit and validation data

Age	Number of plots	Dominant height (m)	Number of trees per ha	Basal area (m^2/ha)
		Fit Data		
15	34	12.7 (1.8)	1843 (605)	28.9 (7.4)
20	33	16.4 (1.4)	1291 (250)	34.3 (8.4)
25	33	18.5 (2.0)	1346 (263)	40.1 (8.1)
		Validation Data		
15	34	13.1 (1.7)	1742 (579)	30.0 (6.3)
20	33	16.3 (2.2)	1305 (254)	34.0 (6.9)
25	33	18.9 (2.0)	1350 (255)	41.1 (6.2)

Table 2—Summary of ten parameter recovery methods

Method	Equation for *a*	Equation for *b* and *c* [1/]
	Moment methods	
Method 1 ($\hat{\bar{D}}$ and $\hat{D}\text{var}$)	$a = 0.5\,\hat{D}_0$	$b = (\hat{\bar{D}} - a)/G_1$ c is obtained from $b^2(G_2 - G_1^2) - \hat{D}\text{var} = 0$
Method 2 ($\hat{D}q$ and $\hat{D}\text{var}$)	$a = 0.5\,\hat{D}_0$	$b = \frac{-aG_1}{G_2} + \sqrt{\left(\frac{a}{G_2}\right)^2 (G_1^2 - G_2) + \frac{\hat{D}q^2}{G_2}}$ c is obtained from $b^2(G_2 - G_1^2) - \hat{D}\text{var} = 0$
	Percentile methods	
Method 3 ($\hat{D}_{31}$ and $\hat{D}_{63}$)	$a = 0.5\,\hat{D}_0$	$c = \frac{\ln\left(\frac{\ln(1-0.63)}{\ln(1-0.31)}\right)}{\ln(\hat{D}_{63} - a) - \ln(\hat{D}_{31} - a)}$ $b = \frac{\hat{D}_{63} - a}{[-\ln(1-0.63)]^{1/c}}$
Method 4 ($\hat{D}_{50}$ and $\hat{D}_{95}$)	$a = 0.5\,\hat{D}_0$	$c = \frac{\ln\left(\frac{\ln(1-0.95)}{\ln(1-0.50)}\right)}{\ln(\hat{D}_{95} - a) - \ln(\hat{D}_{50} - a)}$ $b = \frac{\hat{D}_{50} - a}{[-\ln(1-0.50)]^{1/c}}$
Method 5 ($\hat{D}_{25}$, $\hat{D}_{50}$, and $\hat{D}_{95}$)	$a = 0.5\,\hat{D}_0$	$c = \frac{\ln\left(\frac{\ln(1-0.95)}{\ln(1-0.25)}\right)}{\ln(\hat{D}_{95} - a) - \ln(\hat{D}_{25} - a)}$ $b = \frac{\hat{D}_{50} - a}{[-\ln(1-0.50)]^{1/c}}$
Method 6 ($\hat{D}_{31}$, $\hat{D}_{50}$, and $\hat{D}_{63}$)	$a = 0.5\,\hat{D}_0$	$c = \frac{\ln\left(\frac{\ln(1-0.63)}{\ln(1-0.31)}\right)}{\ln(\hat{D}_{63} - a) - \ln(\hat{D}_{31} - a)}$ $b = \frac{\hat{D}_{50} - a}{[-\ln(1-0.50)]^{1/c}}$

Table 2—(Continued) Summary of ten parameter recovery methods

Method	Equation for *a*	Equation for *b* and *c*
		Hybrid methods
Method 7 ($\hat{\bar{D}}$ and $\hat{D}_{95}$)	$a = 0.5\,\hat{D}_0$	$b = \dfrac{\hat{D}_{95} - a}{[-\ln(1-0.95)]^{1/c}}$ c is obtained from $a + bG_1 - \hat{\bar{D}} = 0$
Method 8 ($\hat{D}q$ and $\hat{D}_{95}$)	$a = 0.5\,\hat{D}_0$	$b = \dfrac{\hat{D}_{95} - a}{[-\ln(1-0.95)]^{1/c}}$ c is obtained from $b^2G_2 + 2abG_1 + a^2 - \hat{D}q^2 = 0$
Method 9 ($\hat{D}q$, $\hat{D}_{25}$, and $\hat{D}_{95}$)	$a = 0.5\,\hat{D}_0$	$c = \dfrac{\ln\left(\dfrac{\ln(1-0.95)}{\ln(1-0.25)}\right)}{\ln(\hat{D}_{95} - a) - \ln(\hat{D}_{25} - a)}$ $b = -aG_1/G_2 + [(a/G_2)^2(G_1^2 - G_2) + \hat{D}q^2/G_2]^{0.5}$
Method 10 ($\hat{D}q$, $\hat{D}_{25}$, $\hat{D}_{50}$, and $\hat{D}_{95}$)	$a = \dfrac{\hat{D}_0 n^{1/3} - \hat{D}_{50}}{n^{1/3} - 1}$	$c = \dfrac{\ln\left(\dfrac{\ln(1-0.95)}{\ln(1-0.25)}\right)}{\ln(\hat{D}_{95} - a) - \ln(\hat{D}_{25} - a)}$ $b = -aG_1/G_2 + [(a/G_2)^2(G_1^2 - G_2) + \hat{D}q^2/G_2]^{0.5}$

[1/] $G_k = \Gamma(1 + k/c)$, where $\Gamma(\bullet)$ is the gamma function.

Table 3—Parameter estimates for predicting future diameter moments and percentiles

Variable	b_1	b_2	b_3	b_4	R^2
$\hat{D}_0$	-2.29785	4.43916			0.3583
$\hat{\bar{D}}$	3.13645		-1.29982	-0.21411	0.9242
$\hat{D}\mathrm{var}$	2.50950		-1.32765		0.6975
$\hat{D}q$	3.14000		-1.30057	-0.21404	0.9309
$\hat{D}_{25}$	1.08057		-1.16174		0.8554
$\hat{D}_{31}$	1.54103		-1.35951		0.8740
$\hat{D}_{50}$	4.85622		-1.46683	-0.39758	0.9041
$\hat{D}_{63}$	1.30993		-1.19434		0.8862
$\hat{D}_{95}$	3.65865		-1.15230	-0.31641	0.9179

Equation: $\hat{y} = y_0 \{1 + \exp[b_1 + b_2 RS_0 + b_3 \ln(Hd_0) + b_4 \ln(N_0)]\}$

Table 4—Error index for each method from the validation data

Rank	Method	Moments/percentiles	EI [1/]
1	2	$\hat{D}q$ and $\hat{D}\mathrm{var}$	663 [a]
2	9	$\hat{D}q$, $\hat{D}_{25}$, and $\hat{D}_{95}$	670 [a]
3	10	$\hat{D}q$, $\hat{D}_{25}$, $\hat{D}_{50}$, and $\hat{D}_{95}$	674 [a]
4	4	$\hat{D}_{50}$, and $\hat{D}_{95}$	720 [b]
5	1	$\hat{\bar{D}}$ and $\hat{D}\mathrm{var}$	726 [bc]
6	5	$\hat{D}_{25}$, $\hat{D}_{50}$, and $\hat{D}_{95}$	727 [bc]
7	7	$\hat{\bar{D}}$ and $\hat{D}_{95}$	731 [bcd]
8	8	$\hat{D}q$ and $\hat{D}_{95}$	743 [bcd]
9	6	$\hat{D}_{31}$, $\hat{D}_{50}$, and $\hat{D}_{63}$	755 [cd]
10	3	$\hat{D}_{31}$ and $\hat{D}_{63}$	760 [d]

[1/] Values with the same letter are not different at the 5% level.

ASSESSING SOIL IMPACTS RELATED TO FOREST HARVEST OPERATIONS

E. A. Carter and J. M. Grace III

ABSTRACT

Three studies conducted in Alabama evaluated impacts associated with a clear cut harvest in three physiographic regions. Machine impacts were assessed via tabulation of soil disturbance classes, measurement of bulk density and soil strength, or a combination of the two. Soil disturbance classes were similar among all locations with untrafficked areas comprising approximately 20 percent of the harvest tract and the remaining as slightly or heavily disturbed. Soil strength response increased with disturbance intensity in surface and subsurface soil layers, while bulk density did not show a consistent pattern by depth with intensity. Post-harvest erosion data underscored the variability of site response while site preparation and subsequent planting contributed to higher erosion rates. Global Positioning System receivers monitored machine movements and provided a basis for disturbance class assessment. Similarly, positional data were used to create Digital Elevation Models to determine runoff interception by silt fences to assess erosion potential.

Keywords: bulk density, disturbance classes; erosion, GPS, physiographic region, soil strength.

INTRODUCTION

Mechanized forest operations have induced changes in soil properties with the potential to negatively impact soil sustainability and forest productivity. Machine related soil impacts vary spatially and in intensity depending on the interaction between machine and site factors at the time of impact. Attempts to characterize the degree of impact and its variability throughout an affected area have relied on methods that are hampered by the amount of time to complete an assessment as well as a lack of accuracy. Recent advances in global positioning systems (GPS) and geographic information systems (GIS) have allowed more accurate evaluation of the impact of forest operations. The application of more accurate methods may provide more relevant information to guide future management decisions to promote adequate regeneration.

Previously, soil impacts related to harvest and thinning operations were assumed to be distributed uniformly throughout a harvest tract with the greatest impact found on landings and skid trails. To ensure adequate regeneration, land managers employed mechanical and chemical methods of site preparation throughout the harvest tract to control weeds, prepare planting beds and provide adequate water and nutrients (Morris and Lowery, 1988; Allen and others, 1990; Dubois, 1995; Miller and others, 2006). More accurate information on how site impacts vary spatially and in intensity to ensure more cost effective remediation techniques necessitated the use of ground disturbance surveys, measurement of soil properties affected by machine trafficking, or their combination. As stated previously, these are time consuming and lack sufficient accuracy to be useful. The use of GPS receivers to collect positional data has been invaluable in allowing researchers to track machine movements and assist in management activities (McMahon, 1997; McDonald and others, 2002; McDonald and Fulton, 2005; McDonald and others, 2008). Application of GPS technology to assess soil impacts has been conducted by linking GPS positional data to traffic maps or point specific measurement of soil changes (Carter and others, 1999; 2000; McDonald and others, 2002). The current generation of GPS receivers allows the possibility of more precise positional data to link with site specific changes in soil properties **(**Renschler and Flanagan, 2008**).**

An additional consequence of mechanized operations in managed forested landscape is the increased potential for erosion whereby site productivity may be compromised due to soil and nutrient redistribution and loss. Quantification of erosion has typically been conducted by delineating an area of known size and directing the runoff and entrained soil and dissolved solids into a collection device. Numerous studies have reported runoff and soil loss for a wide range of conditions, plot configurations, and collection devices (Dissmeyer, 1982; Pye and Vitousek, 1985; Lacey, 2000; Robichaud and others, 2001; Costantini and Loach, 2002; Field and others, 2005; McBroom and others, 2008). Although the use of bound plots is a standard method, studies that isolate a segment of the surrounding landscape to monitor erosion may not be representative of the full erosion potential of a managed landscape. Forested landscapes subjected to harvesting, thinning, and regeneration activities are highly variable in surface disturbance levels and vary greatly in the degree of erosion potential on a landscape basis. Larger portions of the landscape may be monitored for erosion potential by developing Digital Elevation Models (DEMs) that predict water flow paths and that can be linked with models that predict runoff and soil loss (e.g., Water Erosion Prediction Project-WEPP). Digital elevation models can be easily

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constructed from highly accurate GPS systems (e.g. RTK systems) and imported into GIS applications to predict flow paths and erosion potential (Renschler and Flanagan, 2008**).** The objective of this paper is an assessment of methods utilized in our studies to assess soil impacts from forest operations, including soil compaction and erosion potential. Of significance in assessing the impact of forest operations was the application of GPS and GIS to enhance data collection and interpretation.

MATERIALS AND METHODS

SOIL COMPACTION

The evaluation of soil compaction as a result of forest harvest operations was concentrated in three study sites in Alabama (fig. 1). The upper site (SCUAL) was located in Lawrence County, near Moulton, Alabama, within the southern boundary of the Cumberland Plateau. Soils within the study area were typified by Hartsells, Townley and Sipsey soil series, fine-loamy and loamy, siliceous and mixed, subactive and semiactive, thermic members of Typic Hapludults. The central site (SCCAL) was located in Chambers County, near Lafayette, AL, within the Piedmont region of Alabama. Soils of the study site were composed primarily of fine, kaolinitic, thermic Typic and Rhodic Kanhapludults and Kandiudult families and typified by Cecil and Gwinnett soil series. The lower site (SCLAL) site was located in Covington County, near Andalusia, AL, within the Gulf Coastal Plain; soils within the study site were composed primarily of Orangeburg sandy loam, classified as a fine-loamy, kaolinitic, thermic member of Typic Kandiudults.

The degree of soil disturbance and final soil compaction was based on tabulation of soil surface disturbances and collection of soil cores to determine changes in soil volume and stength. Soil surface disturbance classes typical of sites under consideration were identified and tabulated via transects throughout harvest tracts with the final classes based on ground disturbances tabulated and reported by Lanford and Stokes **(**1995). Ground disturbance was linked to soil changes by removing soil cores from locations representative of soil disturbance classes randomly or at predetermined grid points. Soil cores were removed, subsectioned into 10 centimeter increments, and dried at 105 degrees Celsius to determine bulk density (ρ_b) and gravimetric soil moisture (θ_g) (Klute, 1986). In-situ measurements of soil strength were conducted by inserting a Rimik CP20 recording cone penetrometer to a predetermined depth and measurements recorded in 2.50 centimeter increments and expressed as cone index (CI) (ASAE, 2000**).**

MACHINE TRAFFICKING AND GPS

The Global Positioning System was employed to monitor machine movements during harvest of a loblolly pine plantation and subsequent positional data utilized to facilitate determination of soil disturbance classes and traffic intensity (number of passes). Positional data were collected by GPS receivers mounted on a feller buncher and two skidders, converted into raster maps and displayed as a map of traffic intensities by location in two harvest stands in the Piedmont region of Alabama (McDonald and others, 2002). Traffic intensities were linked to soil disturbance classes by determining surface disturbance on a 9.8 x 9.8 meter grid after harvesting, collecting positional data of grid point locations, and matching disturbance classes with traffic intensities. Subsequently, postharvest soil cores were removed from locations representative of soil disturbance classes and processed for ρ_b**,** θ_g,and CI. Soil sampling locations were linked to traffic intensities via GPS data and ρ_b, θg, and CI averaged by disturbance class and traffic intensities. The spatial variability associated with ρ_b and CI in the harvested tract was determined via spatial analysis techniques.

EROSION

Investigation of the erosion potential associated with harvest activities was examined in two project locations: in lower Alabama (SELAL) and another central Alabama site (SECAL) in the Piedmont region, located in Lee County, near Auburn, AL. The study conducted in SELAL was previously described in the soil compaction section while a harvest operation followed by site preparation and replanting was conducted in SECAL. Soils of SECAL were primarily composed of Gwinnett sandy loam and classified as fine, kaolinitic, thermic members of Rhodic Kanhapludults. Soils typical of SELAL were previously described in the soil compaction section as this site served the dual purpose of examining both compaction and erosion (fig 1).

In SECAL, an erosion collection system consisting of bound plots approximately 5.5 x 2.0 meter in size was installed in select locations to monitor runoff and sediment production from areas disturbed by harvest and tillage operations. Runoff and entrained sediment were routed through a PVC pipe to a 210 liter collection barrel placed down slope from the plot outlet. Runoff was measured and sediment samples were collected after each rainfall event. Each location contained three plots that were installed on similar soils and slope steepness (~ 10 percent). In SELAL, silt fences were installed in down slope locations and positional data collected by a Real Time Kinematic GPS system to create a 1 meter Digital Elevation Model (DEM) (fig.3). Silt fences were placed along the lower portion of a hill slope of approximately 8 percent steepness and sediment captured from an upslope area approximately 25 meters in length.

The collected GPS data were analyzed by a Geographic Information System (GIS) application to predict water runoff paths to evaluate interception of runoff by each silt fence. Final accumulated soil quantities were determined for both harvested and undisturbed locations and runoff interception by each silt fence was investigated.

RESULTS

Soil disturbance classes associated with each study site were tabulated on a grid base system, compiled into categories that denoted impact intensity and the percentage estimated within each category (table 1). Examination of the disturbance category tabulations for clear cut harvests indicated a similar percentage of the harvest stand classified as untrafficked (UNT), or no evidence of traffic disturbance. Differences were noted between the percentage of slightly (SD) and highly disturbed (HD) areas among the study sites. Slightly disturbed was defined as showing evidence of trafficking most often with litter still in place and HD defined as rutted or used as a skid trail. The highest percentage of HD was associated with SCCAL and the lowest percentage tabulated in SCUAL; SD tabulations were higher in SCUAL and relatively similar in SCCAL and SCLAL. The total percentage of area disturbed (SD + HD) was approximately 74 percent in the SCUAL and SCLAL sites and 83 percent in SCCAL. The final tabulation of disturbance classes has been reported to depend on the number of sites evaluated, the distance between points, and the type of tabulation method (McMahon, 1995).

Bulk density and CI measurements collected for the three sites under evaluation were reported by disturbance category (table 2). Gravimetric water contents were also included for each site. As was expected, ρ_b and CI were higher in the subsurface layer (10 – 20 centimeter) compared to the surface layer in all sites; θ_g was typically higher in the surface layers compared to subsurface levels. Bulk density data did not indicate a clear trend with increased disturbance for either soil layer in the sites evaluated but CI data typically increased with disturbance level in both surface and subsurface soil layers.

Soil disturbance classes and traffic intensities determined from machine monitored GPS data indicated disturbed areas tabulated as SD experienced 1 to 3 passes while HD areas, including skid trails and landings, experienced 4 or more passes. Soil measurements (ρ_b and CI) were matched with traffic intensity data and showed an increase with traffic intensity, and appeared to reach a maximum level after approximately 3 passes (table 3).

Machine movements are highly dispersed throughout a stand in the course of harvest operations resulting in changes in soil conditions that vary in intensity and spatial dependence. Two subsections of the harvested loblolly pine stand used in the traffic intensity study were evaluated for spatial dependence and found to vary by soil property and location within the tract (table 4). An initial indication of spatial dependence is often assessed through interpretation of the nugget semivariance in which values less than or equal to 25 percent are an indication of strong spatial dependence while values between 26 and 75 percent indicate moderate dependence and greater than or equal to 75 percent shows weak dependence (Cambardella and others, 1994). Strong spatial dependence was detected in site two for both properties based on the nugget semivariance while site 1 appeared to indicate moderate spatial dependence. Further corroboration of spatial dependence would be indicated by the r^2 value and the range of spatial dependence. The results for CI in site two showed good model fit and a range of spatial dependence that would be reasonably expected under the conditions of the harvest operation. In site one a good model fit was calculated for CI but the range of dependence is greater than the lag distance (approximately75 meters) selected for the analysis and is indicative of not capturing spatial dependence at the selected sampling distance. The results for ρ_b in sites one and two may be questioned due to a low r^2 values although the range of dependence is reasonable. The results for site one may be an indication that the range of correlation was not detectable at the grid spacing chosen but more evident by results for site two.

A typical erosion collection system installed in 1998 in SECAL monitored post-harvest and post site preparation and replanting erosion. Three areas within the stand were monitored during the post harvest phase, two of which had been subjected to harvest disturbances (DIST1 and DIST2) and a control plot (CON); differences in erosion response were detected among locations (fig. 2a). The location labeled DIST2 yielded the greatest amount of sediment, the cumulative total in excess of 200 kilograms per hectare while DIST1 and CON did not exceed 100 and 50 kilograms per hectare, respectively. A statistical comparison of means for sediment displacement indicated DIST2 was significantly different from DIST1 and CON. Runoff quantities followed a similar pattern among locations but cumulative totals for disturbed sites produced more runoff compared to CON; means among treatments were significantly different for all three treatments (fig. 2a). Erosion potential in the initial period after completion of site preparation and replanting was evaluated based on orientation of beds within the framed plots: across the slope (ATS), down the slope (DTS), machine plant only (no beds) (MPO) and control (CON). Sediment totals were excessively high in DTS while MPO exceeded ATS and CON (fig. 2b). Runoff totals were greatest from DTS and measured in excess of 200 millimeters over the study period followed by MPO and ATS between 50 and 100 millimeters; CON was less than 50 millimeters. Sediment and runoff quantities from DTS were significantly different from other treatments (fig. 2b).

Estimation of erosion potential in SELAL was conducted by placing silt fences in select locations. Soil accumulation by each fence was greater in harvested stands compared to undisturbed sites but accumulations in both harvested and undisturbed varied, presumably due to terrain differences that affected water flow (table 5). The utility of silt fences as a reliable estimate of erosion potential would depend on their ability to intercept runoff water with entrained sediment. The degree to which each silt fence was able to intercept runoff was tested by constructing 1 meter Digital Elevation Models (DEMs) from Real Time Kinematic (RTK) GPS derived elevation data. Runoff flow paths were illustrated by analyzing DEM data via TopoGrid, a Geographic Information System (GIS) application, and runoff interception by a randomly placed silt fence illustrated (fig. 3). Runoff flow paths illustrated in figure three were representative of interception by all silt fences in this study and it appears that a portion of slope runoff was captured by each silt fence.

DISCUSSION

Soil compaction and surface disturbances are inevitable where forest operations are implemented, the degree of impact determined by site and machine factors. Soil disturbance classes have been used extensively to evaluate the impact of forest operations and compare types of harvest systems and locations (Dyrness, 1965; Hatchell, 1970; Lanford and Stokes, 1995; Aust and others, 1998; Carter and others, 2006). Surface disturbances can range from undisturbed with no evidence of trafficking to rutting, skid trails and landings indicative of intense trafficking. The utility of tabulating surface disturbance classes as a means of evaluating machine impacts may be limited due to a lack of standardization or determination of the accuracy associated with this method. McMahon (1995) compared soil disturbances from three survey methods with an intensive 1 x 1 meter grid survey and determined how each method compared to the intensive survey. The result of his intensive survey indicated that approximately 70 percent of the harvest area was undisturbed or slightly disturbed while the remainder of the area had been rutted or heavily trafficked; the point transect method at a spacing of 30 m compared favorably to the intensive survey. The upper site (SCUAL) was comparable to the 70 percent level as reported by McMahon (1995) while cumulative percentages of 48 and 57 percent were detected in SCCAL and SCLAL.

Improvement in the ability to link machine trafficking to soil surface disturbances was possible by collecting positional data via Global Positioning System (GPS) receivers, translating GPS data to maps of traffic passes and matching positional data with surface disturbances (McMahon, 1997; McDonald and others, 2002). McDonald and others (2002) concluded that GPS data translated into a raster map of machine passes would be of sufficient accuracy to be used to determine site level disturbances as well as a record of machine movements within a harvest tract. They noted that the ability to use GPS data to assess point specific data e.g. soil compaction would not be sufficiently accurate.

Soil physical changes, an obvious consequence of machine trafficking, are typically reported as changes in bulk density and/or soil strength (Gent and Ballard, 1984; Carter and others, 2000; Shaw and Carter, 2002; Carter and others, 2006). Machine factors, singly or in combination, are often implicated in the reported changes in bulk density and/or soil strength due to high machine loads, high ground pressures, increased traffic intensity or their combination (Koger and others, 1985; Smith and Dickson, 1990; Horn and others, 1995). Machine stresses induce soil volume changes typified by loss of aggregation and reduced soil pore structure and function, with the final compaction status, either increased or decreased bulk density and soil strength, influenced strongly by soil texture, soil organic matter status and soil moisture content. Numerous studies have reported the status of bulk density and soil strength by disturbance class and found a direct relationship between disturbance intensity and soil physical response (Shaw and Carter, 2002; Carter and others, 2006) but inconsistent responses have been reported as well (Meek, 1996; Carter and others, 1999). Bulk density reported by soil disturbance intensity was not consistent while CI data typically increased as soil disturbances intensified. These results may reflect differences in machine configuration or soil properties even when linked with disturbance classes determined by GPS tracking.

Soil erosion is another consequence of machine trafficking as reductions in soil volume result in decreased water infiltration and increased surface runoff (Voorhees and others, 1979; Watson and Laflen 1986). Soil compaction was evident in SECAL as evidenced by changes in bulk density and soil strength throughout the harvest tract (Carter and others, 1999). The postharvest condition (DIST1 and DIST2) indicated differences in sediment displacement and runoff production although each site was subjected to similar impacts. Site response may have differed due to spatial variability of soil physical properties in the soil surface layer as a result of site response to machine movements during harvest operations (Carter and others, 1999; Carter and others, 2000; Carter and Shaw, 2002). Machine traffic during harvesting was more intense in select portions of the harvest tract and less intense in other areas and potentially altered soil physical conditions and response accordingly.

Site preparation had a profound effect on sediment displacement and runoff production depending on the specific treatment. Obviously, erosion potential was greatest when beds were oriented down slope (DTS) and to a lesser degree, on plots where no bedding occurred (MPO). Soil loss and runoff quantities measured in DTS may have been influenced by slope, lack of vegetative cover and soil erodibility (Stein and others, 1986; Burroughs and others, 1992; Kinnell and Cummings 1993; Van Oost and others, 2006**).** Surface soil left unprotected is prone to erosion through the disruption of soil aggregates by rainfall and subsequent release of soil particles; this is especially evident in soils dominated by silt and clay size fractions similar to the textural composition of this study site (Dickerson, 1975; Burroughs and others, 1992; Miller and Baharuddin 1987). In contrast, sediment loss and runoff were substantially lower from ATS plots where ground cover was more plentiful and shorter runoff distances between beds intercepted water flow and potentially reduced sediment loss. Runoff results from MPO indicated levels elevated in comparison to ATS but substantially more sediment loss. The sediment displacement may be the result of the tillage effect imposed during replanting of seedlings that utilized a small shank and bedding plow to provide an opening and small bed for planting new seedlings. Sufficient surface soil was disturbed in this process that when exposed to rainfall, soil particles were entrained by runoff and transported down slope. Soil disturbances resulting from tillage have often been linked to higher erosion rates and the increased soil loss in MPO may have resulted from the loosening of an erodible soil (Stein and others, 1986; Costantini and Loach, 2002; Van Oost and others, 2006). Soil loss and runoff in CON would be expected to be less than other treatments and the results confirm this expectation.

The assessment of erosion potential is often conducted by isolating a portion of a harvest tract to measure runoff and entrained sediment. A simpler and less time consuming procedure of erosion assessment utilizes silt fence technology, or synthetic geotextile material of sufficient mesh size to allow water to pass through while holding sediment. Silt fences have been found to trap a sufficient amount of sediment to provide a fairly accurate assessment of sediment displacement in erosion studies, although less accurate than bound plots (Robichaud and others, 2001). This expectation was confirmed in that more sediment was trapped by silt fences placed in a harvested area when compared to an undisturbed area. Recent advances in GPS technology have provided a means of measuring highly accurate vertical elevations to delineate runoff flow paths and determine contributing areas to runoff and soil movement (Renschler and others, 2002). Renschler and Flanagan (2008**)** determined that topographic data determined by RTK GPS grade receivers accurately predicted soil displacement and runoff by the Water Erosion Prediction Project (WEPP). In this study, it was shown that a silt fence was able to intercept runoff, and ostensibly the entrained sediment, but missed a portion of the runoff as it diverted away from the established silt fence. In the future, a site expected to undergo erosion could be evaluated for runoff contributing areas and silt fences placed where runoff could be intercepted and erosion estimates determined from trapped sediment.

SUMMARY

Clearcut forest operations typically result in compacted soil layers that increase the erosion potential of a harvested site. The final compaction status can vary spatially and in intensity as a result of harvest traffic patterns and systems. Tools exist to assist in determining the extent and intensity of soil compaction and erosion with the potential to be applied on a stand level. Machine impacts are often evaluated by tabulation of soil surface disturbance classes representative of the type and degree of trafficking impact, changes in soil bulk density or soil strength, or in combination. These methods are very time consuming and lack sufficient accuracy. Preliminary investigations have indicated the usefulness of GPS receivers to monitor machine movements and provide a basis for disturbance class assessment through trafficking patterns. Similarly, positional data from GPS receivers can be used to create DEMs to assess runoff interception by silt fence placement.

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Table 1—Soil disturbance class percentages for select sites subjected to harvest operations, Alabama

DISTURBANCE CLASS CATEGORIES	UNTRAFFICKED (UNT)	SLIGHTLY DISTURBED (SD)	HIGHLY DISTURBED (HD)	NON-SOIL (NS)	n	GRID (m)
UPPER CLEARCUT	18	57	17	8	180	18 x 18
CENTRAL CLEARCUT	10	38	45	7	250	10 x 10
LOWER CLEARCUT	15	42	32	11	421	3 x 30

Table 2—Select soil physical properties by disturbance class associated with clear cut forest operations, Alabama

DISTURBANCE CLASS CATEGORIES SOIL PROPERTIES		UNTRAFFICKED (UNT)	SLIGHTLY DISTURBED (SD)	HIGHLY DISTURBED (HD)
BD (Mg/m^3)				
UPPER	0 – 10 cm	1.04 (23.6) ±	1.10 (22.6)	1.14 (26.4)
	10 - 20 cm	1.33 (14.7)	1.35 (16.8)	1.35 (18.8)
CENTRAL	0 – 10 cm	0.98 (19.4)	1.08 (19.7)	1.06 (23.1)
	10 - 20 cm	1.35 (11.9)	1.29 (11.2)	1.31 (12.3)
LOWER	0 – 10 cm	1.03 (22.5)	1.04 (17.6)	0.89 (31.5)
	10 - 20 cm	1.33 (11.2)	1.36 (10.8)	1.35 (12.6)
GMC (%)				
UPPER	0 – 10 cm	29.5 (51.8)	32.4 (40.3)	32.1 (47.5)
	10 - 20 cm	22.7 (30.4)	22.7 (28.4)	25.1 (46.7)
CENTRAL	0 – 10 cm	24.9 (36.6)	22.3 (24.7)	24.1 (24.8)
	10 - 20 cm	22.1 (13.1)	22.8 (19.0)	24.5 (16.5)
LOWER	0 – 10 cm	10.5 (16.8)	11.5 (24.5)	14.8 (50.6)
	10 - 20 cm	8.7 (20.1)	9.0 (23.8)	9.7 (16.8)
CI (MPa)				
UPPER	0 – 10 cm	0.77 (60.8)	0.95 (54.0)	1.12 (50.7)
	10 - 20 cm	0.81 (68.8)	1.07 (51.3)	1.59 (40.6)
CENTRAL	0 – 10 cm	1.20 (62.5)	1.50 (39.6)	1.46 (43.9)
	10 - 20 cm	1.90 (36.3)	2.20 (27.9)	2.16 (27.4)
LOWER	0 – 10 cm	0.57 (45.8)	0.90 (45.0)	0.98 (44.5)
	10 - 20 cm	1.16 (38.9)	1.66 (36.1)	2.09 (43.5)

Table 3—Soil disturbance categories, traffic intensities, and select soil physical properties of a harvested loblolly pine plantation, central Alabama

DISTURBANCE CATEGORIES	TRAFFIC INTENSITY	DEPTH	SOIL PHYSICAL PROPERTIES BD (cv) ±	GMC (cv)	CI (cv)
		(cm)	(Mg/m^3)	(%)	(MPa)
UNT	0	0 – 10	0.98 (19.4)	24.9 (36.6)	1.20 (62.5)
		10 – 20	1.35 (11.9)	22.1 (13.1)	1.90 (36.3)
SD	1 – 3	0 – 10	1.08 (19.7)	22.3 (24.7)	1.50 (39.6)
		10 – 20	1.29 (11.2)	22.8 (19.0)	2.20 (27.9)
HD	4+	0 – 10	1.06 (23.1)	24.1 (24.8)	1.46 (43.9)
		10 – 20	1.31 (12.3)	24.5 (16.5)	2.16 (27.4)

Table 4—Semivariance parameters of select soil properties in a harvested loblolly pine stand in the Piedmont region of Alabama

MODEL† SOIL PROPERTY	MODEL FIT	RANGE	NUGGET	GRID SEMIVARIANCE ±	SPACING
		(r^2)	(m)		(m)
SITE 1					
P_b	exp	0.11	10.2	26.0	6 x 6
CI	exp	0.88	295.0	42.0	
SITE 2					
P_b	exp	0.31	13.2	13.0	3 x 6
CI	sph	0.74	11.4	18.0	

† Geostatistical parameters - models : exp = exponential; sph = spherical. ± Nugget Semivariance: 0 – 25% high; 26-75% moderate; >75% weak

Table 5—Soil accumulation of 5 silt fences in a harvested and non-harvested slash pine stand in Conecuh National Forest, lower Alabama

TREATMENT	SILT FENCE # 1	2	3	4	5	ACCUMULATION (kg)
HARVESTED	5.94	3.35	4.92	1.33	3.09	18.63
NON-HARVESTED	2.48	1.61	2.78	2.16	0.20	9.23

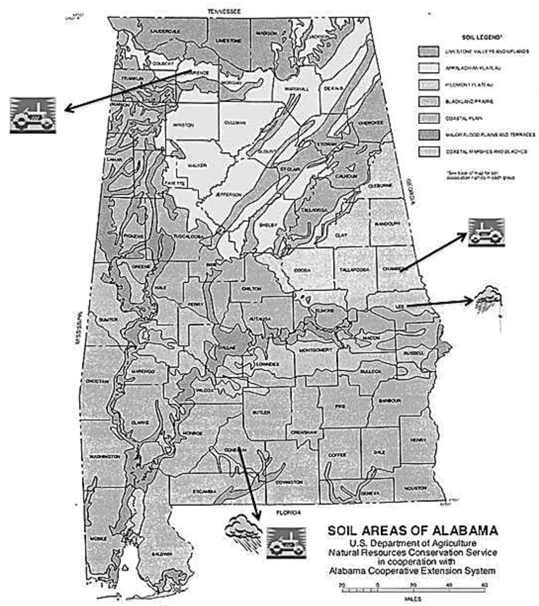

Figure 1—Location of sites evaluated for compaction and erosion response to harvest operations, Alabama, USA.

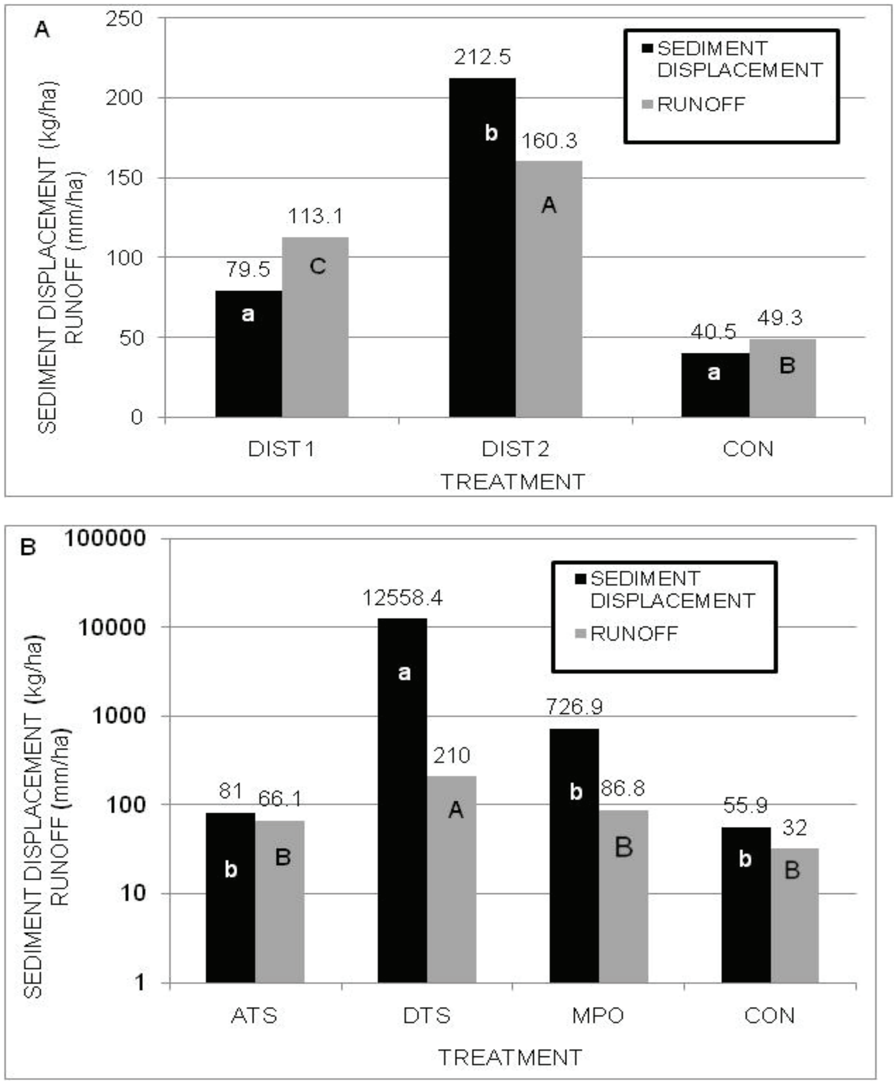

Figure 2—Soil displacement and runoff during postharvest (a) and in response to site preparation and replanting (b) in a loblolly pine plantation, central Alabama.

Sediment and runoff values were significantly different (alpha=0.05) when indicated by different letters.

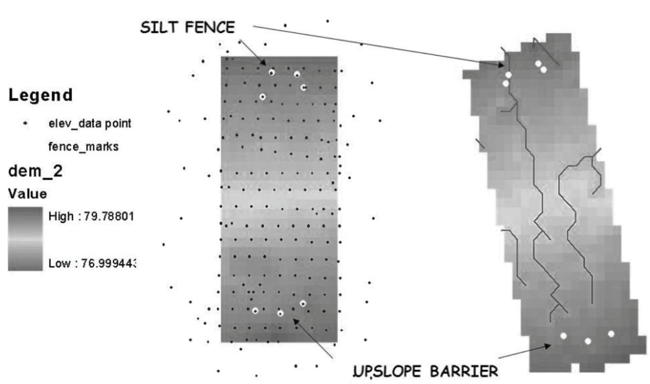

Figure 3—Analysis of water flow paths and interception by silt fence in harvested slash pine stand, lower Alabama.

LESSONS FROM THE FIELD: THE FIRST TESTS OF RESTORATION AMERICAN CHESTNUT (*CASTANEA DENTATA*) SEEDLINGS PLANTED IN THE SOUTHERN REGION

Stacy Clark, Scott Schlarbaum, Fred Hebard, Arnold Saxton, David Casey, Barbara Crane, Russ MacFarlane, Jason Rodrigue, and Jim Stelick

An exotic fungus, the chestnut blight (Cryphonectria parasitica Murr. Barr), decimated the American chestnut tree (Castanea dentata Marsh. Borkh.) throughout eastern North America in the first half of the 20th century. The United States Department of Agriculture, Forest Service (FS), The University of Tennessee, and The American Chestnut Foundation (TACF) are collaborating on chestnut restoration research on National Forest System lands. In autumn 2007 and 2008, TACF used a back-cross breeding technique (Hebard 2001) to produce chestnuts, referred to as the BC3F3 generation, that are predicted to be American chestnut in character with blight resistance from Chinese chestnut (Castanea mollissima Blume).

Chestnut seedlings from four generations (BC1F3, BC2F3, BC3F2, and BC3F3) and two parental species (American and Chinese) were grown as high-quality 1-0 seedlings (Kormanik et al., 1993), averaging 3.1 and 4.3 ft in height and 0.5 and 0.6 inch in root collar diameter for 2009 and 2010 plantings, respectively. Trees were out-planted into five shelterwood harvests (residual basal area of 10-20 ft2 acre-1) on three southern National Forests in 2009 and 2010. Six more plantings were established in 2011 but have not yet been evaluated. Prior to plantings, we divided trees into Large and Small size classes based on visual assessment (Clark et al. 2000). We evaluated seedlings in the first growing season for bud-break phenology, survival, height growth, and presence or absence of chestnut blight and deer browse to the terminal bud.

The BC3F3 generation seedlings were slightly more developed than American chestnut seedlings in bud-break phenology, indicating a departure from the more desirable American chestnut phenotype. First-year survival ranged from 80-93 percent at each location, except one location planted in 2010 that had 44 percent mortality due to a high water table and poor drainage on the site. This site also had the greatest incidence of chestnut blight with 4 percent and 3 percent of the BC3F3 generations and American chestnuts, respectively, with blight. Chestnuts were capable of fast-growth in the first year after planting if not browsed by deer, averaging 3 and 7 inches in height growth for 2009 and 2010 plantings, respectively. Browsed seedlings were 7 inches (2009) and 16 inches (2010) shorter after year 1 compared to unbrowsed trees. Seedlings classified as Small at planting had more browse and more growth than seedlings classified as Large, but Large seedlings remained 11 and 18 inches taller than Small seedlings at the end of year 1 for 2009 and 2010 plantings, respectively. Deer browsing was location specific ranging from 3 percent to 80 percent of trees browsed at each site. In both years, American chestnut and BC3F3 generation seedlings were

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not different in height growth, and Chinese chestnuts had significantly less height growth than American chestnuts and all generations. In 2010, Chinese chestnut seedlings had the best survival (100 percent) compared to Americans and all generations, but had and the worst survival in 2009 (81 percent).

Using high-quality seedlings with terminal buds that are above the deer browse line (~4.5 feet) and/or the use of deer protection for smaller seedlings will be a requirement for the successful restoration of American chestnut in areas with high deer populations. At the beginning of the second growing season hard plastic mesh shelters (5 feet tall) were erected at plantings that had significant deer browsing in the first year. Results presented here are preliminary, but show that chestnut is capable of relatively fast growth and good survival after one growing season if the site is well-drained and free of deer browsing pressure.

The biggest challenges identified by field managers from the NFS were providing and maintaining deer protection, having sufficient financial resources to carry out reforestation and to support research efforts, the lack of available material for planting, and identifying proper areas for planting blight-resistant chestnuts. A major anticipated challenge that was not identified as a significant problem in this study was Phytophthora cinnamomi Rands, an exotic soil pathogen that kills the root system of chestnut plants, particularly on lower-quality sites with wet, compacted soils (Rhoades et al. 2003). Proper planning and resource support are needed to overcome these challenges. Future results from this and similar studies will be used to guide and maximize efficiency of reforestation efforts on NFS lands.

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LONGLEAF PINE AGROFORESTRY

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ABSTRACT

While ecosystem restoration of longleaf pine (*Pinus palustris* Mill.) forests represents a worthy ideal, it is not always a practical alternative for landowners. Agroforestry systems, which can be developed in existing agricultural land, natural forest stands, plantations, or pasturelands, offer the opportunity to provide multiple benefits: high value timber production, continual agricultural production, and improved wildlife habitat when compared to agricultural land. The possibilities for multiple income sources associated with agroforestry are plentiful and, for forest landowners, may mean the difference between profit and loss in times of commodity price fluctuations. Agroforestry can provide a range of income alternatives, including agricultural products, wildlife, medicinal plants, mushrooms, carbon credits, pine straw or biofuels, providing landowners with a stable income until the trees become merchantable. We discuss alternative income possibilities and the necessity to locate and secure dependable markets to supply a steady cash flow for forest landowners.

INTRODUCTION

Research needs for longleaf pine (*Pinus palustris* Mill.) ecosystem restoration are many and of critical importance. These fire-driven ecosystems, which once occupied over 90 million acres in the southern United States, were logged extensively in the late 19th and early 20th centuries (Frost 2006). A number of factors contributed to the decline of longleaf pine, among them a massive regeneration failure. This led to the replacement of longleaf pine primarily with slash pine (*P. elliottii* Engelm.) and loblolly pine (*P. taeda* L.) plantations throughout much of what was the longleaf pine range. These two species became the focus of the intensive management practices required to maximize economic returns (Garrett and others 2004).

An effort is now underway to restore longleaf pine to an approximation of its former prominence (Regional Working Group for America's Longleaf 2009). While some major restoration efforts will concentrate on both the overstory and understory, it is important to remember that 80 percent of the forested land base in what was the longleaf pine range occurs on privately held lands. It is critical that landowners and forest managers involved in restoration activities consider the ecosystem services and silvicultural practices that could serve as incentives for private landowners to establish and maintain longleaf pine forests. Connor and others (in press) suggested that agroforestry might be an attractive land use alternative in areas where row cropping, grazing, or pulpwood markets are no longer viable or where there is a threat of insect and disease epidemics. The combination of intensively managed timber with livestock forage, wildlife habitat, other agricultural or nursery crops, and biofuel crops presents an attractive prospect to those wishing to maintain a productive, pastoral land base.

Land ownership patterns have shifted dramatically in the South (Wear and Greis 2002). As urbanization and development spread further into what were once rural areas, cohesive blocks of forested land are subdivided, and ownership may transfer to those less familiar with traditional forestry practices, such as burning, thinning, and other forest management tools (Clutter and others 2007; Wear 2007; Wear and others 2007). Another effect of urbanization has been changes in land valuation. Since income from traditional forest uses or forest land sale is rarely able to compete with income from real estate development, finding alternate income sources from land management activities is a daunting task. Fluctuating and declining pulpwood markets, insect infestations, plant diseases, and storm events have impacted the values of loblolly pine and slash pine plantations. Land managers now have an unprecedented opportunity to convert these plantations to either longleaf pine plantations or to longleaf pine agroforestry systems.

The environmental benefits of retaining land in forests are many and include positive impacts on water and air quality, soil conservation, and wildlife habitat. However, landowners are not yet rewarded for good stewardship (Shrestha and Alavalapati 2004) and must look elsewhere for economic returns. The objective of this article is to discuss crop alternatives for managers and private landowners interested in longleaf pine agroforestry.

INTERCROPPING

The list of species for intercropping is extensive (Gray and others 2003; Rao and others 2004), and includes traditional crops such as corn, soybeans, and cotton but may also include less traditional crops such as mushrooms and medicinal herbs. However, an investment in planning and marketing surveys prior to beginning any venture is essential for success. In addition, a good business plan should be developed and information on appropriate species that can be grown on the site should be compiled. A good place to start on the latter is the USDA Plants Database (2011). Websites such as Richter's Herbs (2011) can also be useful. Also, some basic site evaluations, such as soil analyses, soil surveys, and nutrient analyses, must be

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completed. Once these tasks are performed, plans can be analyzed for potential economic success. The following are some possible income sources from land maintained in agroforestry:

MEDICINAL PLANTS AND HERBS

Medicinal and aromatic plants were valued worldwide at $1.6 billion in 1996 and almost $4 billion in 1998 (Brevoort 1998; Gray and others 2003). Lists of herbs and understory plants that can be grown as cash crops can be found at various internet sites (e.g. Richter's Herbs 2011) or in reference texts (Clason 2003; Garrett and others 2004). Either shade tolerant or intolerant species are possible candidates, depending on alley width and/or the growth stage of the overstory trees (Jose and others 2004; Lin and others 1999). Some examples of medicinal herbs commonly mentioned as marketable are (nomenclature from USDA Plants Database [2011]):

1. American ginseng - *Panax quinquefolius* L.
2. Black cohosh - *Actaea racemosa* L.
3. Bloodroot - *Sanguinaria canadensis* L.
4. Blue skullcap - *Scutellaria lateriflora* L.
5. Catnip - *Nepeta cataria* L.
6. Echinacea - *Echinacea angustifolia* D.C.
7. Goldenseal - *Hydrastis canadensis* L.
8. Valerian - *Valerian officinalis* L.
9. Wild indigo - *Baptisia australis* (L.) R. Br

Shrubs with medicinal properties include:

10. American witchhazel - *Hammelis virginiana* L. (leaves, bark).
11. Slippery elm - *Ulmus rubra* Muhl. (inner bark)
12. Wild hydrangea - *Hydrangea arborescens* L. (bark and roots)

Habitat requirements and intolerance to extreme temperatures limit many of the herbs listed above from growing well in the South. In addition, some species may have undesirable characteristics which should be considered before planting. If land managers are considering livestock grazing on some of portion of their property, consider, for example, that although common St. Johnswort (*Hypericum perforatum* L.) is reportedly of value as an anti-depressant (Linde and others 2008), it is not native to North America and is considered invasive in some areas. This, combined with its toxicity to livestock, would negate its value as an intercrop species in areas where it might spread to pastures (USDA Plants Database 2011).

Growing herbs can be a risky venture even with the best considered plans. Market and price instability can adversely affect even a well-researched business venture. For instance, U.S. consumer sales of common St. Johnswort, estimated at $400 million dollars in 1998 (Monmaney 1998), has dropped precipitously. The size of the initial investment, scale of the project, and future market all influence profit margins. Burkhart and Jacobson's (2006) paper on goldenseal is an excellent, in-depth study on growth, collection, and marketability of an herb. If a product is to be exported, a set of laws, regulations, reports, and licenses must be considered, especially if the species in question is on the endangered species of flora list.

AROMATICS AND ESSENTIAL OIL/COOKING HERBS

The aromatics, such as rosemary (*Rosmarinus officinalis* L.) and kitchen sage (*Salvia officinalis* L.) are possible species for intercropping. These plants are naturally occurring in the Mediterranean countries and grow well on poor, sandy soils. Caper (*Capparis spinosa* L.), also a Mediterranean species, was at one time cultivated in the United States. Caper thrives in a semi-arid environment, so its success in an area with higher humidity is problematic. Other potential crop species include, but are not limited to:

1. Cayenne pepper - *Capsicum annuum* L. var. glabriusculum (Dunal) Heiser & Pickersgill
2. Sweet basil - *Ocimum basilicum* L.
3. Wild chives - *Allium schoenoprasum* L.
4. Dill - *Anethum graveolens* L.
5. French shallots - *Allium cepa* var. ascalonicum
6. Parsley - *Petroselinum crispum* (Mill.) Nyman ex A.W. Hill
7. Peppermint - *Mentha x piperita* L. (pro sp.) [aquatica x spicata]
8. Spearmint - *Mentha spicata* L. var spicata
9. Garden thyme - *Thymus vulgaris* L.

All species would require further investigation before planting. Preferred climate and soils, tolerance to temperature and humidity extremes, ease of cultivation, and markets may all be limiting factors. While some of the above listed species are not normally found in the southern states, some will survive and flourish here if soil and climatic conditions are conducive to growth and development. However, it may be necessary to consider that some non-native or non-local plants, as previously mentioned, can become invasive or are otherwise undesirable.

MUSHROOMS

Edible and medicinal mushrooms present intriguing alternative crop possibilities. Freshly cut 5 to7 inch diameter hardwood stems (e.g. small sweetgum [*Liquidambar styraciflua* L.] removed from a planting site or during clean-up of existing stands) can be inoculated with shitake (*Lentinula edodes* [Berk.] Pegler) and oyster (*Pleurotus* spp.) mushroom spores. Holes are drilled into the wood, the spores implanted, and the drill hole painted with a coating of paraffin to prevent desiccation. Propped against longleaf or other pine crop trees, the inoculated logs are kept out of alleys so they do not interfere with mowing or use of the alleys for other cash crops. Informational sources on species of edible mushrooms that can be grown in this manner are Cannon-Crothers (2009) and http://www.mushroommountain.com.

FRUIT CROPS

Installing fruit orchards in rows between crop trees may have limited application. It generally takes at least 4 to 5 years for fruit trees to become established and produce a crop. In this interval, rapidly growing crop trees may overtop and shade the fruit trees, substantially reducing yields. Additionally, the droughty, poor quality soils suitable for pine production may not be appropriate for fruit trees.

Soft fruits (stoneless fruits, such as strawberries, raspberries, blueberries, blackberries, and grapes), however, are potential crop species and market possibilities can include a pick-your-own variation (with appropriate insurance for protection against injuries). If this is not an option, other sales avenues must be assessed, as should skills necessary to maintain the canes of blackberries and raspberries to maximize fruit production. Grapes require the construction and maintenance of a trellis infrastructure, adding to startup costs.

LANDSCAPE PLANTS

Ornamental trees and shrubs—Landscape trees and shrubs could be grown either in the ground or in containers under longleaf pine trees. The latter application offers the greatest versatility, since soil conditions would not limit species selection. A newly planted agroforestry system would favor shade-intolerant species, while shade-tolerant species could be grown in mature systems. Hagan and others (2009) found that shade-tolerant native understory species American beautyberry (*Calliocarpa americana* L.), wax myrtle (*Morella cerifera* [L.] Small), and inkberry (*Ilex glabra* [L.] A. Gray) performed poorly as an intercrop under a 15-year-old longleaf pine stand. However, unlike an agroforestry system with upwards of 12 m between tree rows, the overstory trees in this study were planted with 1.5 m between trees and 3 m between rows. Additionally, intense intraspecific competition may have been exacerbated by limited rainfall. In any intercropping system, especially for plants cultured in containers, supplemental water would be critical for success in areas with sporadic or limited rainfall.

Crop trees would provide shade and wind protection for the landscape plants, while the landscape plants could be a lucrative yearly crop for the landowner. It would be necessary to mow among rows and containers or perform some other management activity to prevent uncontrolled herbaceous vegetation in open areas (Greg Ruark, pers. comm., July 23, 2009), but this might facilitate the harvest of other products, such as pine straw and pine seeds and cones. A new line of large-pot stock types have been developed for restoration efforts, a departure from traditional-sized pots (Landis and others 2002). These containers may readily adapt to use in landscape plant growing endeavors but may be too small for most ornamental trees and shrubs as the growing season progresses. Although there does not seem to be literature on the subject, it may also be possible to grow orchids and bromeliads on trunks of crop trees in areas where frosts are of limited occurrence and relative humidity is high.

Species for restoration or revegetation—Other stocktypes that could be grown either in-the-ground or in containers under a longleaf pine agroforestry system are grasses and woody plants commonly used in reforestation projects. Grasses can be grown and planted as plugs. Additionally, grasses may be harvested for seeds if they are planted in the ground and if seeds of the species are rare or hard to collect (Steinfeld and others 2007). For example, wiregrass, a desirable grass species in longleaf pine restoration efforts, is in great demand, and seed for sale to the public is often in short supply. Seed transfer zones for understory plants in longleaf pine ecosystems have been proposed (Walker and Hernandez in press) with the intent of increasing the availability of regionally adapted native plant material. Native plants grown under agroforestry crop trees could provide certified seed to a developing industry.

BIOFUELS

Where markets are available, intercropping can be focused on the production of biofuels and bio-oils. Switchgrass, hybrid poplars, and other cellulosic sources, such as tropical maize, can all be used to produce cellulosic ethanol (Rockwood and others 2004) while corn and soybeans can either be harvested as a food crop, silage, or used to produce oil. As with any product, markets, inputs (fertilizer, pesticides), harvesting costs, and transportation costs must all be considered in the business plan, as should issues such as soil pH, water availability, and the effects of shading. An advantage of corn and soybeans is that they have more than one outlet if the biofuel market fluctuates. However, they also require more intensive management which increases production costs, and plentiful sunlight, which may make them a good intercrop only when the longleaf pine crop trees are young (Jose and others 2004). Additional consideration about the use of crops like corn for biofuels is that such use competes with the use of the crop for human food and animal feed. A number of other biofuel crops are suitable and can be grown in longleaf agroforestry systems.

WILDLIFE

Compared to agricultural fields, most agroforestry systems offer improved habitat for enhancing wildlife populations (National Agroforestry Center 2008). Longleaf agroforestry systems are no exception. Whether for game species or songbirds, management activities can be adapted to enhance habitat or forage for wildlife. Lands that include fee hunting-related activities can yield up to 14 percent more value per acre than traditional silvopasture systems (Grado and Husak 2004). Acreage involved may limit some larger species, and the landowner must consider effects of larger animals on crop trees and other plant species during the silvopasture establishment phase. Bobwhite quail (*Colinus virginianus* L.) and wild turkeys (*Meleagris gallopavo* L.) are ideally suited to agroforestry and silvopasture. Food, roost trees, and shelter considerations for either of these two species could readily be met in some agroforestry systems. For example, landowners may plant the necessary food and cover crops among trees on their acreage to attract and maintain wildlife populations while still growing agricultural row crops. Quail thrive in frequently burned longleaf pine forests, and a quail-blackberry or soybean-crop tree system should, with proper planning, be a manageable alternative. In addition to providing a soft fruit for market, blackberry canes would provide shelter for quail. Soybean seeds would provide food for the birds plus a biofuel. In addition, lease hunting opportunities are an achievable option for landowners who successfully establish and retain wildlife on their property.

CARBON CREDITS

Carbon credits give a monetary value to the above and below ground carbon stored in trees and other plants. Credits can be purchased to offset greenhouse gas emissions. Thus the carbon stored in trees in an agroforestry system can be sold as credits to companies or individuals to reduce their carbon footprint.Longleaf pine agroforestry systems offer opportunities for more carbon credits than traditional agricultural systems.

SUMMARY

The above are just some of the possibilities that exist for the landowner interested in agroforestry and land conservation. Agroforestry practices may not suit the needs of all landowners. The importance of a sound business plan, market research, and thoroughly examining plant growth habits and characteristics before investing in any intercropping system cannot be over-emphasized. Agroforestry systems offer an opportunity to re-establish longleaf pine on private lands that are currently in agricultural use. These are lands where there is a desire for continued agricultural use and a resistance for conversion of fields and pastures to plantations.

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FIRST YEAR RESPONSE OF OAK NATURAL REGENERATION TO A SHELTERWOOD HARVEST AND MIDSTORY COMPETITION CONTROL IN THE ARKANSAS OZARKS

K. Kyle Cunningham

ABSTRACT

A study evaluating the response of oak reproduction to a shelterwood harvest and midstory competition control in an upland hardwood stand within the Ozark Highlands of Arkansas is being conducted. The study site is located in the dissected Springfield Plateau physiographic region on the University of Arkansas – Division of Agriculture Livestock and Forestry Research Station near Batesville, AR. Five-acre treatment plots have been established within a 140 acre shelterwood harvest on north-facing slopes (SI 65 - 75 for oaks) in a 110 year old upland hardwood stand. The overstory is dominated by white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), and northern red oak (*Quercus rubra* L.). Treatments include: 1) shelterwood harvest to basal area (BA) 50 ft^2 a^{-1} (BA50); 2) shelterwood harvest to BA 50 plus injection of undesirable stems greater than 1inch DBH (BA50+MR); and 3) non-harvested/ control treatment (NHC). For BA50 and BA50+MR, post-treatment basal areas ranged from 45 to 55 ft^2 a^{-1}, resulting in approximately a 55 percent reduction in over-story density. The NHC remained at initial basal area levels (~ 94 ft^2 a^{-1}). The mean post-treatment mid-story density for BA50 was 157.5 TPA, resulting in approximately a 51 percent reduction from initial mid-story density from harvest damage. The BA50+MR mid-story trees were near 100 percent removed from chemical injection treatments (~ 310 TPA). NHC mid-story densities were approximately the same as initial stand conditions. Mean mid-day photosynthetic photon flux densities (PPFDs) following treatment applications were 476.0 (± 75.3, α=0.05), 640.8 (± 180.3, α=0.05) and 62.5(± 60.0, α=0.05) µmol photons m^2 s^{-1}, respectively for BA50, BA50+MR, and NHC.

INTRODUCTION

Throughout the hardwood forests of North America, regenerating oak stands on productive upland sites presents a major problem to resource managers (Brose et al. 1998). The physiological and morphological adaptations of oak seedlings often narrow the environmental conditions in which they survive and grow. A basic assumption is that success in survival and growth is influenced by: 1) microclimate and edaphic factors, 2) morphological and physiological characteristics of a particular species, and 3) interaction between the two (Hodges and Gardiner 1993). Understanding these relationships is important to understanding management strategies for perpetuating oaks into new forests.

Mature, undisturbed hardwood stands typically do not have enough sunlight reaching the understory for the development of oak seedlings into the mid and upper canopies. Canham et al. (1990) found closed canopy hardwood forests to exhibit understory light levels from 0.4 to 2.5 percent of total available sunlight. Also, 48 to 69 percent of PAR transmittance occurs in sunflecks with 4 to 11 minute duration. Low understory light levels in hardwood stands may be the most limiting factor to the establishment and growth of oak regeneration (Hodges and Gardiner 1993). Battaglia et al. (2000) stated that environmental factors such as light and soil moisture may have independent or interacting influence on hardwood seedling survival and growth. Quero et al. (2008) found that irradiance levels have greater impact on oak seedling growth than water supply. Increases in sunlight aid in promoting both the successful establishment and subsequent growth of oak reproduction in hardwood stands. However, too much light in the initial stages of development may hinder oak seedlings by favoring faster growing, more shade intolerant, tree species and herbaceous vegetation (Hodges and Janzen 1986). Hodges and Gardener (1993) suggested that sufficient sunlight levels for growth and survival for cherrybark oak (*Quercus pagoda* Raf.) occurred at 27 percent of total available PAR and optimal growth conditions occur at 53 percent of total available PAR.

Sources for hardwood regeneration include: seedlings, seedling sprouts, and stump sprouts. When present prior to harvest, these sources are known as advanced reproduction (Rogers et al. 1993). The level of partial overstory removal may affect the amount of advance reproduction present following harvesting activity as it impacts both the amount of site disturbance and the resulting available sunlight. Shelterwood harvests may present the most flexible alternative to naturally regenerating desirable species such as oaks. A shelterwood harvest is a management system that promotes a standing crop of regeneration through a series of partial removals of the overstory (Smith et al. 1996). An alternate version of the classical approach to

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shelterwood harvests may be required for the desirable oak species on the more productive sites. Combining herbicide treatments and/or prescribed fire along with the shelterwood has been evaluated by many researchers (Hicks et al. 2001). Although there are no universal prescriptions for the hardwood regeneration problem, modified shelterwood systems that remove canopy and sub-canopy individuals prior to overstory removal to increase light reaching the ground can increase seedling dominance and survival for desirable species such as the oaks (Loftis 1993). This study attempts to further supplement our knowledge of oak natural regeneration by evaluating understory light levels and hardwood regeneration response to two modified shelterwood methods.

MATERIALS AND METHODS

The study site is located in the Ozark Mountains of Arkansas, within the dissected Springfield Plateau physiographic province. The predominant soils are listed as Clarksville very cherty silt loam, 20 to 40 percent slopes and Clarksville very cherty silt loam, 8 to 20 percent slopes. These soils are described as deep, somewhat excessively drained, low available water, low organic matter content, and strongly acidic (Ferguson et al. 1982). It should be noted that the description provided is a general soil description based on broad ranges of slope positions. The areas selected for this study were only on north aspects, which potentially have somewhat higher organic matter, higher moisture content, and are generally considered more productive than ridge-tops and south facing slopes.

Site indices for white oak, black oak, and northern red oak dominant and co-dominant trees were determined from equations developed by Graney and Bower (1971). Oak site indices ranged from 65 to 75 feet, depending on slope position. Initial over-story mean basal area of treatment replicates was 93.8 $ft^2 a^{-1}$ (± 8.5 $ft^2 a^{-1}$), representing a fully stocked to slightly overstocked stand. Initial over-story species composition was dominated by approximately 75 percent oak species. Initial mean mid-story density was 310 trees per acre (TPA) and dominated by non-oak, shade tolerant species. Mean understory (regeneration source) density included 475 oak seedlings per acre (SPA) (± 147 SPA) and 2,532 non-oak seedlings per acre (± 366 SPA). Species composition in the under-story was dominated by shade tolerant species. Red maple, winged elm, and hickory comprised 48 percent of understory, while oaks, collectively, comprised 15 percent.

The study utilizes two primary treatments that incorporate two shelterwood methods to potentially generate an adequate to optimum environment for mid-tolerant oak seedling establishment and development. A third treatment is a control, where no stand manipulation has occurred. Treatments include: 1) shelterwood harvest to BA 50 (BA50); 2) shelterwood harvest to BA 50 plus injection of undesirable stems greater than 1inch DBH (BA50+MR); and 3) non-harvested/ control treatment (NHC). Mid-story removal treatments were applied from November 2008 to February 2009. Follow-up treatments were applied in July 2009. Non-oak species were removed using herbicide injection. One milliliter of an aqueous solution of 25 percent imazapyr and 75 percent water was injected for every three inches of circumference around tree trunks. The mechanical thinning operation was applied to the BA50 and BA50+MR from October 2009 through March 2010. The target residual basal area was 50 $ft^2 a^{-1}$. Desirable residual tree characteristics were well spaced oak species with large vigorous crowns.

EXPERIMENTAL LAYOUT AND FIELD MEASUREMENTS

The experimental design is a randomized complete block (RCB). However, a physical constraint on randomization exists. The BA50 and BA50+MR are blocked and replicated into four blocks within the harvested area, while NHC replicates are located adjacent to the harvest area. This design was necessary to fit geographical constraints and to reduce the potential for bias between harvested and non-harvested treatments, potentially having significant impacts on data quality. The tradeoff is that the control replicates are not truly blocked with BA50 and BA50+MR. The author feels the modified design does not jeopardize confidence in results. 1) The treatment replicates are all in relatively close proximity, and 2) appreciable homogeneity existed among site and initial stand conditions.

Each treatment within a block contains twelve 1/100 acre circular regeneration sample plots spaced on a grid along the slope gradient. Regeneration measurements at each plot included species and height class (<1 feet, 1 to 3 feet, and >3feet). Over-story measurements were taken from two (one upper slope and one lower slope) fifth acre circular plots. Over-story measurements included species, DBH, merchantable height, log grade, damage, and number of epicormic branches. Mid-story measurements were taken from 2, 1/20 acre circular plots. Mid-story measurements included species and total height. Initial over-story, mid-story and understory measurements were taken in the summer of 2009.

Photosynthetic Photon Flux Density (PPFD) was measured at each of the twelve regeneration plots per replicate. PPFD was measured at plot center using a quantum sensor attached to a Mini-PAM 2000 (WALZ, Inc.). Mini-PAM readings were calibrated against a Li-COR quantum sensor for accuracy. The sensor was mounted to a leveled tripod at each measurement point. Plot center light measurements were taken in September 2010. PPFD measurements were taken under mostly sunny conditions.

STATISTICAL ANALYSES

All statistical analyses were performed in SAS 9.2. Normality tests were performed through the PROC UNIVARIATE procedure utilizing the Shapiro-Wilks W-test. Sunlight level and regeneration response were analyzed for treatment differences using analysis of variance (ANOVA) using PROC GLM. Individual means separation was conducted with Student Newman-Kuels SNK tests. All tests were run at the $\alpha = 0.05$ level.

RESULTS

Treatment applications had appreciable impact on residual over-story and mid-story conditions. For the BA50 and BA50+MR, post-treatment basal areas ranged from 45 to 55 square feet/acre, resulting in approximately a 55 percent reduction in over-story density. The NHC remained at initial basal area levels (~ 93.8 $ft^2\ a^{-1}$). The BA50 mid-story density was approximately 125 TPA for upper slope plots and 190 TPA for lower slope plots. The mean post-treatment, mid-story density for BA50 was 157.5 TPA, resulting in approximately a 51 percent reduction from initial mid-story density. The BA50+MR mid-story trees were approximately 100 percent removed (~ 310 TPA). The NHC mid-story densities were approximately the same as initial stand conditions.

IRRADIANCE

September 2010 plot center mean understory light levels were 476.0, 640.8 and 62.5 µmol $m^2\ s^{-1}$ for BA50, BA50+MR, and NHC, respectively. A one-way analysis of variance determined significant differences to exist, with an F-Value of 44.10 ($P < 0.0003$) for treatment effects. A SNK means analysis determined significant differences to exist between all three treatments (Figure 1). BA50 mean PPFD values for slope positions 1 – 4 were 131.1, 449.8, 514.8, and 808.0 µmol $m^2\ s^{-1}$, respectively. Significant differences among rows for plot center PPFD measurements for BA50 were determined to exist, with an F-Value of 5.65 ($P = 0.0186$). Significant differences were determined between slope position 1 versus slope positions 2, 3, and 4. Also, slope position 4 significantly differed from slope positions 1, 2, and 3. No differences existed between rows 2 and 3 (Figure 2). BA50+MR mean PPFD values for slope positions 1 – 4 were 377.0, 740.5, 768.5, and 675.6 µmol $m^2\ s^{-1}$. A one-way analysis of variance for treatment effects found no significant differences to exist, with an F-Value of 2.95 ($P = 0.09$). NHC mean PPFD values for slope positions 1 – 4 were 21.9, 108, 31, and 75 µmol $m^2\ s^{-1}$. No significant differences were determined to exist for NHC slope positions, with an F-Value of 2.95 ($P = 0.10$) (Figure 2).

REGENERATION

No statistical difference occurred between initial and year 1 species composition among treatments. Year 1, post harvest, mean oak SPA were 260.4, 682.6, and 552.0 SPA for BA50, BA50+MR, and NHC, respectively. The percent change in mean oak SPA was -1.6, 10.3, and 0.7 percent for BA50, BA50+MR, and NHC, respectively. Year 1, post harvest, mean non-oak SPA were 2244.8, 2400.4, 2406.3 SPA for BA50, BA50+MR, and NHC, respectively. The percent change in mean non-oak SPA was -9.5, -13.5, and -0.3 percent for BA50, BA50+MR, and NHC, respectively (Figure 3 and 4).

Year 1, mean oak SPA for BA50 were 129.2, 118.8, and 12.5 SPA for height classes 1, 2, and 3, respectively. Height class 1 experienced a loss in oak SPA, while height classes 2 and 3 experienced a slight increase for BA50 oak reproduction. Year 1, mean non-oak SPA for BA50 were 553.1, 978.1, and 713.5 SPA for height classes 1, 2 and 3, respectively. Height class 1 and 3 experienced a loss of non-oak SPA, while height class 2 exhibited an increase in SPA (Figure 3 and 4). Mean oak SPA for BA50+MR were 378.6, 265.7, and 38.3 SPA for height classes 1, 2, and 3, respectively. Height classes 1 and 2 experienced an increase of oak SPA, while height class 3 experienced a slight decrease for BA50+MR oaks. Year 1, mean non-oak SPA for BA50+MR were 568.9, 1,125.4, and 706.1 SPA for height classes 1, 2 and 3, respectively. Height classes 1 and 3 experienced a loss in SPA, while height class 2 exhibited an increase (Figure 3 and 4). Mean oak SPA for NHC were 385.4, 154.2, and 12.5 SPA for height classes 1, 2, and 3, respectively. Height classes experienced negligible changes in oak SPA. Year 1, mean non-oak SPA for NHC were 572.9, 879.2, and 954.2 SPA for height classes 1, 2, and 3, respectively. Height classes also experienced negligible changes in non-oak SPA for NHC (Figure 3 and 4).

DISCUSSION

In the BA50, a portion of the mid-story was inadvertently removed during the overstory harvest operation. The result was that approximately one-third to one-half (depending on slope position) of mid-story trees were either snapped off near ground level or removed by the mechanical operation. The mid-story component represents the key difference between the BA50 and BA50+MR. Approximately 100 percent of the mid-story trees were removed from the BA50+MR and none were removed from the NHC. Mid-story trees that were killed had positive impacts on understory light levels. However, trees that were snapped off by the mechanical operation have a high sprout potential and will certainly remain as competition for oak reproduction. Additionally, there existed a gradient from lower slope to upper slope damage intensity to mid-story trees in the BA50. The result is a low to high understory light level gradient from lower slope to upper slope for BA50 (Figure 2). The BA50+MR differed in that mid-story stems were deadened, thus removed equally from lower to upper slope positions. The result is a higher intensity, more uniform canopy transmittance pattern across the slope (Figure 2) and little to no chance of stump sprout competition from deadened mid-story trees. Thus far in the study, understory light levels in BA50+MR most closely mimic those suggested for mid-tolerant oak species development.

Harvest damage also appeared to reduce seedling abundance for non-oak species in both treatments 1 and 2. Figure 3 illustrates the changes for non-oaks by height class. The author feels the primary harvesting impacts to non-oaks was experienced in height class 3. The reduction in non-oak SPA for height class one is potentially a combined result of harvest damage and influx from height class 1 into height class 2 (generated by the increased light environment). There appeared to be little negative harvest impact on oak seedling abundance (Figure 3). BA50 exhibited little change in oak SPA. The BA50+MR experienced an influx of height class 1 oak seedlings (primarily *Q. alba*). The BA50+MR also experienced an increase in height class 2 SPA, potentially a function of the improved light conditions. Additional growing seasons will be required to fully evaluate seedling abundance among treatments.

CONCLUSIONS

Initial data indicates that a shelterwood harvest alone (BA50) created somewhat variable sunlight conditions at ground level, with only a portion of its area exhibiting potentially adequate sunlight for oak seedling development. Year 1 results suggest that a modified shelterwood, combining partial overstory and complete mid-story removal, generate adequate (potentially optimal) sunlight conditions for oak seedling growth and survival in the Ozark uplands of Arkansas. Additional analyses will be performed in future growing seasons to more fully evaluate the treatment effects on oak abundance and competitive position.

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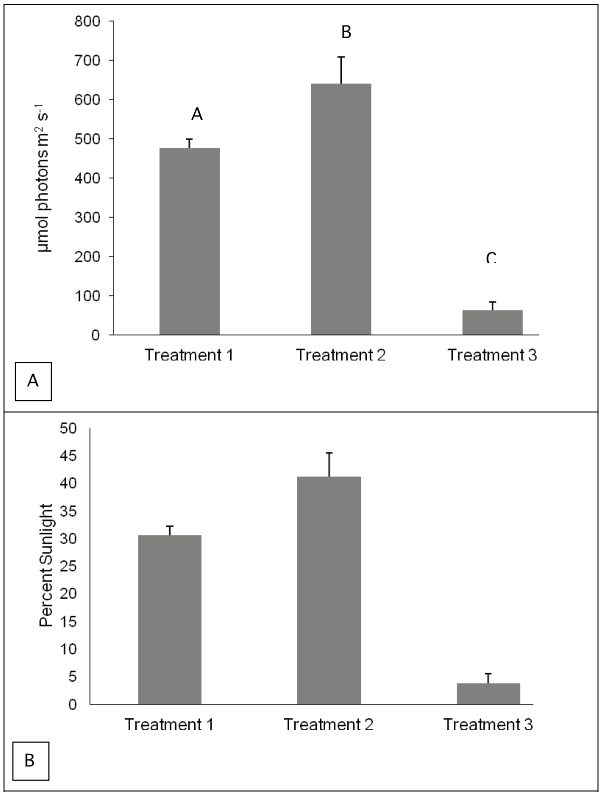

Figure 1—A) Plot center PPFD values by treatment for September 2010. B) Plot center PPFD values by topographic position and treatment. (Means followed by same letter do not significantly differ, SNK Pr > F ≤ 0.05)

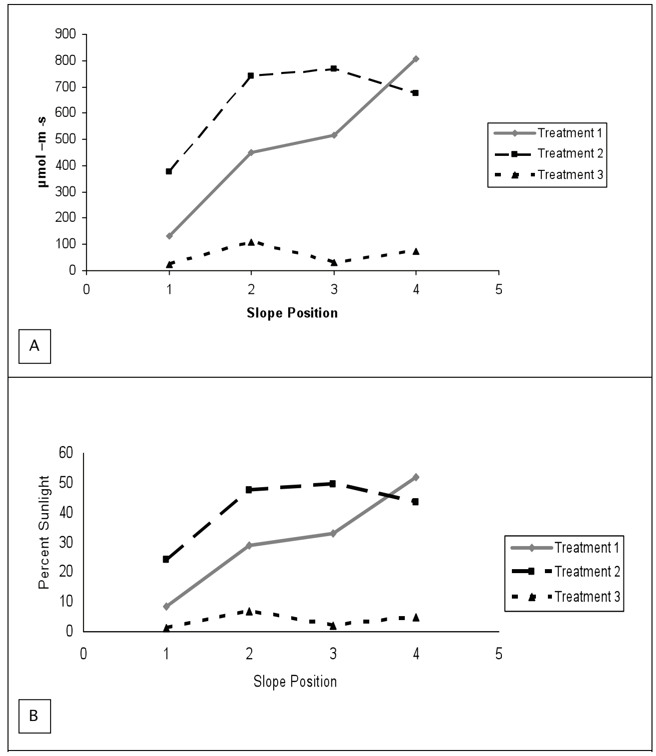

Figure 2—A) Plot center PPFD values by treatment for September 2010. B) Plot center PPFD values by topographic position and treatment.

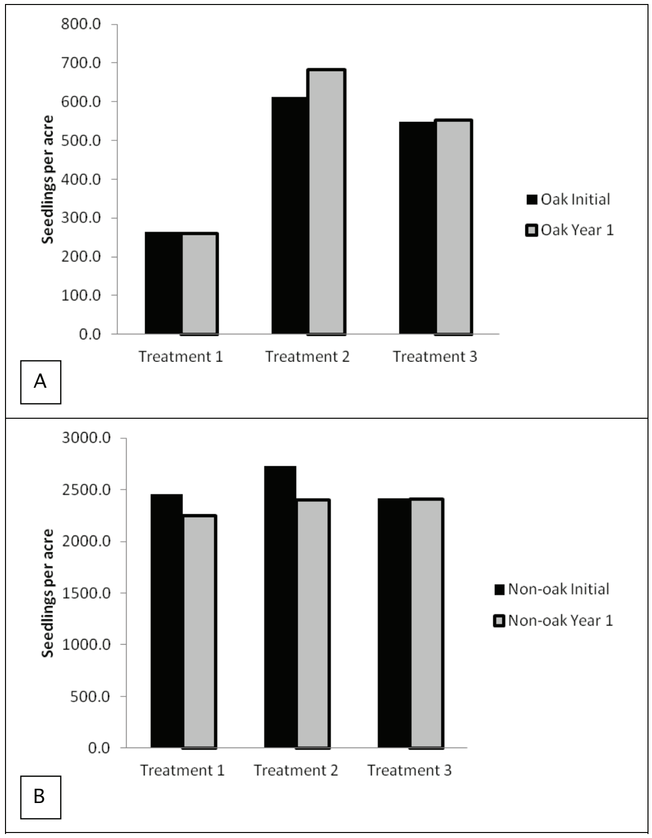

Figure 3—A) SPA initial and year 1 measurements for oaks. B) SPA initial and year 1 measurements for non-oaks.

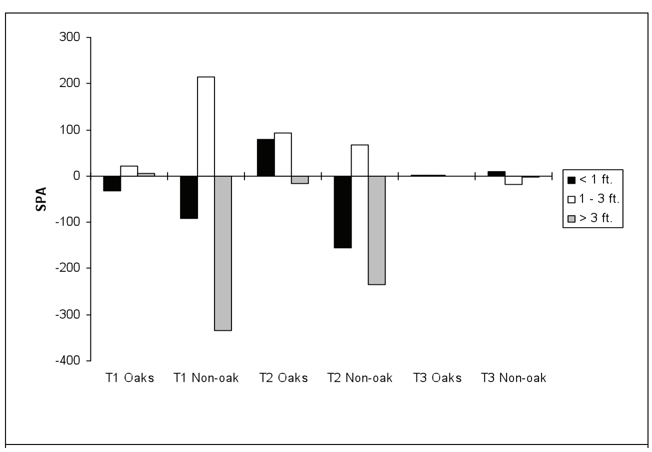

Figure 4—Change in oak and non-oak seedlings per acre (SPA) by height class and treatment between initial and year 1 measurements.

EFFECTIVENESS OF TIMBER HARVESTING BMPS: MONITORING SPATIAL AND TEMPORAL DYNAMICS OF DISSOLVED OXYGEN, NITROGEN, AND PHOSPHORUS IN A LOW-GRADIENT WATERSHED, LOUISIANA

Abram DaSilva, Y. Jun Xu, George Ice, John Beebe, and Richard Stich

ABSTRACT

To test effectiveness of Louisiana's voluntary best management practices (BMPs) at preventing water quality degradation from timber harvesting activities, a study with BACI design was conducted from 2006 through 2010 in the Flat Creek Watershed, north-central Louisiana. Water samples for nutrient analyses and measurements of stream flow and of in-stream dissolved oxygen (DO) were taken monthly at 7 sites: upstream and downstream of three harvested tracts, and at one control site. Harvesting occurred in 2007, with two of the tracts harvested with BMPs and the third without BMPs. One of the BMP-implemented tracts was further analyzed with intensive DO data. Preliminary results show no trend for significant changes in nutrient concentrations from harvests (with or without BMPs), and both monthly and intensive DO measurements show no DO depletion for BMP-implemented harvests. For these harvests occurring in the Flat Creek Watershed, Louisiana's current BMPs were effective in preventing water quality degradation.

INTRODUCTION

Forestry activities have the potential of introducing nonpoint sources of pollution (NPSP) into adjacent water bodies if no steps for mitigation are implemented (Binkley and Brown, 1993). Timber harvest without best management practices (BMPs) can introduce slash into adjacent stream- and river-beds; expose streams to increased direct solar radiation (causing water temperatures to increase), cause increased leaching of nutrients from watersheds (decreases nutrient uptake and increased mineralization rates); and increase sediment loads to streams due to disturbance from road-building, timber yarding, and even the increased runoff resulting from decreases in evapotranspiration. Eroded topsoil is often rich in fine decomposable organic matter that can increase stream respiration and lower aquatic dissolved oxygen (DO) concentrations. Forestry NPSP can lead to eutrophication due to excess nitrogen (N) and phosphorus (P), which both depletes and elevates DO concentrations during daily and seasonal patterns, and can potentially decrease biodiversity and even lead to toxic algal blooms.

Louisiana is divided into 12 major river basins with 475 sub-segments (watersheds). Nearly 50 percent of these watersheds are currently listed on the 303(d) list as impaired for the low DO levels in their water bodies (Xu, 2009), and nearly 25 percent are listed for excess nutrients (LDEQ, 2010). Efforts to prevent NPSP from forestry activities include the development of best management practices (BMPs) for the forestry community to follow. In 2000, the Louisiana Forestry Association, the Louisiana Department of Environmental Quality, and the Louisiana Department of Agriculture and Forestry developed a manual of Recommended Forestry Best Management Practices for Louisiana (LDEQ, 2000). The BMPs include practices that minimize erosion and sediment delivery to streams, reduce organic loads to streams, and maintain shade. Although implementation of the BMPs is currently high across various land ownerships and regions in Louisiana (Xu and Rutherford 2005), it is unknown how effective the state's forestry BMPs actually are at preventing stream water quality degradation in forested areas of Louisiana.

Over the past two decades, there have been many studies conducted to measure forestry BMP effectiveness (e.g., Martin and Hornbeck, 2000; Ice, 2004). However, to our knowledge very few studies have been conducted to test the effectiveness of Louisiana's forestry BMPs at preventing water quality degradation. Louisiana is a state with many low-gradient watersheds and streams. The topography and the subtropical climate often cause accumulation of stream

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nutrients and oxygen depletion. This study was designed to monitor the effectiveness of Louisiana's current BMPs at 1) preventing DO depletion and 2) preventing excessive increases of nitrogen and phosphorus concentrations.

MATERIALS AND METHODS

STUDY SITE AND DESIGN

This study was conducted from 2006-2010, in the Flat Creek watershed (Figure 1), in Winn Parish, Louisiana. This watershed covers 369 km^2 within the 41,439 km^2 Ouachita River Basin. Topography of the watershed is flat to slightly hilly, with a maximum elevation of 91 meters in the northern upland and minimum of 24 meters at the southern outlet (Saksa et al., 2010). Flat Creek is listed as having impaired water quality due to low DO and high total dissolved solids concentrations. Land use of the drainage area is predominantly forestry with some rangeland. The subtropical watershed receives about 150 cm rainfall per year. The dominant soils in the watershed are Sacul-Savannah (fine sandy loam) in the upland areas and Guyton series (silt loam) along the Turkey Creek and Flat Creek floodplains (Saksa, 2007).

First-order streams running through three forested tracts were chosen for monitoring water quality conditions within the Flat Creek watershed. For each of these tracts, two monitoring sites were established: One site immediately upstream of the forested tract, and a second site immediately downstream. An additional site in the watershed was selected to serve as a control; this site was also placed on a first-order stream in the watershed, but was not affected by any silvicultural activities during the study. The three tracts were harvested in late summer 2007. For two of the tracts, harvest occurred under Louisiana's current BMPs (between sites I3-I4, and N1-N2). These BMPs included maintaining streamside management zones (SMZ) with a basal area of 11.4 m^2 Ha^{-1} (50 ft^2 ac^{-1}) along perennial stream channels, minimizing stream crossings, limiting equipment within SMZs, constructing water bars and lateral ditches, reconstructing haul roads, restoring stream crossings, and removing slash and logging debris from stream channels (Brown and Xu, in review). The third tract was harvested using no BMPs (between sites 9up-9down). A HOBO weather station was utilized within the watershed to record continuous meteorological data such as rainfall and air temperature (Figure 1). Monthly site visits were conducted during which flow was measured (Acoustic Doppler Velocimeter, Sontec, California, USA) at each site to develop stage discharge rating curves for daily flow rate calculations.

DISSOLVED OXYGEN

In-stream measurements of water quality were made monthly at each site. These daytime "snapshot" measurements were conducted using a handheld YSI 556 (Yellow Springs Instruments, Yellow Springs, Ohio, USA), and measured numerous variables including DO concentration (mg L^{-1}) and saturation (percent). Paired t-tests (SAS analytical software) were conducted by site set (I3-I4; N1-N2; 9up-9down) on the monthly DO data. These allowed us to see any harvest-induced changes between the upstream and downstream DO relationships, by comparing pre-harvest means, and then comparing post-harvest means.

To increase resolution, and provide an additional test of BMP effectiveness at preventing DO depletion, multi-parameter water quality sondes (YSI 6920 V2, Yellow Springs Instruments, Ohio) were deployed at sites N1 and N2 in June 2006. These sondes recorded DO concentrations, temperature, conductivity, and depth at 15-minute intervals. Monthly site visits were made for calibration and maintenance of the sondes. During these monthly trips, additional water samples were taken from sites N1 and N2 for carbon and biochemical oxygen demand (BOD) analysis. Total carbon was analyzed by the Wetland Biogeochemistry Institute, Louisiana State University. The water samples for BOD analyses were kept at room temperature and analyzed for 5-day BOD (YSI 5000 dissolved oxygen meter). Paired t-tests (SAS analytical software) were performed on the DO data to compare pre-harvest relationships between N1 and N2 to post-harvest relationships. For these tests, DO measurements were averaged by day to reduce the number of observations and eliminate a falsely enhanced ρ-value. To assure that any harvest-induced changes in daily fluctuations would not be overlooked by using this daily-averaging method, the daily differences between the maximum and the minimum DO concentration were determined, and pre-harvest means were compared to post-harvest means for both sites. There were no changes in the daily differences between maximum and minimum DO concentrations from the pre- to the post-harvest at either N1 (two-sample t-test, $\rho = 0.19$) or N2 (two-sample t-test, $\rho = 0.64$). Having confirmed the suitability of the daily-averaging method, the daily averaged data were then split into two seasons: summer (May-October), and winter (November-April). Paired t-tests were also conducted on BOD, water temperature, and total carbon to search for before-and-after-harvest differences. The water temperature at each site was also averaged by month. Significance was determined by using an alpha of 0.05 in all cases except for the intensive DO concentration and saturation tests (in which the high sample number required us to use an alpha of 0.01).

NUTRIENTS

Water samples were collected monthly at each of the sites, placed on ice, and taken to the LSU Agriculture Chemistry Lab in Baton Rouge. These samples were analyzed within 30 days for total Kjeldahl-N (TKN), ammonia, nitrate-N, and nitrite-N, total P (TP), and dissolved P. For much of the analyses, ammonia and TKN were below the detection limit. Therefore, nitrate-N and nitrite-N were added together to estimate total-N (TN). To analyze N and P data, paired t-tests were used by site set to compare upstream pre-harvest values to downstream pre-harvest values, and likewise for the post-harvest values. Again, these tests enabled us to look for changes in the up-stream and down-stream relationship due to the harvest.

RESULTS AND DISCUSSION

MONTHLY DISSOLVED OXYGEN

There was quite a large range of DO concentration and saturation monthly-measured values over the course of the 5-year study period. The lowest concentration recorded was 0.14 mg L^{-1} at site I4 during the post-harvest, and DO concentration was measured at the highest point of 12.44 during a post-harvest December monthly at site 9-down. Minimum and maximum saturation values occurred at these same two down-stream sites; with the lowest monthly measurement again occurring at site I4, and on the same date that the lowest concentration was measured. The highest DO saturation was 138.9 percent, at site 9-down, during June 2009. When measurements of supersaturation were isolated, DO saturation was over 100 percent only seven out of the 358 monthly recordings. All of these events were measured during the post-harvest, at 9Down, the site chosen to show impacts from the no-BMP harvest. Not coincidentally, the only significant harvest-induced change occurred between 9-up and 9-down (Figure 4), with there being an increase in DO downstream of the harvest. DO at the control site, I1, did not change from the pre- to the post-harvest period. Measurements of air temperature taken at the Flat Creek watershed's weather station also show no significant difference between pre-harvest monthly means and post-harvest monthly means (two-sample t-test; ρ=0.6297). Neither was there any difference between pre-harvest and post-harvest monthly sums of precipitation (two-sample t-test; ρ=0.9795).

The increase in day-time DO downstream of the no-BMP implemented timber harvest is likely due to the decreased canopy cover, and possibly slightly elevated levels of TN. The 11.4 m^2 Ha^{-1} basal area SMZ that was implemented at the BMP-harvested tracts was not installed between 9-up and 9-down; all the timber was harvested right up to the stream-banks. Following the removal of these trees, the increased sunlight availability likely acted to spur algal growth. Analysis of N/P ratios within the Flat Creek watershed, calculated as TN/TP, indicates a N-limited system—using a classification of below 20 to mean N-limited (Turner et al., 2003). The mean N/P ratio was 4.54 (±7.63) for all the sites, using all the data from both pre- and post-harvest. Before the no-BMP harvest, there was no significant difference between N/P ratios at 9-up and N/P ratios at 9-down (Figure 5). For the post-harvest period, however, 9-down had a significantly higher N/P ratio than that of 9-up. With a system as severely N-limited as this one appears, it could be that the observed spikes in TN following the harvest allowed algal blooms to form. During post-harvest monthly site-visits, we did in fact observe algae at 9-down, while none was observable at 9-up. The DO increase at 9-down following the harvest is a likely effect of these algae, and it is entirely possible that both the increase in N/P ratios and the increased insolation contributed to these blooms.

INTENSIVE DISSOLVED OXYGEN

Daily averages of DO concentrations at the intensively-monitored DO sites varied greatly over the four year period: Daily averages at the upstream site (N1) ranged from concentrations of 0.00 to 10.75 mg L^{-1}, and saturation values of 0.00 to 111.5 %. DO concentrations and saturations at the downstream site (N2) ranged from 0.00 to 10.96 mg L^{-1}, and from 0.00 to 107.9 %. For greater than 70% of the year, DO levels at both sites were below 5 mg L^{-1} (DaSilva et al., in review). Pre-harvest DO measurements (saturation and concentration) during the summer months (May - October) were not significantly different from N1 to N2 (Table 1). During November and April, DO concentration at N2 was significantly higher than that at N1. Following the harvest, both summer and winter months showed significantly higher DO saturation and concentration measurements at N2 than N1.

A previous reference-stream study in Louisiana found that DO concentrations in Louisiana were limited by natural conditions (Ice and Sugden, 2003), including low velocity streams, bottoms high in organic matter, and high temperatures. Our study seems to underscore this point, as DO was below 5 mg L^{-1} for the great majority of both pre- and post-harvest. The significant increases in DO seen for both seasons are surprising in light of our findings on total carbon (TC), and BOD. During pre-harvest, TC was not significantly different between N1 and N2 (paired t-test; ρ=0.8025), but following the harvest TC at the downstream site was significantly higher than upstream TC (paired t-test; ρ=0.0059). A harvest-induced BOD increase was also recorded, with there being no difference between N1 and N2 pre-harvest BOD means (paired t-test; ρ=0.874), but a significantly higher BOD at N2 for the post-harvest period (paired t-test; ρ=0.002). When we averaged water temperature by month, and compared the sites, we saw a change in the relationship going from no difference during the pre-harvest (paired t-test; ρ=0.6675) to a slightly elevated (about 1°C) monthly water temperature mean downstream of the harvest. This 1°C increase was, however, significant (paired t-test; ρ<0.0001). This combination of factors-- the observed increase in DO following the harvest, and the seemingly contradictory increases in TC, BOD, and water temperature-- is unusual. Many studies have found decreases in DO caused by increasing TC, BOD, and/or water temperature (Binkley and Brown, 1993; Ensign and Mallin, 2001). The reduction in evapotranspiration following the harvest may have resulted in increases in groundwater reaching the stream; this excess groundwater could have increased turbulence, subsequently raising reaeration. This possibility is supported by our monthly stream-flow measurements: Before the harvest, there was no difference between N1 and N2 (paired t-test; ρ=0.0898). Post-harvest, however, showed N2 with higher stream-flow than N1 (paired t-test; ρ=0.0211).

NUTRIENTS

Nutrient concentrations for all sites remained low over the duration of the study: TP ranged from a low of 0.01 mg L^{-1} to a high of 0.661 mg L^{-1}; TN ranged from a low of 0.02 mg L^{-1} to a high of 1.234 mg L^{-1}. This TN range is well below the EPA recommended limits of 10 ppm for nitrate-N, and 1 ppm nitrite-N (nitrite-N concentrations never went above 0.0323 mg L^{-1}). Our analyses showed no statistically significant differences in the TN concentrations between any up-stream and down-stream sites either before or after harvest (whether BMPs were implemented or not; Figure 2). There was a significant decrease in TN at the control site, I1, from pre- to post-harvest (two sample t-test; ρ=0.0065). There also appears to be a change in the relationship between TN concentrations at 9-up and 9-down following the harvest, but this apparent increase was not significant (paired t-test; ρ= 0.0759). This relatively high post-harvest mean (0.26 mg L^{-1}) at 9-down was belied by a median of only 0.114 mg L^{-1}; the elevated mean was mostly due to the first two months following harvest, where TN at 9-down was 1.14 and 2.17 mg L^{-1}, respectively. The only statistically significant differences in TP were between post-harvest I3 and I4 concentrations (paired t-test; ρ=0.042), with I4 having higher post-harvest TP concentrations (Figure 3). The overall relationship between I3 and I4 appears nearly unchanged, however, since I4 had consistently experienced higher TP concentrations during the pre-harvest period.

Timber harvest without BMPs induced an immediate spike in monthly measurements of TN for the first two months (October and November 2007) following the harvest, but no such increases were seen from either of the down-stream sites of harvests with BMPs (I4 and N2). This indicates that the timber harvesting BMPs employed during this study were successful at preventing excess TN from reaching the streams. The only significant change in TP occurred at one of the two tracts harvested under BMPs. This change may not be attributable to the harvest; the uncertainty is due to the fact that there was no significant change in TP relationships between the up-stream and down-stream sites for the no-BMP implemented harvest. The pre-harvest TP mean at 9-up was observably--though not significantly--lower than that of 9-down, while for the post-harvest period this relationship was observably reversed. The fact that timber harvest without BMPs did not significantly increase TP makes it difficult to say that the slight but significant increase at one of the two BMP-implemented tracts was due to harvesting. All measured values over the duration of this study were below current EPA recommended limitations.

CONCLUSIONS

This study monitored changes of dissolved oxygen and nutrient concentrations in the headwater streams of a low-gradient, subtropical watershed from 2006 through mid-2010. During the period, timber harvest was conducted at three tracts near the monitored streams in order to evaluate effectiveness of Louisiana's current forestry BMPs in maintaining water quality conditions. The results showed that BMPs were effective in keeping dissolved oxygen levels from decreasing below pre-harvest levels. They also showed no significant increases in TN from the two BMP-implemented harvests, though there were spikes in TN from the non-BMP implemented tract. At two out of three of the tracts there were no significant differences in TP concentrations between pre-harvest and post-harvest. At the remaining tract, a BMP-implemented tract, there was a slight but significant increase from pre- to post-harvest TP. Overall, however, there was no clear harvest-caused trend in nutrient concentrations either with or without BMPs.

ACKNOWLEDGMENTS

This study was funded by the Louisiana Department of Environmental Quality (CFMS Contract No: 595451 and 654551) and the National Council of Air and Stream Improvement Inc. (Contract No: 10R434). Plum Creek Timber Company Inc. provided critical field assistance and logistical operations. A number of graduate students provided field and laboratory assistance throughout this study, including Derrick Klimesh, Timothy Rosen, Kris Brown, Den Davis, Ryan Mesmer, April BryantMason, Philip Saksa, and Adrienne Viosca. The first author wishes to thank the Gilbert Foundation for providing graduate assistantship.

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Table 1—Dissolved oxygen saturation (%) and concentration (mg L^{-1}) means and standard deviations at sites N1 and N2 during summer (May-October) and winter (November-April) months. Paired t-tests were used, and * indicates significant difference between up-stream and down-stream sites over the same time period (α=0.01)

		Pre		Post	
		N1 ± std	**N2 ± std**	**N1 ± std**	**N2 ± std**
DO %	*Summer*	14.0 ± 20.0	16.8 ± 19.8	9.20 ± 17.6 *	12.9 ± 20.0*
	Winter	39.9 ± 34.1 *	44.1 ± 33.1 *	38.8 ± 25.4 *	44.8 ± 26.8 *
DO mg/L	*Summer*	1.49 ± 1.97	1.44 ± 1.68	0.84 ± 1.63 *	1.16 ± 1.83 *
	Winter	4.33 ± 3.83 *	4.77 ± 3.75 *	4.24 ± 2.87 *	4.87 ± 3.04 *

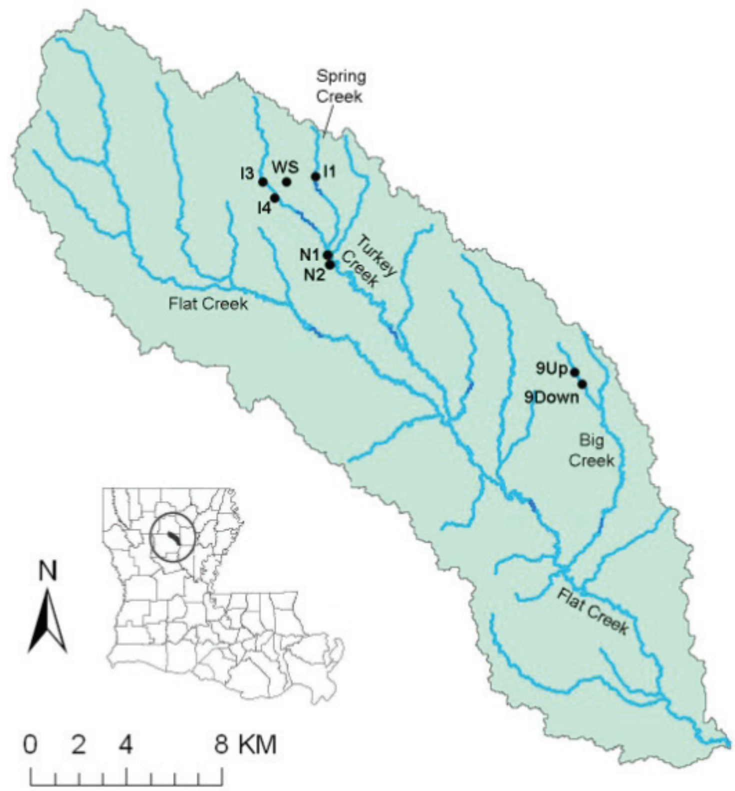

Figure 1—The Flat Creek Watershed, with labeled sites, including the weather station (WS).

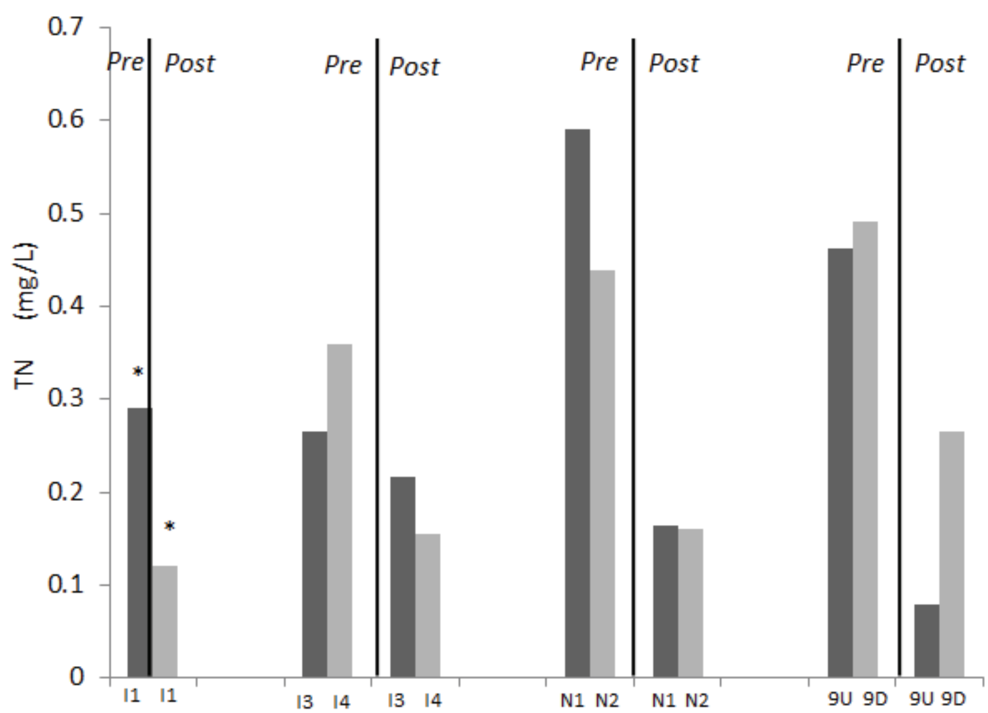

Figure 2—Total nitrogen (TN) means for each site during both pre- and post-harvest periods. Paired t-tests were conducted on I3-I4, N1-N2, and 9U-9D, while a two sample t-test was used on site I1 to test for significant differences (α=0.05; significance indicated by *).

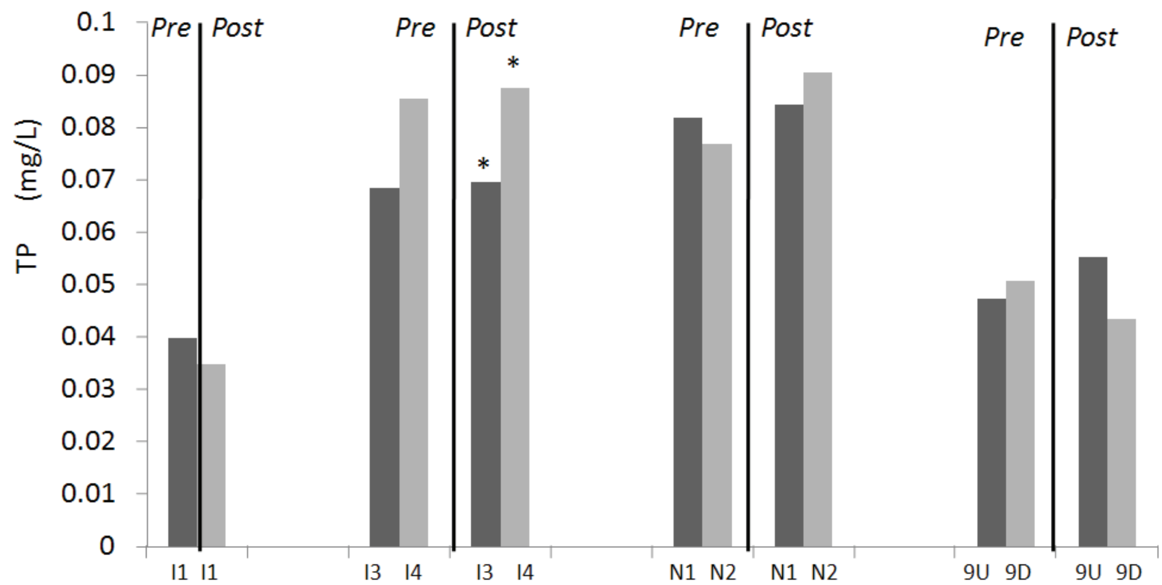

Figure 3—Total phosphorus (TP) means for each site during both pre- and post-harvest periods. Paired t-tests were conducted on I3-I4, N1-N2, and 9U-9D, while a two sample t-test was used on site I1 to test for significant differences (α=0.05; significance indicated by *).

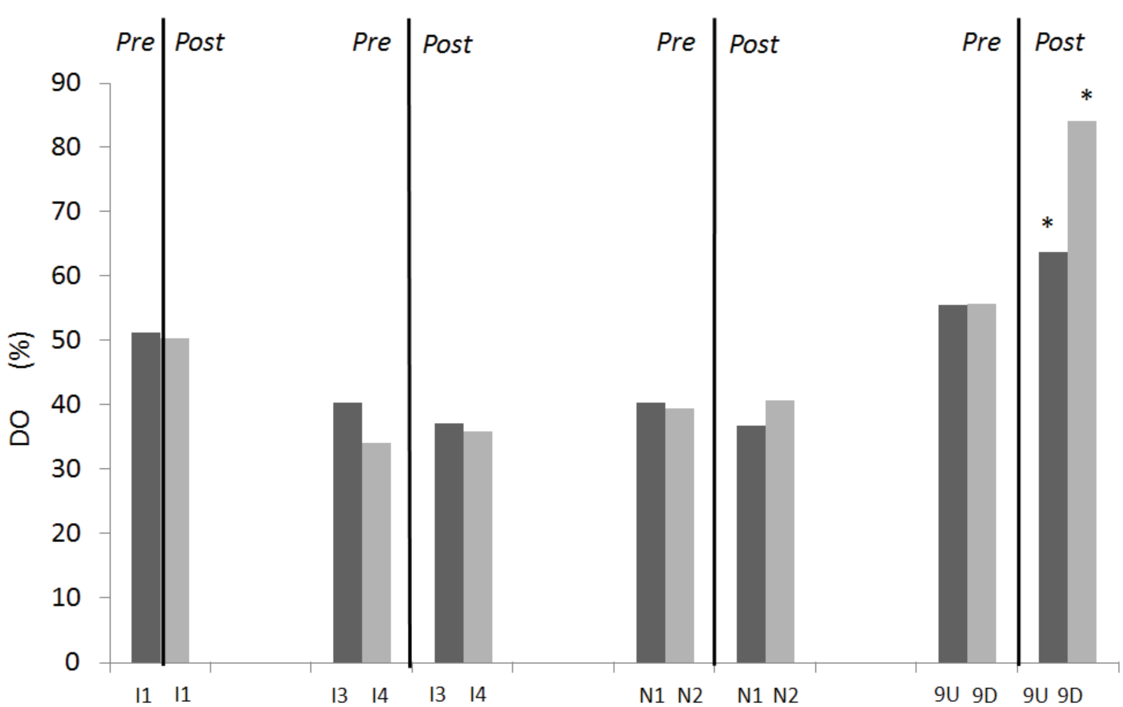

Figure 4—Monthly in-stream dissolved oxygen saturation (%) means at each site, for the pre- and the post-harvest periods. Paired t-tests were conducted on I3-I4, N1-N2, and 9U-9D, while a two sample t-test was used on site I1 to test for significant differences (α=0.05; significance indicated by *).

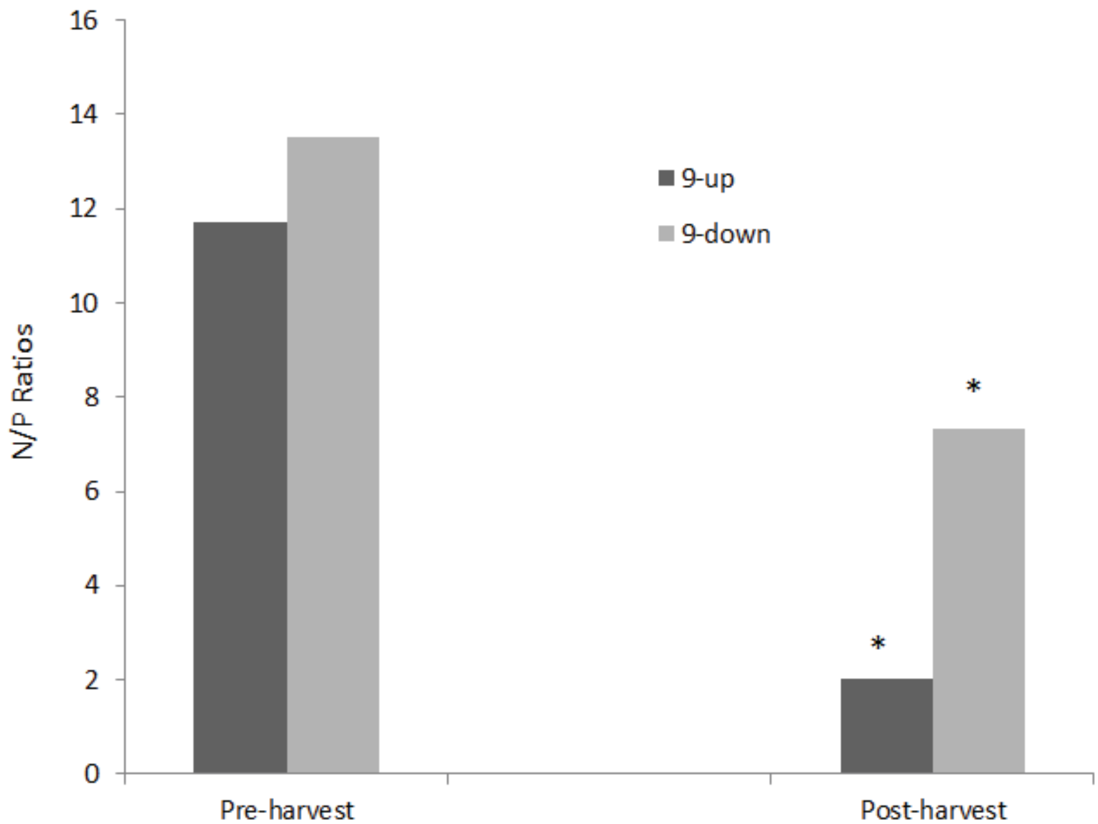

Figure 5—Pre- and post-harvest means of monthly N/P ratios at sites 9-up and 9-down. Paired t-tests were conducted for both time periods to test for differences between the upstream and downstream sites (α=0.05; significance indicated by *).

SUSTAINING *QUERCUS HUMBOLDTII* AND *COLOMBOBALANUS EXCELSA* ON THE COLOMBIAN LANDSCAPE: PRESERVATION OR CONSERVATION – A RESEARCH PERSPECTIVE

Daniel C. Dey, Alejandro A. Royo, Emile S. Gardiner, and Luis Mario Cardenas

ABSTRACT

The Tropical Andes in Colombia is in the top 25 biodiversity hotspots in the world (Myers and others 2000). It has the highest level of species endemism in the world and they comprise 12 percent of the world's species. Humans have lived in the Colombian Andes for over 12,000 years. Population estimates of native peoples at the time of Spanish contact range between 3 to 5 million and about 60 percent of them lived in the Andes (Colmenares 1997, Etter and van Wyngaarden 2000). Today, about 45 million people call Colombia home, and 66 percent of them live in the Andes (Etter and van Wyngaarden 2000). Over the past several thousand years, the Andes region has progressively become a highly fragmented landscape, where only 30 percent or less of the original forest cover remains (Etter 1993, Cavelier and Etter 1995, Armenteras and others 2003, Etter and others 2006). Deforestation and conversion to agricultural land uses have eliminated much of the native ecosystems in the Andes region. Brooks and others (2002) state that the extent of habitat loss is a good predictor of the number of threatened or extinct endemic species because many biologists recognize fragmentation of habitat and its loss as the principal cause of biodiversity loss in the world (Armenteras and others 2003).

In the Colombian Andes, grazing occurs on approximately 42 percent of the land, subsistence, commercial or shifting agriculture occurs on another 20 percent of the land, and the remainder is in forest cover (Etter and others 2006, Aubad and others 2008). In this region, coffee growing is a significant industry, with over 500,000 private landowners producing coffee largely on small ownerships. Conversion of forests to agriculture on steep mountain slopes has caused great concern and a desire to protect the remaining forests for wildlife, water yield and quality, and biodiversity conservation. *Quercus humboldtii* and *Colombobalanus excelsa* are important endemic species throughout this region and they are valued by the people for their high quality timber and fuelwood. Colombia ranks third in fuelwood use in South America, with each family using an average of 5 to 8 tons/yr. Armenteras and others (2003) identified the Andean oak forests as the most threatened ecosystem and a priority for conservation efforts, while Etter and others (2006) stated that they were at an intermediate level of threat and noted that the humid mid-Andean and the humid and sub-humid high-Andean forests were vulnerable to clearing (Etter and others 2006). *Q. humboldtii* is listed as Low Risk-Conservation Depending and *C. excelsa* is Vulnerable in their conservation status (Calderon 1998, Oldfield and Eastwood 2007). Preservation of existing primary forests in national parks, laws that regulate the cutting of *Quercus* spp. on private lands, and reforestation are strategic directions and actions being taken to reverse the loss of forest and reclaim marginal crop fields to forests. The challenge to preserve and conserve healthy and productive native ecosystems and minimize species loss is complicated because the people live by subsistence and local economies based on farming, grazing and forestry and they own 67 percent of the forest land. It will take a coordinated program of preservation and conservation that integrates human communities within a landscape made up of a patchwork of natural and managed ecosystems to achieve the goal of sustainable communities and ecosystems.

Parks and reserves are important for protecting the remaining primary forests. The national park system in Colombia protects forests on about 10 percent of the land base (Wikipedia 2010). Maintenance of forest cover in parks and reserves is assured provided illegal use and deforestation is controlled. What is less certain is the sustainability of the current stocking of *Q. humboldtii* and *C. excelsa* in these forests. Much is unknown of the biology and ecology of these two species, and it is uncertain if their populations are sustainable in national parks and forest preserves. Monitoring is essential to determine if regeneration and subsequent recruitment into the forest overstory is sufficient to sustain these species under current natural disturbance regimes. It is unclear how historic disturbance regimes led to the presence of mature oak in the forest canopy, and how they may differ from factors operating today that regulate forest regeneration and development, or how forest processes will be altered by a

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changing climate. In other regions of the world where oak forests are common, oak dominance is in decline due to altered disturbance regimes that favor other species over oak (Johnson and others 2009).

Conservation on private lands is critical to achieving regional and national goals for sustainable ecosystems and economies. Comprehensive conservation programs would include research and development, education, and economic and marketing components. Management systems and silvicultural practices are needed that promote *Quercus* and *Colombobalanus* in both natural and agroforest environments (Fig. 1). Alternative strategies for the management of these and other valuable tree species are needed that achieve conservation and ecological objectives while providing income and subsistence to landowners on small- to moderate-sized properties. The incorporation of these species in farm and coffee plantation settings using agroforestry practices, or in reforestation of degraded lands has the potential to meet both ecological and social needs of the forests across a large portion of the Colombian landscape. Education is critical for the development of resource and management professionals, and to foster an informed community of landowners and agricultural associations and cooperatives. Markets that bring added value for products that are grown and manufactured using conservation practices are important to encourage landowner adoption of best management practices and participation in regional conservation programs. Conservation of these species and the ecosystems they occur in will require a landscape strategy and approach that integrates a gradient of forest states from agroforests to primary forests in a connected and functional patchwork that maintains ecological integrity in this Andean Region (Fig. 2). It will take strong partnerships between organizations such as Fundación Natura, Cenicafé, universities, governmental agencies, and community organizations such as the regional coffee grower associations working with private landowners to sustain these valued species.

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Figure 1—Forest management and silvicultural systems are needed to sustain *Q. humboldtii* and *C. excelsa* in (A) primary forests, and to improve forest quality and productivity while restoring them in (B) old fields, (C) degraded secondary forests, and (D) over-grazed shrublands. Agroforestry practices are needed that incorporate Q. humboldtii and C. excelsa into (E) silvopastures, (F) living fences, and (G) intercropping plantings with traditional agricultural crops such as shade-grown coffee.

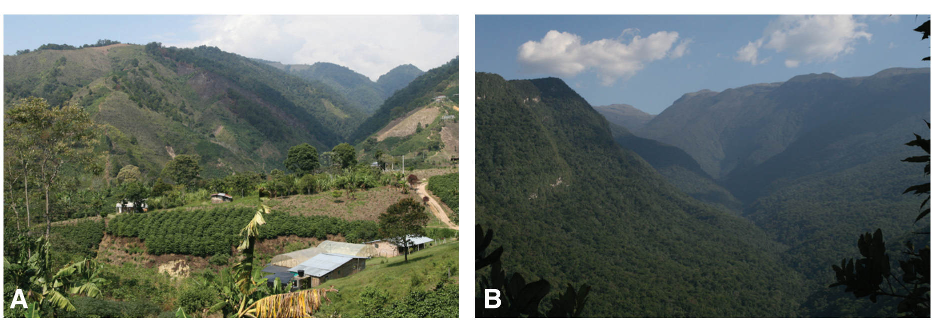

Figure 2—In addition to site-specific conservation practices that promote *Q. humboldtii* and *C. excelsa* in farm and forest, landscape plans are needed that integrate the many varied forest states from (A) agroforest to (B) primary forests spatially on the Andean landscape to meet regional and national conservation and economic goals.

LONGLEAF PINE WOOD AND STRAW YIELDS FROM TWO OLD-FIELD PLANTED SITES IN GEORGIA

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ABSTRACT

Little is known or published concerning longleaf pine's growth rate, or wood and pine straw yields on old-field sites. Two study areas were installed in unthinned longleaf plantations established on former old-fields in Screven and Tift Counties, Georgia to address pine growth and straw yields. Soil series were delineated and replicated plots with three levels of fertilization (control = no fertilizer, a NPK single dose, and a NPK split dose) were imposed at each site. This paper will focus on longleaf pine stand growth and wood yields through age 21-years and pine straw yields through age 23-years. The results indicate that these two old-field longleaf pine stands without fertilization were growing at a rate of 203 cubic feet per acre per year at Tift County site and 221 cubic feet per acre per year at the Screven County site through age 21-years. Mean annual increments for all treatments at both sites were increasing from age 17- through age 21-years. Mean dbh values ranged from 8.8 inches (control at Tift County site) to 9.5 inches (split NPK at the Screven County site) through age 21-years. Mean tree heights through age 21-years ranged from 59.1 feet (single NPK dose at the Screven County site) to 60.8 feet (control and split NPK dose at the Tift County site). Pine straw yields without fertilization averaged 4306 pounds (dry weight) per acre per year from ages 15- through age 23-years at the Screven County site and 3764 pounds per acre (dry weight) at the Tift County site from ages 17- though 23-years. Fertilization did not significantly improve longleaf pine growth parameters during the reported study period. Pine straw yields were significantly improved with fertilization at both sites generally two and three years after application becoming non-significant compared to the control in the fourth year after treatment.

INTRODUCTION AND OBJECTIVES

Approximately 203,500 acres of old-field sites in Georgia have been planted to longleaf pine from 1999 through 2010 (Weaver 2011). Little is known of the upper end of longleaf pine growth rate and wood and pine straw yields on old-field sites. Most old-field sites have a large fertility reserve, essentially no competing hardwoods and good surface soil tilth. Accelerated growth rates for loblolly and slash pine have been noted in Georgia during first 10- to 20-years on these old-field sites. The main objectives of this study on old-field sites were to: (1) determine the growth rate and wood yields of longleaf pine, (2) estimate pine straw yields, and (3) quantify the benefit of fertilization with a single or split application of nitrogen, phosphorus, and potassium. Pre-treatment longleaf pine growth means at the end of the 17th growing season (December 2003, February 2004) and the end of the 21st growing season and pine straw yields through age 23-years are reported in this paper.

MATERIALS AND METHODS

Two study areas were installed in unthinned longleaf plantations established on former old-fields in Screven and Tift Counties, Georgia. Bareroot (replications 1 and 2) and containerized seedlings (replications 3 and 4) were planted at the Screven County site and bareroot seedlings (all replications) were planted at the Tift County site. Both sites were planted at an approximate 6 feet by 12 feet spacing (605 seedlings per acre). The Screven County site was terraced and subsoiled prior to planting, mowed between the rows two times per year for the first five years post plant, and burned four times from age 8-years-old to age 21-years old. The Tift County site was chisel plowed prior to planting then Oust® (DuPont; 75 percent sulfometuron methyl) was sprayed in years one and two post-plant, burned (backing fire, accidentally) in year two, prescribe burned in years five and seven, pruned in year eight, and spot raked starting in year 10. The soil series were delineated by a Natural Resource Conservation Service soil mapper as Blanton (well drained, fine sand Grossarenic Paleudult) and Bonneau (well drained, loamy sand Arenic Paleudult) at the Screven County site and Albany (somewhat poorly drained, sandy Aquic Arenic Paleudult) and Leefield (somewhat poorly drained, loamy sand Arenic Plinthaquic Paleudult) at the Tift County site. Baseline soil (0-6") and foliage samples were collected in December 2003 at the Screven county site and in February 2004 at the Tift county site. Surface soil (0-6 inches) available phosphorus (P) levels averaged 11 lbs/ac (5 to 19 lbs/ac range) and a mean soil pH of 5.8 (5.4 to 6.2 range) at the Screven County site prior to treatments. Surface soil (0-6 inches) available phosphorus (P) levels averaged 18 lbs/ac (5 to 38 lbs/ac range) and a mean soil pH of 4.8 (4.6 to 5.0 range) at the Tift County site prior to treatments. Longleaf pine foliar nitrogen, phosphorus, and potassium concentration means were 1.14 (0.971 to 1.52

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range) percent, 0.10 (0.09 to 0.15 range) percent, and 0.43 (0.29 to 0.57 range) percent, respectively prior to treatments at the Screven County site. Longleaf pine foliar nitrogen (N), phosphorus, and potassium (K) concentration means were 0.91 (0.73 to 1.1 range) percent, 0.095 (0.066 to 0.12 range) percent, and 0.37 (0.32 to 0.42 range) percent, respectively prior to treatments at the Tift County site. Mean surface soil available P levels were above sufficiency (6 to 10 lbs/ac P; Wells et al. 1973) at both locations prior to treatments. Mean longleaf foliar N, P, and K concentrations (Blevins et al. 1996, Dickens and Moorhead 2006) were above sufficiency (0.95, 0.08, and 0.25 to 0.30 percent for longleaf pine, respectively) at the Screven County site and above sufficiency for P and K at the Tift County site but slightly below sufficiency for N prior to treatments.

A randomized complete block experimental design was used at both locations. There were three (Tift County) or four (Screven County site) replications of each treatment per study area. Gross treated (1/4 acre) plots were installed with a 1/10th acre internal permanent measurement plots (IPMP). There were 40 feet of untreated buffer between each plot. Treatments included: (a) control (Control; no fertilization), (b) a full dose of NPK (full NPK; DAP+urea+muriate of potash; 150 N, 50 elemental-P and 50 elemental-K lbs/ac), and (c) a split (half + half) dose of NPK (split NPK; 75 N + 25 elemental-P + 25 elemental-K lbs/ac/application as DAP+urea+muriate of potash) with the first application applied in mid-February 2004 (both full and half dose treatments). The second half dose of the split dose treatment was applied in February 2007 to the split dose plots.

Each living tree in the IPMP was aluminum tree tagged, numbered, and measured for diameter at breast height (dbh; or 4.5 feet above groundline, measured with diameter tapes to nearest 1/10th inch), total height (measured with a Haglof Vertex II Laser Hypsometer), height to base of live crown, and fork or broken top in December 2003 for the Screven County site and February 2004 for the Tift County site prior to treatments, in January 2006, January 2008, and January 2010. Visible stem defects, including a fork or broken top, sweep greater than 3 inches in any 10 feet stem length, ramicorn branch, excessive branching (> 6 branches per linear foot) or branch base diameters greater than 2.5 inches were noted for each tagged tree at each site at the end of the 17th growing season and 23rd growing season. A single glyphosate herbicide with a surfactant was used one-time in mid-summer 2004 on all study area plots to keep the stand clean for straw production. Planted longleaf volume equations from Baldwin and Saucier (1983); log (total tree wood+bark volume) = -2.552214 + 0.99928 log (dbh^2 * total height) where dbh was in inches, height in feet, and volume in cubic feet were used to estimate total volume per tree, total volume per acre, and total volume per acre mean annual increment on these old-field stands. Pine straw (litter layer only collected) yields were estimated in each plot from four 16 square feet angle iron grids annually at the Tift County site and periodically at the Screven County site (as variable operational raking regimes made for unreliable annual pine straw yields). The litter layer from each grid were collected, bagged, field weighed, oven dried for 48 hours at 60^{o} C, dry weighed and converted to dry weight per acre. Stand parameters (trees per acre, dbh, basal area, height, live crown ratio, total volume per tree, and total volume per acre and pine straw yields treatment means for each measurement year at each site were tested for significant differences using Duncan's Multiple Range Test at the five percent alpha level using the SAS® STATS package Version 9.2 (SAS® 2010).

RESULTS

There were no significant treatment differences for longleaf pine growth parameters at the Screven County site (Table 1 and 3) or the Tift County site (Table 2 and 4) during the study period. Mean trees per acre ranged from 303 to 360 at age 17-years (Table 1 and 2). In unfertilized plots through age 21-years, mean trees per acre were 303 at both the Screven and Tift County sites, approximately one-half of the original planting stocking level. Mean diameters at 4.5 feet above groundline (dbh) ranged from 7.96 inches to 8.47 inches at age 17-years and 8.80 to 9.52 inches by age 21-years (Table 1 and 2). Basal areas at age 17-years ranged from 113 to 127 square feet per acre and from 125 to 146 square feet per acre by age 21-years (Table 1 and 2). Estimated longleaf pine total volume (stemwood+bark) yields ranged from 3096 (split NPK at the Tift County site) to 3845 cubic feet per acre (full NPK at the Tift County site) and from 4261 (control at the Tift County site) to 5245 cubic feet per acre (full NPK at the Tift County site) by age 21-years (Table 2 and 4). Mean annual increments through age 17-years ranged from 186 (control at the Tift County site) to 226 cubic feet per acre per year (full NPK at the Tift County site) at age 17-years and 203 (control at the Tift County site) to 250 cubic feet per acre per year (full NPK at the Tift County site) by age 21-years (Table 3 and 4).

Pine straw yields without fertilization averaged 4308 pounds per acre per year at the Screven County site and 3764 pounds per acre per year at the Tift County site (Table 5 and 6). Pine straw yields were significantly increased with fertilization by age 19-years, two years after the initial split NPK treatment and full NPK treatment (applied one-time) at the Screven County site (4878, 6248, and 6459 pounds per acre for the control, ½+½ NPK, and full NPK treatment, respectively; Table 5). The mean pine straw yields from the split NPK treatment tree plots were significantly greater than the control at age 20- and 23-years (3811 compared to 4715 pounds per acre and 3760 compared to 4423 pounds per acre for the control and split NPK treatment at age 20- and 23-years, respectively; Table 5). The mean pine straw yields from the full (one-time) NPK treatment were not significantly greater than the control at age 20- or 23-years at the Screven County site. Mean pine straw yields from the split NPK treatment and full NPK treatment were approximately 550 and 380 pounds per acre year greater than the control, respectively, from age 15- through 23-years at the Screven County site (Table 5). Pine straw yields were significantly increased with the full NPK treatment compared to the control (5560 and 4591 pounds per acre, respectively) at age 19-years, two years after treatment at the Tift County site and at age 20-years (4613 and 3443 pounds per acre, respectively, Table 6). Pine straw yields from the full NPK treatment plot trees were not significantly different than the control at ages 21-, 22- and 23-years at the Tift County site (four, five, and six years after the one-time application; Table 6). Pine straw yields from the split NPK treatment plot trees were significantly greater than the control at age 20- (5311 versus 3443 pounds per acre), 21- (3395 versus 2295 pounds per acre), and 22-years (4658 versus 4199 pounds per acre) but not significantly different at age 23-years (Table 6) at the Tift County site. Mean pine straw yields from the split NPK treatment and full NPK treatment were approximately 500 and 330 pounds per acre year greater than the control, respectively, from age 17- through 23-years at the Tift County site (Table 6).

Percent defective trees; trees with a visible stem canker, fork or broken top below 25 feet (one and a half logs with a one foot stump allowance), stem sweep greater than three inches per 10 feet run, or excessive branching (>6 per linear foot), ramicorn, or large (> 2.5 inches branch base diameter) branches starting below 25 feet were noted at each study site across all plots at age 17- and age 21-years. These tallied defective trees, based on our ocular observations, would not make a product class jump from pulpwood into the higher valued product classes of chip-n-saw, sawtimber, or poles. Percent defective longleaf pines at age 21-years at the Screven County site were estimated to be 50 percent in the control plots (42 to 59 percent range), 37 percent in the split NPK treatment plots (26 to 43 percent range), and 49 percent in the full NPK plots (43 to 59 percent range). Percent defective longleaf pines at age 21-years at the Tift County site were estimated to be 43 percent in the control plots (36 to 50 percent range), 47 percent in the split NPK treatment plots (38 to 50 percent range), and 47 percent in the full NPK plots (43 to 52 percent range). With an overall defect average of 46 percent at both study areas through age 21-years and an average of 294 and 321 trees per acre at the Screven and Tift County sites, this equates to 135 and 148 final crop trees per acre, respectively, if all defective trees are removed in the first thinning.

DISCUSSION AND CONCLUSIONS

The estimated growth rates of 203 and 221 cubic feet per acre per through age 21-years, without fertilization, in these two old-field longleaf pine stands is greater than the 164 cubic feet per acre per year growth rate for the high site index longleaf through age 20-years reported by Goelz and Leduc (2001). The longleaf pine growth parameter responses to the ½+½ NPK or full NPK fertilizer treatments were not significantly greater than the control over the four year study period. Single dose fertilization (N+P) studies on loblolly pine indicate that fertilization response typically peaks four years after application (Hynynen et al. 2000), yet in these studies on longleaf pine the benefit to fertilization was not realized through four years post-treatment. The lack of longleaf pine growth response to fertilization is most likely due to the fact that these two sites were former old-fields in annual crops with moderate to high residual nutrient availability. There was a significant pine straw response to the fertilizer treatments usually occurring two years after application and lasting into year three or four post treatment. The estimated percent defective trees in each study area averaged 46 percent after 21-years may be due to a number of factors; no genetically improved longleaf seedlings available for planting for these two study sites in 1986, the original rectangular spacing (6 feet by 12 feet; with more and larger branches growing into the rows compared to the branches growing in between the trees above 16 feet), the relatively low stocking by age 21-years for longleaf pine, and the fast growth rate. The number and intensity of fires in each stand may have aided in lower (first ½ log or below 8 to 9 feet) stem pruning but by age 21-years most of first ½ to full log branches (number and size) were not the issue in a tree being defective.

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Table 1—Trees per acre, diameter at breast height (dbh or 4.5 feet above groundline), basal area, and height for December 1986 unthinned, old-field planted longleaf pine plots at the Screven County, Georgia site (Bonneau and Blanton soils) through age 17- and 21-years-old

	Trees per acre		dbh (inches)		Basal area (ft^2/ac)		Height (feet)	
Treatment	Age (years)							
	17	21	17	21	17	21	17	21
Control	325	303	8.37	9.24	121	135	50.4	60.1
Split NPK	303	273	8.47	9.52	114	125	49.9	59.9
Full NPK	328	305	8.32	9.24	120	136	49.3	59.1

Treatment means followed by a different letter within a column are significantly different using Duncan's Multiple Range Test at the five percent alpha level. Treatments: Control = no fertilization, split NPK = 75 N, 25 elemental-P and 25 elemental-K lbs/ac/application, applied February 2004 and again in February 2007, and full NPK= 150 N, 50 elemental-P and 50 elemental-K lbs/ac applied one-time February 2004.

Table 2—Trees per acre, diameter at breast height (dbh or 4.5 feet above groundline), basal area, and height for December 1986 unthinned, old-field planted longleaf pine plots at the Tift County, Georgia site (Albany and Leefield soils) through age 17- and 21-years-old

	Trees per acre		dbh (inches)		Basal area (ft^2/ac)		Height (feet)	
Treatment	Age (years)							
	17	21	17	21	17	21	17	21
Control	320	303	7.97	8.80	114	126	52.1	60.8
Split NPK	317	310	7.96	8.84	113	129	51.6	60.8
Full NPK	360	350	8.26	9.09	127	146	52.4	60.7

Treatment means followed by a different letter within a column are significantly different using Duncan's Multiple Range Test at the five percent alpha level. Treatments: Control = no fertilization, split NPK = 75 N, 25 elemental-P and 25 elemental-K lbs/ac/application, applied February 2004 and again in February 2007, and full NPK= 150 N, 50 elemental-P and 50 elemental-K lbs/ac applied one-time February 2004.

Table 3—Live crown ratio, volume per tree, and volume per acre for December 1986 unthinned, old-field planted longleaf pine plots at the Screven County, Georgia site (Bonneau and Blanton soils) through age 17- and 21-years-old

	Live crown ratio (percent)		Total volume per tree (ft^3)		Total volume per acre (ft^3)		Mean annual increment: MAI (ft^3/ac/yr)	
Treatment	Age (years)							
	17	21	17	21	17	21	17	21
Control	43.0	39.7	10.5	15.3	3428	4643	202	221
Split NPK	45.1	43.4	10.7	16.2	3240	4426	191	211
Full NPK	43.6	39.8	10.2	15.1	3344	4596	197	219

Treatment means followed by a different letter within a column are significantly different using Duncan's Multiple Range Test at the five percent alpha level (MAI treatments were not tested). Treatments: Control = no fertilization, split NPK = 75 N, 25 elemental-P and 25 elemental-K lbs/ac/application, applied February 2004 and again in February 2007, and full NPK= 150 N, 50 elemental-P and 50 elemental-K lbs/ac applied one-time February 2004.

Table 4—Live crown ratio, total volume per tree, total volume per acre, and mean annual increment for December 1986 unthinned, old-field planted longleaf pine plots at the Tift County, Georgia site (Albany and Leefield soils) through age 17- and 21-years-old

	Live crown ratio (percent)		Total volume per tree (ft^3)		Total volume per acre (ft^3)		Mean annual increment: MAI (ft^3/ac/yr)	
Treatment	---------- Age (years) ----------							
	17	21	17	21	17	21	17	21
Control	47.5	44.7	9.89	14.1	3164	4261	186	203
Split NPK	49.6	41.9	9.77	14.2	3096	4399	182	210
Full NPK	50.2	41.8	10.7	15.0	3845	5243	226	250

Treatment means followed by a different letter within a column are significantly different using Duncan's Multiple Range Test at the five percent alpha level (MAI treatments were not tested). Treatments: Control = no fertilization, split NPK = 75 N, 25 elemental-P and 25 elemental-K lbs/ac/application, applied February 2004 and again in February 2007, and full NPK= 150 N, 50 elemental-P and 50 elemental-K lbs/ac applied one-time February 2004.

Table 5—Pine straw yields for December 1986 unthinned, old-field planted longleaf pine plots at the Screven County, Georgia site from age 15- through age 23-years

	---------- Age (years) ----------					
Treatment	15	18	19	20	23	Mean yield
	---------- Pounds per acre (dry weight) ----------					(lbs/ac/yr)
Control	4119	4971	4878 b	3811 b	3760 b	4308
Split NPK	3768	5172	6248 a	4715 a	4423 a	4865
Full NPK	3634	5080	6459 a	4401 ab	3781 b	4689

Treatment means followed by a different letter within a column are significantly different using Duncan's Multiple Range Test at the five percent alpha level. Mean yields were not tested. Treatments: Control = no fertilization, split NPK = 75 N, 25 elemental-P and 25 elemental-K lbs/ac/application, applied February 2004 and again in February 2007, and full NPK= 150 N, 50 elemental-P and 50 elemental-K lbs/ac applied one-time February 2004.

Table 6—Pine straw yields for December 1986 unthinned, old-field planted longleaf pine plots at the Tift County, Georgia site from age 17- through age 23-years

	---------- Age (years) ----------							
Treatment	17	18	19	20	21	22	23	Mean yield
	---------- Pounds per acre (dry weight) ----------							(lbs/ac/yr)
Control	3503	4608	4591 b	3443 b	2295 b	4199 b	3712	3764
Split NPK	3262	4755	5150 ab	5311 a	3395 a	4658 a	3336	4267
Full NPK	3324	4754	5566 a	4613 a	2800 ab	4216 b	3425	4100

Treatment means followed by a different letter within a column are significantly different using Duncan's Multiple Range Test at the five percent alpha level. Mean yields were not tested. Treatments: Control = no fertilization, split NPK = 75 N, 25 elemental-P and 25 elemental-K lbs/ac/application, applied February 2004 and again in February 2007, and full NPK= 150 N, 50 elemental-P and 50 elemental-K lbs/ac applied one-time February 2004.

CHARACTERIZATION OF YIELDS FOR PINUS TAEDA GENOTYPES AT THE HALF-SIB, FULL-SIB, AND VARIETAL LEVELS OF GENETIC IMPROVEMENT AT TWO PLANTING DENSITIES AT AGE 5 IN THE UPPER COASTALPLAIN OF GEORGIA

Derek Dougherty, Michael Kane, Robert Teskey, Richard Daniels, and Jeff Wright

Seedling deployment options for the establishment of operational *Pinus taeda* plantations in the Southeastern U.S. now include half-sib families, full-sib crosses, and varietals. In 2005, a study to evaluate the effects of genotype and density on yield and quality was established on a moderately well-drained upland site in the Upper Coastal Plain in Marion County, GA. Establishment culture intensity was operational and included chemical and mechanical site preparation and herbaceous weed control. The genotypes used in the trial included four varietal entries (C32 and C93 referred to as "high yielding" below, and C36 and C40 referred to a "low-yielding"), three full-sib genotypes (M2, M15, M16), and one well-known and widely-planted half-sib family (OP3). The density treatment included a 388 tree per acre planting level and a 518 tree per acre planting level. The trial design is a split-block, randomized complete block. Tree measurements were completed at the end of the 5th growing season. Genotype and density treatment mean differences were evaluated for statistical significance for traits including survival, DBH (diameter at 4.5 ft), height, and mean tree volume, at the alpha level of 0.01. These means and their relative significance are summarized in Table 1.

Survival was not significantly different for either the density or genotype treatments. Differences between means for all other measured traits were statistically significant for both treatments. There was not a significant genotype by density interaction for any of these traits.

Mean DBH of the low density plots was significantly greater than that of the higher density plots (Table 1). Mean DBH of the high yielding clones C93 and C32, the full-sib crosses M2, M15, and M16, and the open-pollinated entry OP3 were not significantly different at age 5. Mean DBH of these genotypes was significantly greater than those of the low-yielding varieties C36 and C40. At low density, M15 and C93 had the greatest mean DBH at 4.5 inches and 4.4 inches respectively. In the high-density plots, M15 and M16 had the greatest diameters at 4.1 inches and 4.3 inches respectively.

Mean height was one foot greater on the low density than the high density plots. The mean height of Variety C93 at 24.41 feet was significantly greater than all other genotypes (Table 1, Figure 1).

Mean tree volume was greater on low density than high density plots. M16 had the greatest volume but was not significantly different than that of C93, M2, or M15. Variety C93 and cross M16 were significantly different than the elite half-sib family OP3. Varieties C36 and C40 were significantly lower than OP3.

Results suggest that the individual genotype is more important that the level of genetic improvement when considering mean yield characteristics, i.e. some open pollinated seedlings may have higher yield characteristics than some varieties. However, in general, for the genetic entries compared at the Marion County, GA location, varieties C93 and C32

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and mass-control-pollinated crosses M2, M15, and M16 performed very well and showed a statistically significant improvement in yield through 5 years of growth as compared to historically elite and widely planted half-sib family OP3.

The statistical difference in mean height by density at age 5 is worth highlighting. The difference observed suggests that even at this moderate density contrast (388 versus 518) but at a high operational level of culture, differences in height may have occurred prior to age 5. The low density treatments demonstrating greater heights at this young age may be attributed to the existence of larger crowns with more potential for light interception and resource storage in fast growing trees.

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Table 1—Loblolly pine mean DBH, height, tree volume and proportion of surviving trees by density and genotype treatment at age 5 in the Upper Coastal Plain of Georgia. DBH in inches, total height in feet, and mean tree volume in cubic feet; For a particular treatment and attribute, means followed by the same letter are not significant at alpha = 0.01

	Density Treatment		Genotype Treatment							
			Variety				Mass-control pollinated			OP
Factor	Low	High	C93	C32	C40	C36	M2	M16	M15	OP3
DBH	4.09a	3.72b	4.14a	3.99a	3.48b	2.82c	4.16a	4.37a	4.27a	4.01a
Height	21.52a	20.51b	24.41a	22.26bc	18.48d	15.80e	21.97bc	22.64b	21.74bc	20.82c
Volume	1.16a	0.94b	1.26ab	1.10bc	0.76d	0.46e	1.19abc	1.34a	1.23abc	1.07c
Survival	0.94a	0.94a	0.96a	0.95a	0.89a	0.94a	0.95a	0.94a	0.91a	0.94a

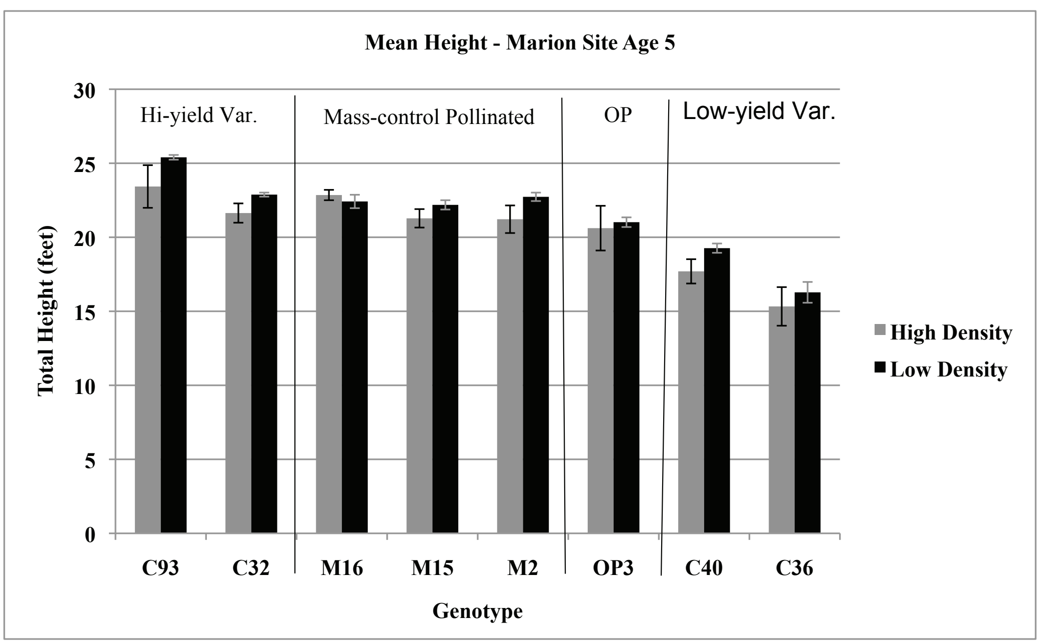

Figure 1—Loblolly pine mean height at age 5 by genotype and planting density in the Upper Coastal Plain of Georgia. Error bars are provided to represent the standard error for each mean.

PINE STRAW PRODUCTION: FROM FOREST TO FRONT YARD

Janice F. Dyer, Rebecca J. Barlow, John S. Kush, and John C. Gilbert

ABSTRACT

Southern forestry may be undergoing a paradigm shift in which timber production is not necessarily the major reason for owning forested land. However, there remains interest in generating income from the land and landowners are exploring alternatives, including agroforestry practices and production of non-timber forest products (NTFPs). One such alternative more recent to the Southeast is collecting and selling pine straw for use in urban landscapes. It has been shown that longleaf pine straw will bring the landowner more money than straw from other southern pine species. The Regional Longleaf Growth Study will be utilized to provide information on the potential for pine straw production based on overstory density, age class, and site quality. This information will be combined with results of surveys of pine straw producers and buyers in Alabama to provide insight into pine straw markets in the state –from the forest to the front yard.

INTRODUCTION

Markets for timber are disappearing as demand for forest products declines and manufacturing facilities are moved overseas. Recent decades have witnessed forest industry consolidation (Bliss et al. 2010), transfer and subdivision of large amounts of forest acreage (Wear and Greis 2002), and the decline of long-term ownership (Clutter et al. 2007). Owners of small tracts are increasingly cut out of traditional markets. Landowners seek new ways to generate income from their forestland, while maintaining ecologically diverse, sustainable forest systems. Harvesting of pine straw is one option available to forestland owners looking to get short-term income while allowing timber to remain "on the stump." Harvesting pine straw is considered a form of "forest farming," one category of agroforestry (Hill and Buck 2000). Pine straw is a byproduct of a natural biological process – pine trees shed their needles regularly. Aside from being decorative, pine straw provides many mulching benefits, which is why it has become a valuable commodity among landscapers across the country. Pine needles interlock and stay in place while protecting against surface erosion, moderating soil temperature and moisture, and inhibiting growth of weeds (Pote et al. 2004).

Pine straw is considered a non-timber forest product (NTFP) and provides forestland owners with short-term income while allowing timber to remain standing. Through proper planning and development of a management regime, landowners can harvest straw without jeopardizing the growth potential of their pine trees. Pine straw yields usually peak well before stands reach rotation age (Gholz et al. 1985), and many authors recommend beginning harvesting operations as early as 7 or 8 years old (Duryea 2000, Morris et al. 1992, Taylor and Foster 2004). This provides an opportunity for landowners to secure regular, short-term income early in a rotation, prior to any thinning that may occur. Extra income can be used by landowners to cover living expenses, property taxes (thus, continued ownership), or to further invest in land management.

Taylor and Foster (2004) state that pine straw can be harvested on marginal or poor quality forest acreage or sites unsuitable for wood fiber production. The authors estimate that (in East Texas) 25- to 50-pound bales of pine straw sell (wholesale) for $5 to $10. Landowners who chose to lease their land for pine straw operations are typically paid on either a per-bale basis or a per-acre basis. One source states that if paid on a per-bale basis, landowners can expect to receive approximately $0.10 to $0.25 per bale (Taylor and Foster 2004); another source cites higher estimates of $0.50 to $0.65 (Cassanova 2007). If paid on a per-acre basis, landowners get approximately $12.50 to $30 per acre (Taylor and Foster 2004). However, higher-quality straw (especially longleaf pine straw) can yield much higher rates.

Figure 1 shows the farm gate value for pine straw in Georgia starting in 2000 (the first year the University of Georgia Center for Agribusiness and Economic Development compiled data for pine straw as a separate commodity). In 2000, pine straw was valued at $15,563,253 and accounted for 2.1 percent of the forest products market (Doherty et al. 2001). Boatright and McKissick (2010) estimate that in 2009, pine straw contributed more than $81 million to Georgia's economy (up 80.9 percent from the 2000 commodity figures), and accounted for more than 16 percent of the forest products market.

The top pine straw producing county in Georgia (Laurens County) harvests straw from about 55,000 acres at an average per-acre value of $125, totaling $6,875,000 for 2009

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(Boatright and McKissick 2010). For the most part, pine straw is harvested from privately-owned property. Alabama ranks number two in the country in terms of the percent of forestland owned by non-industrial private landowners – second only to Georgia. Alabama, Georgia, Florida and Mississippi contain more than half of the area of pine plantations in the South. In 1995, Alabama ranked third in the area of pine plantations on private land, but is expected to surpass Florida and become second by 2040 (Wear and Greis 2002). It is difficult to estimate pine straw harvests for Alabama – yields are not reported in the state's Agricultural Statistics. Yet, despite the high potential for pine straw production in the state's many pine plantations, the market is not well developed.

Anecdotal evidence and unpublished data suggest that buyers in Alabama (e.g. garden centers, landscapers, and nurseries) often purchase pine straw from more than 200 miles away, usually from Florida or southwest Georgia. Research of alternative forest management regimes provides insight to why landowners are not engaging in such practices. Workman et al. (2003) cite poor market development and inadequate education of the public and of land use professionals as constraints to agroforestry development (including forest farming). Access and distance to markets is an important factor in the successful implementation of alternative forestry systems (Hauff 1998).

In a mail survey conducted by Workman et al. (2003), 67 percent of landowners in Alabama and Florida were familiar with non-timber forest products, but only 18 percent of Alabama landowners engage in forest farming. More than 40 percent of Alabama landowners expressed interest in learning about forest farming and production of non-timber forest products. When asked about benefits of agroforestry regimes, Alabama landowners rank wildlife habitat, soil conservation, and aesthetic value as the most important potential benefits. Top rated obstacles among respondents were lack of equipment, component competition, lack of land area, and lack of demonstrations. Land use professionals in Alabama and Florida cite lack of familiarity with the practices and lack of demonstrations as obstacles to agroforestry (Workman et al. 2003).

Workman et al.'s (2003) findings provide a starting point for the proposed research project. Yet, many questions remain regarding the 40 percent of Alabama landowners who expressed interest in NTFPs. Information is needed about their ownership objectives, current management practices, environmental concerns, market awareness, and interest in harvesting pine straw. There is also a need for information about the pine straw market and consumer demands.

This study aims to expand upon the work of others and develop a clearer picture of the pine straw market in Alabama and the potential for landowners to engage in that market and better meet market demands. The results of this study can help identify ways outreach programming can meet landowner needs while boosting the pine straw production market. This paper represents a first step in answering questions about the potential for pine straw as a commercial non-timber forest product in Alabama. Along with presenting three major project objectives, we share preliminary results from pine needle yield data (Objective 1) and from a mail survey of pine straw buyers located in six metro regions of Alabama (Objective 2).

PROJECT OBJECTIVES

Objective 1: Analyze pine straw yield data collected as part of the Regional Longleaf Growth Study.

The goal of Objective 1 is to develop a biological framework within which the remaining components of the study can be conducted. The information collected and generated through tasks associated with Objective 1 will be a quantitative assessment of the biologic potential of longleaf pine forests, based on various stand characteristics. This information is crucial to knowing production potential and, therefore, market potential of longleaf pine straw in the Southeast. Research questions to be addressed in Objective 1 include: What variables show strong correlations to higher needle fall? How do interactions of different site characteristics impact pine straw production? What stand characteristics appear to have biggest impact on pine straw production?

Several tasks under Objective 1 have been completed. The first task was to obtain data, including trees per acre, basal area, site indices, stand locations (by county), and needle fall by weight, for plots throughout the Southeastern United States. These data come from the Regional Longleaf Growth Study, or RLGS (Kush et al. 1987). In the mid-1960s, the U.S. Forest Service established this study to track growth and mortality of naturally-regenerated, even-aged longleaf pine (*Pinus palustris*) stands in five Southeastern States (Mississippi, Alabama, Georgia, Florida, and North Carolina). The study, now in its 45-year re-measurement, includes collection of pine straw yield data (needle fall) on more than 200 plots. Figure 2 shows the locations of pine straw data collection by county. After obtaining these data, the information was organized, and means for plots, years, and months were generated. Classes were defined for site index, age, basal area, and density (classes will be ranges of the number of trees per acre based on square tree spacings). Project personnel will test for correlations between the independent variables and the dependent variable (pine straw yield), as well as run multiple regressions. An alpha level of 0.05 will be used to determine statistical significance.

Objective 2: Determine demands and preferences of pine straw consumers.

The goal of Objective 2 is to assess the current pine straw market in Alabama in terms of volume demand and characteristic preferences. The information collected through tasks associated with this objective (including a mail survey of companies) will be used to help outreach professionals know what pine straw producers and retailers can expect as they enter the market. Included in the tasks will be an assessment of quality preferences of landscapers, contractors, and retailers, as well as consumer willingness to pay (WTP) for pine straw. With this knowledge, outreach professionals can help prepare landowners for potential market-related challenges and inform them of management practices that may increase product quality and efficiency of pine straw operations. Research questions to be addressed in Objective 2 include: How much demand is there for pine straw? Are there preferences regarding species, bale shape, or bale binding? How important are certain quality characteristics, such as cleanliness, needle length, or location or timing of harvesting? How much do wholesale buyers and retail consumers pay for pine straw? Do buyers receive volume discounts? How much do retailers or suppliers sell pine straw for? How far are sellers willing to travel? Does demand fluctuate by month/season?

As with first objective, several tasks associated with Objective 2 have been completed. The first task was to review literature related to pine straw markets, in particular reports on markets in the Southeastern United States. There is limited information available, however, what has been published proved helpful when conducting the second task: developing a questionnaire aimed at assessing volume demand, seasonality, and market structure of pine straw as well as characteristic preferences of buyers. This mail survey was administered in Fall 2010 using Dillman's (2000) Tailored Design Method (TDM). TDM calls for four mailings (a prenotice letter, a first-round survey, a follow-up postcard, and a second-round survey). The survey was sent to 198 retailers, landscapers, lawn maintenance specialists, landscape suppliers, and nurseries in six metropolitan regions in Alabama. These types of businesses buy and sell pine straw. Owners and managers of such companies can provide insight to the pine straw market and identify consumer preferences, while providing data on sales volume and prices. Those selected for the study have operations in six metropolitan regions in Alabama (Huntsville/Madison, Birmingham, Montgomery, Mobile, Tuscaloosa, and Dothan). These regions were selected because they are in the top ten metro regions of the State and are geographically diverse.

Names and addresses for survey subjects were selected from a list provided by the executive director of the Alabama Nursery and Landscaper Association (ALNLA). Additional names and addresses were selected from publicly-available listings of businesses (such as the Yellow Pages). As completed surveys were received, responses were coded. Predictive Analytics Software (PASW) was used to generate descriptive statistics and will be used to analyze the data and observe statistically significant relationships between variables. Tests will also be run to check for differences among regions and respondent type (e.g. retailers, landscape contractor). A alpha level of 0.05 will be used to determine statistical significance.

Objective 3: Assess willingness of Alabama forestland owners to establish pine straw harvesting operations.

The goal of Objective 3 is to gauge the potential for higher involvement of Alabama forestland owners in a pine straw market. Mail survey results will be used to assess landowner interest and knowledge of agroforestry systems and, more specifically, production of non-timber forest products (NTFPs). Those whose lands do produce pine straw will be asked willingness to accept (WTA) questions in order to determine an approximate expected price range based on various factors (such as respondent location and pine species). This information is vital to developing programming geared toward expanding market opportunities. Research questions to be addressed in Objective 3 include: What factors are important to non-industrial private forestland (NIPF) owners when making management decisions about forestland? How interested are Alabama forestland owners in harvesting pine straw? For what reasons would forestland owners engage in agroforestry practices? Why might they choose not to?

Many private landowners in Alabama own and manage their forests to fulfill non-economic objectives (Zhou 2010). However, ownership objectives often correlate with tract size – Zhou (2010) reports that large-scale landowners in Alabama are more interested in timber production. This project will test several hypotheses regarding willingness of forestland owners to harvest pine straw and factors in that willingness, including tract size, species, and current management practices. Pine straw holds potential even for those for whom timber is not the primary ownership objective. Pine straw operations require a clean understory, meaning they can complement plans already managing for aesthetics.

For Objective 3, only initial tasks have been completed thus far and no preliminary results are available. The first task associated with the objective was to review literature related to private forestland owners and willingness to engage in alternative practices and markets. Based on that information, the second task was to develop a questionnaire aimed at understanding landowner management practices, ownership objectives, awareness of – and interest in – agroforestry practices (including production of non-timber forest products), perceived costs and benefits of such practices, and needs for technical assistance or incentive programs. Again, Dillman's Tailored Design Method will be used to conduct the survey, which will be sent to owners of forestland in six counties in Alabama (Jackson, Shelby, Autauga, Baldwin, Houston, and Pickens). These counties were chosen because of their close proximity to the metropolitan areas selected for the survey administered as part of Objective 2. Survey questions will be designed to elicit information that will provide insight to the potential for forestland owners in the region to meet the market demands of pine straw buyers in the adjacent urban area. Recipient names have been collected from publicly-available tax assessment records.

Once surveys are received and all responses coded and entered into a spreadsheet, statistical analyses will be performed to identify (1) trends among Alabama forestland owners, (2) correlations between independent variables, and (3) causal relationships between landowner or site characteristics and willingness to engage in production of NTFPs (including pine straw). An alpha level of 0.05 will be used to determine statistical significance. The primary dependent variable will be landowner interest in harvesting pine straw from their land.

PRELIMINARY RESULTS

OBJECTIVE 1

Table 1 displays descriptives of the longleaf stands and pine needle yield data generated through the RLGS. Plots were measured monthly with an average of 38 recordings between 1993 and 1997. All data were recorded in metric units then later converted to English. On average, stands were 51 years old with approximately 551 trees per acre. Basal area averaged 80 square feet per acre and site index averaged 70 feet, with a base age of 50. Mean needle fall was 3,494 pounds per acre per year. This amounts to an average of 175 bales per acre per year. This is based on 20-pound green-weight bales.

Figure 3 shows mean pine straw yield (in green bales per acre per year) by basal area class at various age classes. As to be expected, as basal area increases, so too does pine straw yield. However, once basal area reaches a certain point (this point appears to be about 120 square feet per acre when looking at 30-square-feet increments), younger stands with lower basal area produce more pine straw than older stands with higher basal area.

Figure 4 shows mean pine straw yield (in green bales per acre per year) by tree density class at various site index classes. At lower densities, site index does not appear strongly correlated to pine straw yield. In contrast, as density increases, stands with higher site indices yielded much higher amounts of pine straw.

Further analyses will be conducted using the data, including running multiple regressions with pine straw yield as the dependent variable. A resulting regression equation can be used to make estimations of pine straw yield using known independent variables, such as basal area, stand age, and site index.

OBJECTIVE 2

Wolfe et al. (2005) examine pine straw characteristic preferences among buyers of pine straw; however, their study was limited in size (29 respondents, only 20 of whom use pine straw) and geographic scope (within a 60-mile radius of Eufaula, Alabama). The strongest characteristic preference among respondents was that pine straw be free of sticks and cones (90 percent), followed by free of leaves (75 percent). Findings such as these have implications for landowners, who are expected to maintain clean, flat stands with little herbaceous material (Taylor and Foster 2004). The main research method employed thus far to achieve Objective 2 of the research project was a mail survey administered in Fall 2010. The survey was designed to elicit kinds of information similar to that found in Wolfe et al. (2005), but with more detail and the ability to test for differences by region of the state and buyer type. Questionnaires were sent to 198 recipients located in six metro regions of Alabama. A response rate of 42 percent was attained.

An analysis of the pine straw market can help answer questions about whether there is room for more producers to enter the market and whether forestland owners would benefit from developing management regimes geared toward pine straw production and harvesting. Information collected through this survey on product preferences and market demands can be used by pine straw producers who may be interested in expanding operations or need guidance determining pricing schedule or marketing channels. What follows are some preliminary findings from the survey mailed to pine straw buyers.

The majority of respondents were landscape contractors (37 percent), followed by retailers (29 percent), then lawn maintenance specialists (17 percent). The remaining respondents were categorized as "other" or were a combination of the previous buyer types. Respondents were asked what species of pine straw they usually purchase (responses were not mutually exclusive). Approximately 43 percent of the respondents purchase longleaf straw, about 38 percent purchase slash, and about a fourth buy loblolly. Eighteen percent of respondents said they do not know what kind of pine straw they buy. Respondents were also asked to rank each species in terms of preference with 1=most desired, 2=second most desired, and 3=least desired. There was a strong preference for longleaf (mean rating of 1.20). In second was loblolly (2.24), closely followed by slash (2.29). Approximately 18 percent had no preference, which is not surprising given that 18 percent didn't know what species of pine straw they are purchasing. This suggests, however, that those who are familiar with the three different species have preferences.

Table 2 shows the mean number of bales of pine straw purchased by respondents, both on an annual basis and at a single time. On average, respondents are buying more than 8,000 square bales per year and about 600 square bales at a single time. More than half of the respondents pay between $2.50 and $3.50 per square bale.

Respondents were asked to estimate the distance between the origin (i.e. the forest) of the pine straw they purchase and their place of business. More than one-fourth of the respondents do not know where their pine straw is coming from. Approximately one-third of respondents are buying their pine straw from more than 150 miles away. Several respondents wrote in responses, saying they get their straw from southwest Georgia or the Florida panhandle.

Respondents were asked to rank each month of the year in terms of seasonality as a buyer of pine straw, with 1=busiest to 4=least busy. Results revealed that the busiest months are in spring (March, April, and May) while the least busy months are in winter (December, January, and February). These findings are interesting to note because most harvesting occurs around the time when (or shortly after) needle fall is highest – typically in September, October, and November. Therefore, straw is frequently harvested a full six months before demand peaks.

Respondents were also asked to express their preferences in terms of bale shape, binding, and method used to bale pine straw. Seventy-seven percent of respondents prefer square bales, 13 percent prefer round bales, and 10 percent expressed "no preference" for either bale shape. When it came to bale binding, there was a strong preference for bales bound with twine – 85 percent. Seven percent preferred bales bound with wire and eight percent expressed "no preference." Wolfe et al. (2005) found that buyers had a preference for hand-baled pine straw because of ease of application. However, our respondents appeared to feel differently – 53 percent preferred machine-baled pine straw. Only 20 percent expressed a preference for straw baled by hand. Approximately 27 percent stated "no preference" when it came to baling method.

Finally, respondents were given a list of pine straw characteristics and asked to rank each one in terms of importance. In other words, they were asked to state whether it was "not important" (coded 0), "important" (coded 1), or "very important" (coded 2) that the straw they buy possess these characteristics. Figure 5 shows that buyers do not care whether the pine straw they buy is harvested locally. Surprisingly (given the strong preference expressed by respondents for longleaf pine straw), "needles not broken" and "long needles" ranked lower than other characteristics. Also, "dry" and "fresh (recently harvested)" ranked lower than expected. The characteristic that ranked the highest in terms of importance was "no weeds or briars." In second place was "no foreign material (trash)." This is important to note because there are implications for landowners considering how best to utilize resources and prepare a site for pine straw harvesting operations. Keeping a clean stand and applying herbicide are clearly important components of a site preparation plan. Also, if needle length is less of a concern, then mechanical baling (which can cause breakage) can be a better option because it is less expensive than hand baling.

CONCLUSION

Based on the Farm Gate Value data out of Georgia – and the similarities between Georgia and Alabama forestlands – we believe there is potential for a more robust pine straw market in Alabama. However, there are biological factors that affect production potential and there needs to be a better understanding of those factors and how they interact. The buyer survey (Objective 2) showed that buyers prioritize clean straw over fresh and dry straw and long and unbroken needles. However, many buyers were unaware of the species they purchase or the origin of the pine straw; this suggests a need for consumer education efforts. The big unanswered question is whether landowners in Alabama are willing to harvest pine straw from their land. The research conducted under Objective 3 should help answer this question and help guide future outreach programming.

We expect research results to provide useful information for Extension personnel interested in educating forestland owners about the revenue-generating pine straw market and in identifying cost and logistical issues that need to be considered when developing management regimes that incorporate pine straw harvesting operations. It is important that landowners, prior to beginning pine straw harvesting operations, be aware of how different management strategies impact the landscape. The survey conducted as part of Objective 3 will provide insight to what management practices landowners are currently employing and the level of importance placed on environmental stewardship, biodiversity, water quality, and soil conservation. Extension publications and programming based on research findings can raise awareness among landowners of these issues and help them incorporate management practices from a landscape perspective.

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Table 1—Descriptive statistics of data collected from 201 plots as part of the Regional Longleaf Growth Study, 1993-1997

Variable	Unit	Minimum	Maximum	Mean	Standard Deviation
Age	Years	18	110	51	27
Density	Trees per acre	15	4452	551	800
Basal area	Square feet per acre	22	152	80	36
Site index (base age 50)	Based on height in feet	43	89	70	11
Needle fall	Pounds per acre per year	929	6696	3494	1273
Pine straw	Bales per acre per year[1]	46	334	175	64

[1] Based on 20-pound green weight bales

Table 2—Number of bales of pine straw purchased by respondents to the 2010 pine straw buyer survey, by bale shape

	N	Mean	Min	Max	SD
Purchased annually					
Square	56	8,272	50	100,000	17,840
Round	6	5,900	100	25,000	9,501
Purchased at a single time					
Square	58	635	10	7,500	1,047
Round	7	401	100	650	206

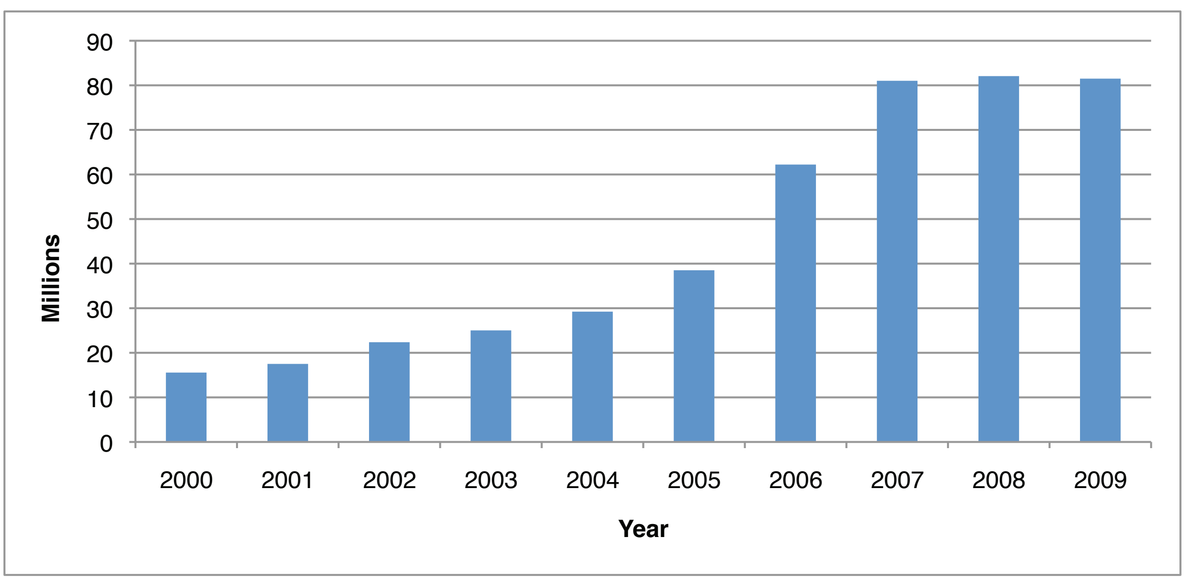

Figure 1—Farm Gate Value for Pine Straw in Georgia, 2000-2009

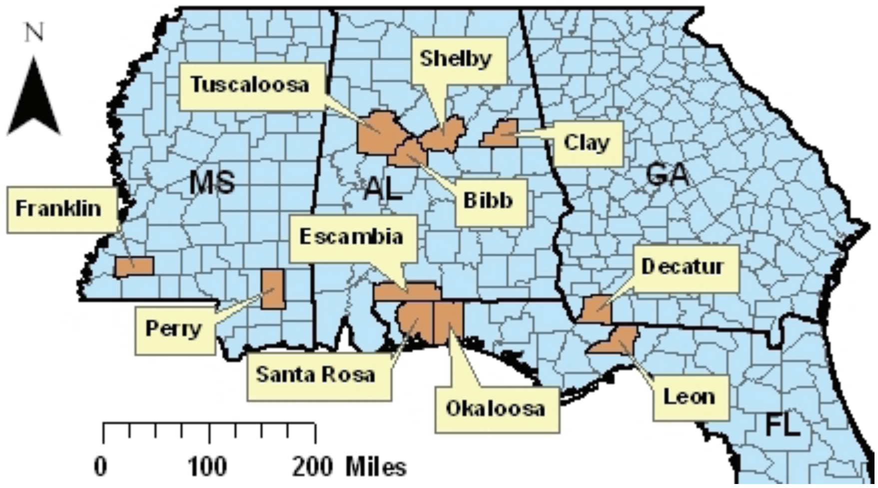

Figure 2—County locations of pine needle data collected as part of the Regional Longleaf Growth Study

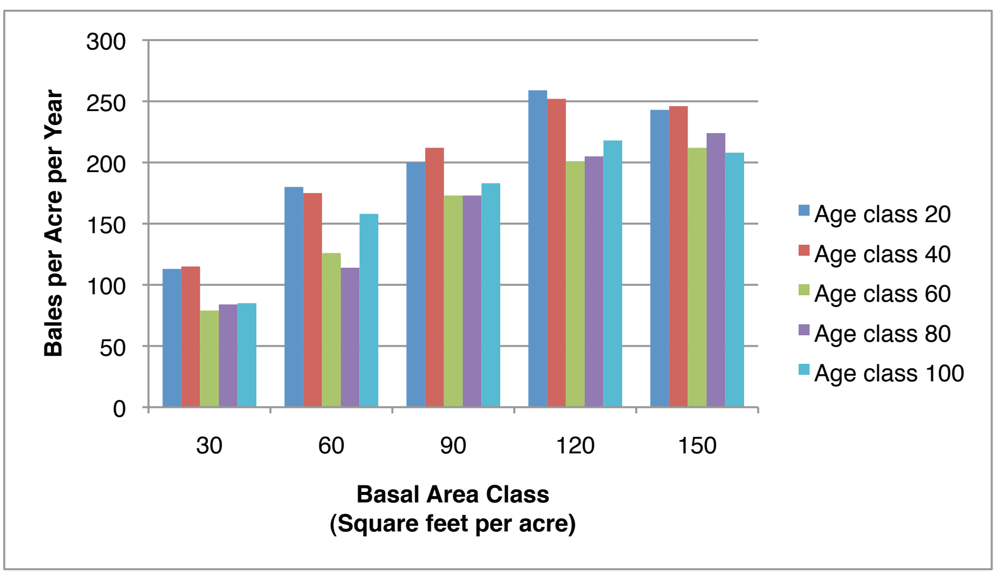

Figure 3—Mean pine straw yield, in green bales per acre per year, by basal area class at various age classes

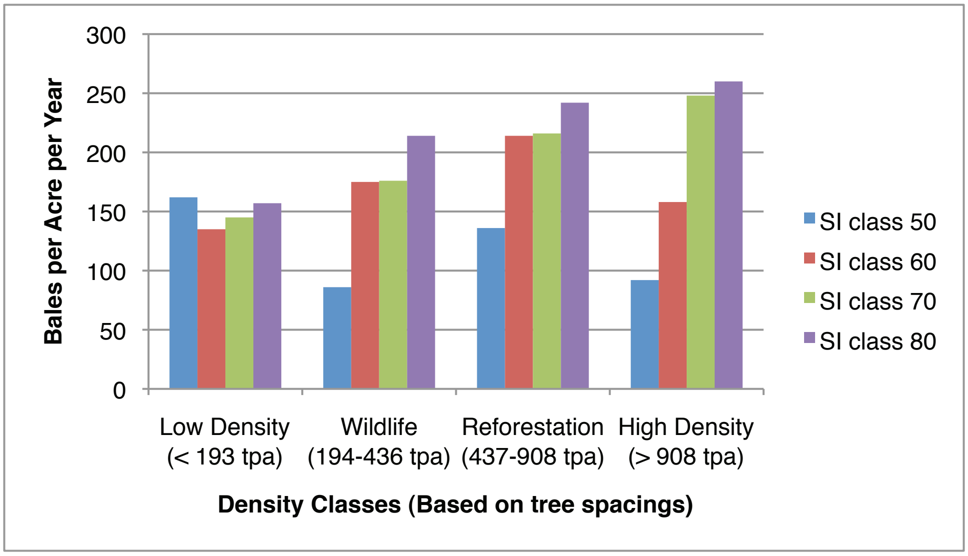

Figure 4—Mean pine straw yield, in green bales per acre per year, by tree density class at various site index classes

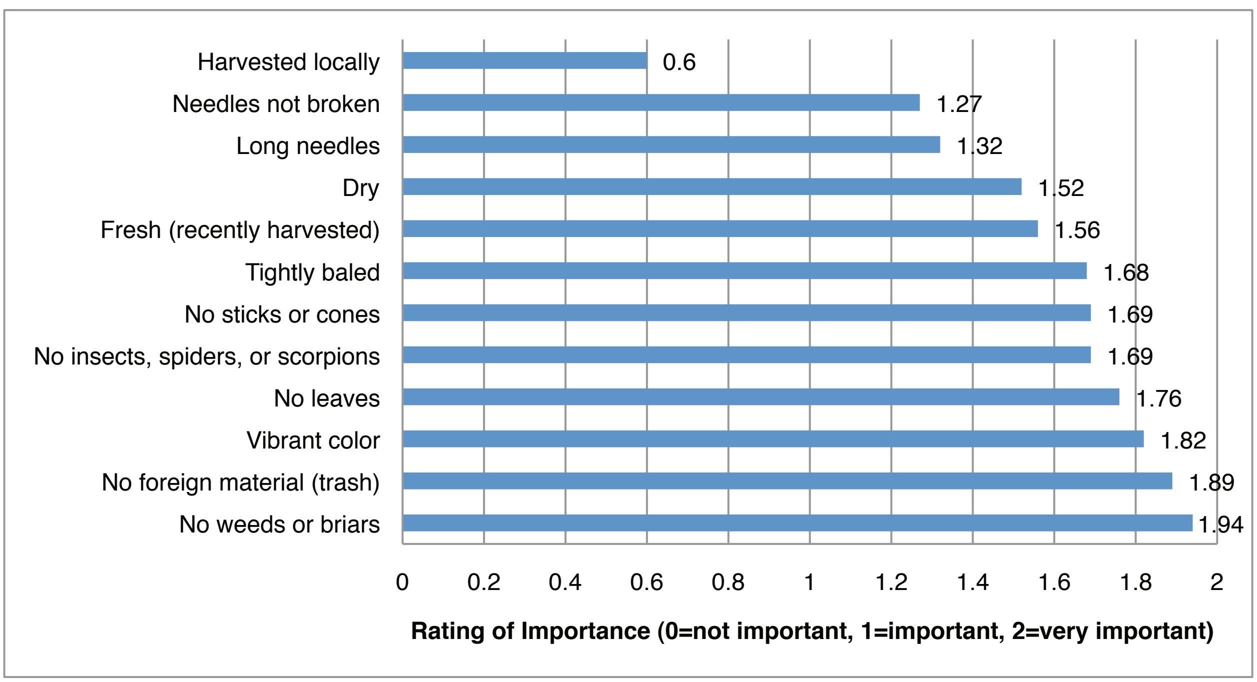

Figure 5—Pine straw characteristic preferences according to the 2010 pine straw buyer survey, by mean rating

INFLUENCE OF LIGHT AND MOISTURE ON LONGLEAF PINE SEEDLING GROWTH IN SELECTION SILVICULTURE

David S. Dyson, Edward F. Loewenstein, Steven B. Jack, and Dale G. Brockway

ABSTRACT

Selection silviculture has become increasingly common for longleaf pine management, yet questions remain regarding residual canopy effects on seedling survival and growth. To determine what levels of residual overstory promote adequate seedling recruitment, 600 containerized longleaf pine seedlings were planted on two sites during the 2007-2008 dormant season. To differentiate overstory from understory influences, half of the seedlings were randomly selected for understory removal (with herbicide). Canopy gap fraction was determined using hemispherical photography and average soil moisture was determined from four time domain reflectometer (TDR) measurements during the 2008 and 2009 growing seasons. Seedling groundline diameter (GLD) was measured at planting and in August, 2008 and 2009. First-year results showed weakly positive relationships between soil moisture and seedling growth, whereas generally negative but statistically non-significant relationships existed between gap fraction and seedling growth. Second-year results showed few significant relationships, but generally positive trends between gap fraction and GLD growth. No general trend was present between soil moisture and GLD growth. Data collected during this study support previous research suggesting that initial longleaf pine survival and growth are limited by moisture availability, but following establishment, light becomes the primary driver of longleaf pine seedling growth.

INTRODUCTION

Longleaf pine (*Pinus palustris* Mill.) forests and woodlands of the Southeastern Coastal Plain have declined by more than 98 percent from their previous 28-36 million hectares (Means and Grow 1985, Noss 1988, 1989, Goetz 1998, Ware and others 1993, Mitchell and others 2000). Interest in restoring and managing longleaf pine ecosystems has steadily increased during the past four decades and especially in recent years (Brockway and others 2005), with restoration a high conservation priority (Kirkman and others 2004). Concern has also been expressed due to recent statistics showing that most remaining longleaf stands are aging without replacement (Brockway and Outcalt 2000), meaning that many mature longleaf pine stands lack the younger age classes necessary to replace mortality in the near-term. Noting this dramatic decline in longleaf acreage and unsustainable demographics of remnant longleaf pine stands, Noss (1989) and Gilliam and Platt (2006) call for silviculture that mimics natural processes rather than the often more artificial and intensive methods employed by modern industrial silviculture.

Longleaf pine savanna ecosystems lend themselves to simultaneous management for timber and biodiversity better than any other forest ecosystem in the United States (Freeman and Jose 2009). Thus, one potential silvicultural tool that could fulfill the aforementioned restoration and conservation goals for longleaf pine is uneven-aged management, which can allow for managing timber and biodiversity together. Specific research has addressed the use of selection silviculture in longleaf pine forests and has found that both group selection and single-tree selection are practicable (Mitchell and others 2006). Still, selection silviculture represents a trade-off, because a spatially and temporally continuous overstory suppresses seedling growth by outcompeting seedlings for available growing space.

Previous studies have addressed competitive effects of residual overstory on longleaf pine seedlings on various sites and site types. These studies investigated growth of planted and natural seedlings in natural and artificial canopy gaps as well as underneath the forest matrix. Brockway and Outcalt (1998) found that natural-seedling aggregations in the center of canopy gaps on a xeric sandhill site were largely a result of competition for moisture and other soil resources. Therefore, they suggested that gap-based regeneration techniques should be included in uneven-aged management systems. Similarly, studies on mesic sites also have shown that growing season soil moisture availability can limit radial growth of artificial and natural reproduction (Rodriguez-Trejo and others 2003, Pederson and others 2008).

Contrary to studies from xeric sites, some experiments on mesic sites have shown that competition for light may be a more limiting factor in longleaf pine seedling growth and eventual recruitment than competition for moisture and nutrients. For example, studies from southwest Georgia have shown seedling growth to decrease as overstory stocking

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increases (Palik and others 1997, McGuire and others 2001, Pecot and others 2007). Furthermore, the overstory has been shown to actually facilitate seedling survival over the short term in some instances (Pecot and others 2007). Management recommendations resulting from these studies have focused on localized disturbances, particularly single-tree selection, since that approach allows for precise regulation of overstory density and thus understory light availability. Given these mixed results, site appears to be an important factor in the competitive relationships affecting longleaf pine seedling growth and recruitment, and as a result the appropriate selection systems may differ with site.

Prior studies have all examined only one site type per study. Additionally, methodologies have varied among studies and site types. To address those gaps in the literature, the objective of this study was to determine what levels of overstory retention in selection silviculture best promote longleaf pine seedling growth and recruitment by examining growth of longleaf pine seedlings planted within mature longleaf pine stands on both a subxeric and a mesic site.

METHODS

STUDY SITES

This project was installed on two study sites: the Blackwater River State Forest (30.8°N, 86.8°W) in Santa Rosa County, Florida, (hereafter: "Blackwater") and The Joseph W. Jones Ecological Research Center at Ichauway (31°N, 84°W) in Baker County, Georgia (hereafter: "Ichauway"). Blackwater is a subxeric sandhill site, whereas Ichauway is considered a richer, more mesic site. Both sites lie in the Middle Coastal Plain physiographic province (Craul and others 2005) and experience a warm, subtropical climate with a mean annual temperature of 19 °C. Annual rainfall at Blackwater averages 1650 mm, with 45 percent occurring between June and September; Ichauway receives mean annual rainfall of 1320 mm evenly distributed throughout the year. Troup loamy sand was the primary soil series at Blackwater, whereas the Ichauway site was located on Wagram soils. Both sites contain 75-95 year old second-growth longleaf pines in the overstory and species-rich native groundcover dominated by wiregrass (*Aristida beyrichiana* Trin. & Rupr.). Management activities at both sites have included prescribed burning targeted on one to three year return intervals and periodic timber harvests. During this study, the Ichauway site was burned by prescription in March of 2008.

EXPERIMENTAL DESIGN AND SAMPLING

Six hundred containerized longleaf pine seedlings were planted at Blackwater in December, 2007, and at Ichauway in February, 2008. Seedlings were grown at Meeks Tree Farm in Kite, Georgia, in 108 mL containers at a density of 530 seedlings m^{-2}. To standardize planting date, 120 additional seedlings were planted at Blackwater the week following the planting at Ichauway. Seedlings at both sites were planted in twelve arrays of 50 seedlings, with arrays arbitrarily located to provide an adequate range of canopy densities resulting from different uneven-aged silvicultural systems. Seedlings in each array were arranged in 5 rows of 10 trees on a 5-by-5 meter grid. The second planting at Blackwater was arranged as a sixth row of seedlings at each existing seedling array and was treated and sampled identically thereafter. To separate the competitive influences of the forest canopy and the understory, half of the seedlings in each array were randomly selected for complete understory removal and treated with RazorPro herbicide (41 percent glyphosate) following the label instructions (5 percent solution; spray to wet) in May, 2008. The treatment extended to a 0.5 meter radius from the seedling and was re-treated or weeded by hand as necessary to insure complete elimination of understory competition. At Ichauway, fuels were raked away from seedlings prior to the prescribed fire to protect them from open flames.

All measurements were conducted at each seedling. Canopy gap fraction was determined from hemispherical photographs taken 1.4 m above the ground between May and August (so the canopy had reached its maximum cover) when the solar disk was completely obscured. Obscured-disk conditions result in canopy gap fraction estimates falling on an approximately 1:1 line with actual percent photosynthetic photon flux density in longleaf pine forests (Battaglia and others 2003). Volumetric soil moisture content for the top 30 cm of soil at each seedling was recorded four times each growing season using time domain reflectometry (TDR). Seedling groundline diameter (GLD) was measured at time of planting and again in August, 2008 and 2009. GLD growth was calculated as the difference between August diameter measurements and initial seedling diameters.

Because the herbicide treatment was applied to randomly-selected seedlings within each seedling array and all measurements were repeated at each seedling, it was possible to conduct statistical analyses with the seedling as the experimental unit. Statistical analyses were conducted using SAS version 9.1 software (SAS Institute Inc. 2004). For all tests, statistical significance was determined at $\alpha = 0.05$. Mean growing season soil moisture for each seedling was calculated as the average of the four 30 cm depth TDR samples taken in both 2008 and 2009. Mean seedling GLD growth was analyzed between sites, treatments, and years with factorial ANOVA F-tests; significant differences were separated with Tukey's Honestly Significant Difference (HSD) test. Square-root transformations were applied as necessary to meet the assumptions of ANOVA. Regression analyses were used to relate canopy gap fraction, mean soil moisture, and seedling diameter growth.

RESULTS AND DISCUSSION

CANOPY GAP FRACTION

Mean gap fraction was 0.497 at Blackwater and was significantly larger than the mean gap fraction of 0.402 at Ichauway (two-tailed t-test for unequal variance: $t= 23.65$, $p< 0.0001$). Figure 1 shows histograms of gap fraction at Blackwater and Ichauway. These histograms document horizontal canopy structure and show that light is more available in the understory on the subxeric site. In contrast, the mesic site has a less-open canopy, resulting in less available understory light. Previous studies have shown that more xeric sites do not necessarily have higher mean canopy gap fraction (Brockway and Outcalt 1998, Sheffield and others 2003). Still, more xeric sites characterized by low soil fertility and common moisture stress tend to support more-open canopies (Myers 1990). Thus, site quality likely is one factor affecting the forest structure at these sites, but is not the only factor.

SURVIVAL

Survivorship figures for 2008 and 2009 are presented in Figure 2. Following one growing season (2008), survivorship was over 90 percent at Blackwater but was less than 80 percent at Ichauway. Survivorship among remaining seedlings during the 2009 growing season was above 90 percent for Ichauway; for Blackwater, survivorship was 76 percent for control seedlings and 84 percent for understory removal. Total survivorship (Figure 2) represents the number of surviving seedlings in 2009 as a percent of the original number of seedlings planted and was similar between the two sites even with the differing annual patterns. At Blackwater, survivorship was initially higher among seedlings with understory removal, but the pattern was reversed after the 2009 growing season. At Ichauway, survivorship was lower among control seedlings in both growing seasons (Figure 2). Seedling survival in this study was not substantially different from figures reported for old-field, cutover, and intact forest sites, which have ranged from 70 to greater than 90 percent (Palik and others 1997, South and others 2005, Jackson and others 2010). Furthermore, previous studies at Ichauway have documented similar survival rates for containerized seedlings (McGuire and others 2001, Pecot and others 2007).

SEEDLING GROUNDLINE DIAMETER

To maintain valid comparisons, results reported below are those for Ichauway and the second Blackwater planting, which have comparable planting dates. Mean initial seedling GLD for each treatment at both sites was significantly greater than the 6.35 mm minimum suggested by Barnett and others (2002) and Dumroese and others (2009) (one-tailed t-tests: $t= 18.39$ (Blackwater); $t= 35.82$ (Ichauway); $p< 0.0001$). At Ichauway, 3 seedlings were smaller than the recommended 4.75 mm "cull" threshold. There were no significant differences in initial seedling diameters, and means for both treatments at both sites were greater than 8 mm. Although seedling diameter is not the only factor in seedling quality, it is most important because, with proper seedling handling and planting, it is strongly correlated with seedling survival and growth after outplanting (South and others 2005, Jackson and others 2007).

After two growing seasons, two-way ANOVA showed that control seedlings at Ichauway grew significantly less than all Blackwater seedlings ($F= 6.86$, $p= 0.0002$), but no growth difference existed between Ichauway understory removal seedlings nor any Blackwater seedlings (Figure 3). Examining growth differences by year showed that Blackwater seedlings grew less during the second growing season than in the first, whereas Ichauway seedlings showed increased growth during the second year (Figure 4). In the 2009 growing season, understory removal at Ichauway resulted in mean seedling growth significantly greater than both treatments at Blackwater, whereas no statistically significant growth differences were present between control seedlings at Ichauway and all Blackwater seedlings in 2009 (Figure 4). It is also interesting to note that, even though the Ichauway site is classified as a mesic site, survival and growth were not necessarily greater for this site. As is intuitive, this result shows that weather conditions in the first few years after planting may be more important for survival and growth than rankings of broad site classifications.

First-year seedling survival and growth at Ichauway was negatively affected by prescribed fires during the spring of 2008, shortly after planting. Even though seedlings were protected from the flaming front, most seedlings lost all foliage due to scorch from radiant heat. Jack and others (2010) examined natural-seedling mortality resulting from prescribed fires and found similar survival rates ("low litter" treatment is comparable to what seedlings in the present study experienced). They also point out that mortality was concentrated in the smallest seedlings (<0.2 m tall), in which all seedlings in this study would be classified.

It is worth noting that mean two-year seedling growth measured in this study was minimal compared to some seedlings planted in even-aged systems, yet was not aberrant for underplanted seedlings. For instance, Jackson and others (2010) report seedling diameter growth of up to 10 mm per year in old-field conditions. In contrast, Gagnon and others (2003) planted seedlings in artificial canopy gaps during a multi-year drought and found seedling diameter growth between 1-4 mm per year for the first two growing seasons post-planting. Thus, although weather conditions (especially rainfall) and planting sites do affect seedling growth responses after planting, the suppressive effects of mature overstory trees are clear.

Seedling growth at Ichauway was negatively affected by the forest understory, whereas effects were negligible at Blackwater. Not only did understory removal result in a greater increase in seedling survival at Ichauway, but it also led to significantly greater seedling diameter growth. In contrast, understory removal did not significantly affect seedling growth at Blackwater. These results point to potentially more vigorous understory competition on the mesic site and possibly more growth suppression because of that competition.

GROWTH MODELS

First-year (2008) results did not suggest the existence of clear controls of longleaf pine seedling growth. While a negative trend between seedling growth and gap fraction existed in each case except for that of control seedlings at Blackwater (Table 1), gap fraction was a significant predictor only for control seedlings at Ichauway ($t= -2.61$, $p= 0.01$). In contrast, a positive relationship existed between mean percent soil moisture and seedling growth for all seedlings during the first growing season. This trend was significant for each group except understory removal seedlings at Blackwater. In each case, relationships were weak: coefficients of determination were all below 0.1.

Regression analyses after the 2009 growing season gave similarly unclear results. The only significant relationships existed at Ichauway, where there was a highly significant positive relationship between seedling growth and gap fraction for both control ($t= 3.16$, $p= 0.002$) and understory removal ($t= 5.30$, $p< 0.0001$) seedlings. At Blackwater there were positive but non-significant trends between seedling growth and gap fraction for seedlings of both treatments. While soil moisture was no longer a significant predictor at either site, the trend was generally positive. Still, all relationships remained weak, with the largest coefficient of determination only 0.13 (Table 1).

Results of the present study support those of prior research showing that high light exposure is initially a negative factor for longleaf pine seedlings, but that over time increased light availability can result in greater seedling growth (Palik and others 1997, McGuire and others 2001, Gagnon and others 2003, Pecot and others 2007). In effect, relative increases in overstory shade may have been a benefit to seedlings in this study until the seedlings developed root systems capable of procuring dependable soil moisture. At that point, increased light levels tended to positively affect growth. Even though soil moisture was less important to seedling growth during the second growing season of this study, it was possibly due to greater and more regular rainfall. As a result, seedlings may have been less limited by soil moisture, thus reducing the identification of soil moisture-effects on seedling growth.

MANAGEMENT IMPLICATIONS

Results of this study document both positive and negative effects of a mature forest canopy on longleaf pine seedlings. While residual overstory trees typically suppress seedling growth relative to that on clearcut sites, an intact forest overstory appears to provide seedlings some shelter from extreme moisture stress and benefits seedling growth in the short term. As a result, preliminary results from this study give more short-term examples of the effectiveness of multi-aged stand management. The importance of the observed reduction in early seedling growth in multi-aged stands will depend on objectives and may be acceptable for ecological rather than production-oriented management objectives. However, results also show the negative impacts that prescribed fire can have on seedling survival and growth and document the importance of using precise burn prescriptions to achieve specific objectives.

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Table 1—Regression models for seedling GLD growth after the first two growing seasons

	Model	R-square	Pr > F
	2008		
Blackwater			
Understory Removal[1]	y = 1.36 - 0.25GF + 0.04Moisture	0.02	0.53
Control	y = 0.35 + 0.85GF + 0.12Moisture	0.08	0.07
Ichauway			
Understory Removal	y = 0.65 - 2.06GF + 0.07Moisture	0.08	<0.0001
Control	y = 0.45 - 0.76GF + 0.05Moisture	0.03	0.014
	2009		
Blackwater			
Understory Removal	y = 1.45 + 2.81GF - 0.01Moisture	0.03	0.49
Control[2]	y = 1.31 + 3.39GF - 0.02Moisture	0.06	0.25
Ichauway			
Understory Removal[1]	y = -2.25 + 9.87GF + 0.08Moisture	0.13	<0.0001
Control[1]	y = -0.36 + 4.62GF + 0.06Moisture	0.05	0.016

[1]Transformed with square root(1+y) function

[2]Transformed with square-root function

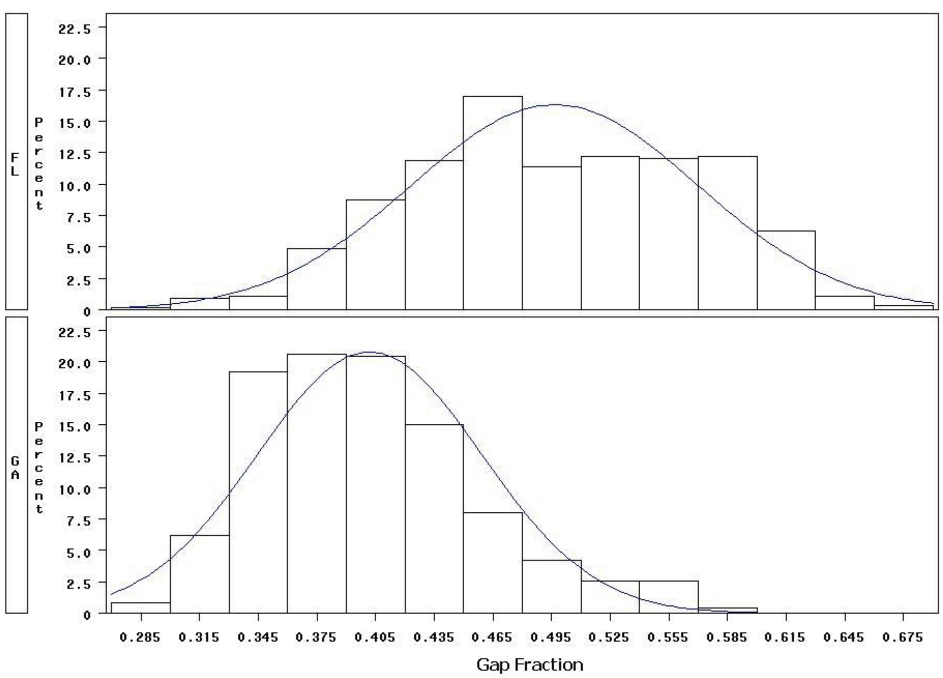

Figure 1—Histogram of gap fraction by site showing Blackwater (top) and Ichauway (bottom). The difference in means is statistically significant.

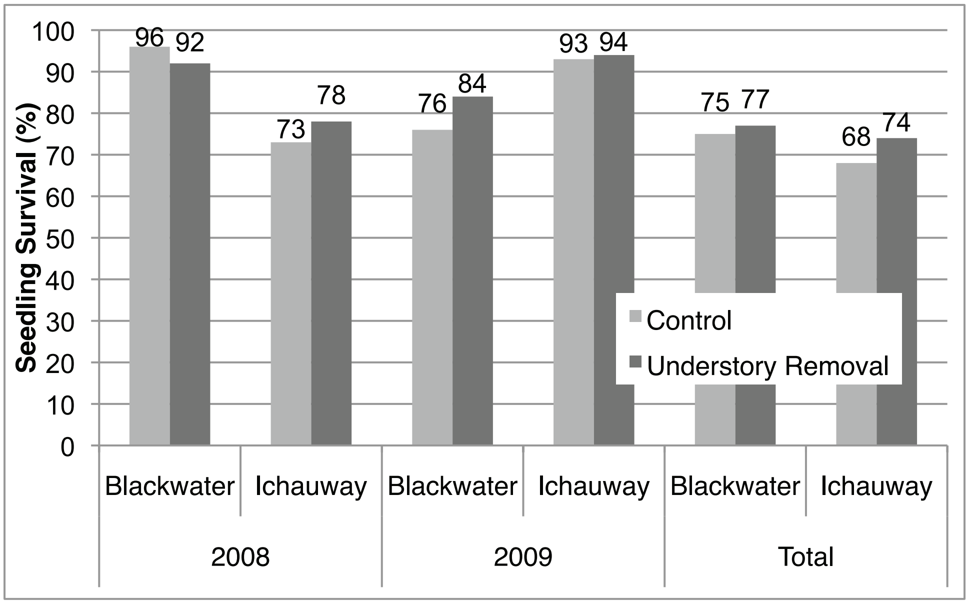

Figure 2—Percent seedling survival by site and year. Figures for 2009 represent percent survival among 2008 survivors. "Total" represents percent survival of original planted seedlings.

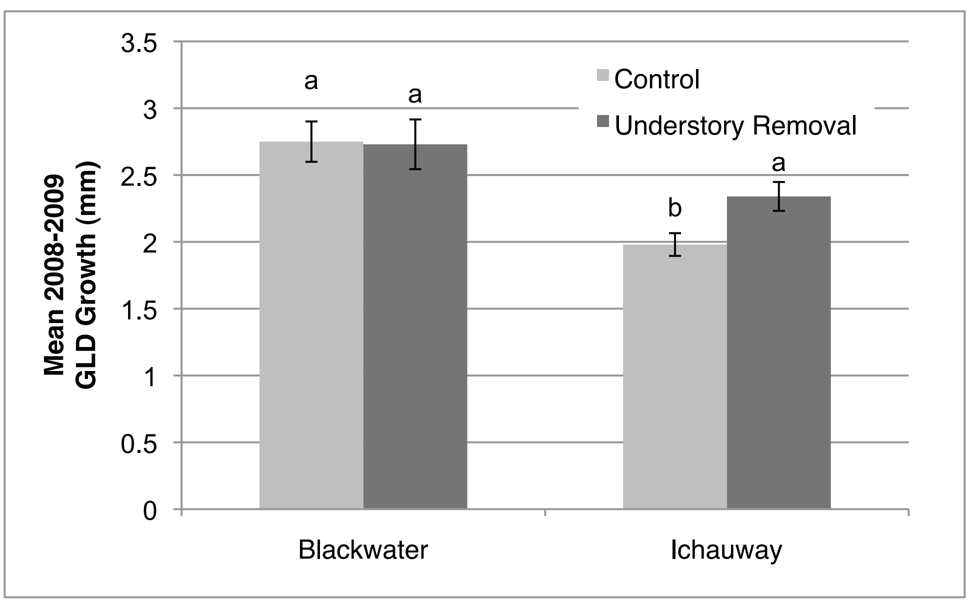

Figure 3—Mean 2008-2009 seedling GLD growth for seedlings planted in February, 2008. Bars with different letters indicate statistical significance.

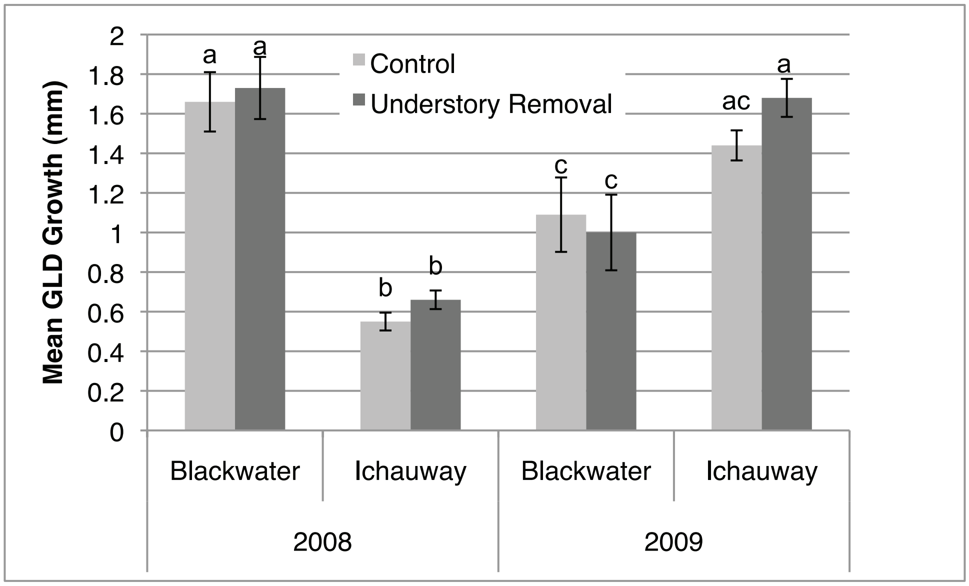

Figure 4—Mean seedling GLD growth by year. Bars with different letters indicate statistical significance.

EFFICACY OF TREATMENTS USING MAT-28 FOR PINE SITE PREPARATION

Andrew Ezell, Jimmie Yeiser, and Pat Minogue

ABSTRACT

Site preparation for pine plantation establishment continues to be the principal use of herbicides in the South. Due to the timing of the work and the cost involved, these applications are critical in both biological and economic terms. In an effort to improve performance in both considerations, a study was undertaken to evaluate a number of herbicide compounds in site preparation applications. A total of 12 treatments were applied with three replications on three sites in a randomized complete block design. Applications were completed in mid-July using a total spray volume of 15 gpa. Treatments included MAT-28 applied alone at three rates and MAT-28 applied in combination with metsulfuron, imazapyr, glyphosate, or sulfometuron. An assessment of hardwood control was evaluated at one year after treatment. Results from all evaluations indicated that MAT-28 applied alone did not control the principal species on these study sites very well. Mixtures with imazapyr and glyphosate provided excellent control of hardwoods.

INTRODUCTION

The use of herbicides continues to be the primary way forestry site preparation is conducted in the South. While more than twenty products are registered for such applications, the majority of acres are treated with three to four active ingredients applied alone or in some combination of two or more products. The cost-efficacy of these treatments is very favorable and the primary reason that so few active ingredients are used is because we are able to obtain high levels of control for comparatively low expense per acre. Such a situation is inhibitive to the introduction of new products into this market. For that reason, very few new herbicide compounds are tested for such use.

Aminocyclopyrachor is a relatively new herbicide which may have potential for use in forestry site preparation. The current formulation (MAT-28) has demonstrated promise for site preparation in terms of both control of some undesirable species and crop tolerance. The objective of the current study was to evaluate the efficacy of site preparation mixtures which contained aminocyclopyrachor which has not been previously tested.

MATERIALS AND METHODS

STUDY SITES

The study was installed on three sites. Full description and results will be provided in this paper for two of the sites. In Mississippi, the study was installed on Weyerhaeuser land near Longview, MS. Soil on the area was a Falkner silt loam with a pH=5.4. The area had been harvested in August, 2008 and no site preparation had been conducted. In Texas, the study was installed on Weyerhaeuser land near St. Augustine, TX. The soil was a sandy loam with a pH=5.2. The site was a former plantation which was harvested in August, 2008.

TREATMENTS

A complete list of treatments is found in Table 1. There were three replications of the 12 treatments applied in a randomized complete block design.

APPLICATION

All plots were rectangular areas 30’x100’. A piece of rebar was set at the center of each end of a plot and a string was stretched down the midline of the plot between the rebar. Treatments were applied using a CO_2-powered backpack sprayer with pole extension and a KLC-9 tip which simulated aerial application. Total spray volume was 15 gpa. All treatments were applied July 15, 2009.

EVALUATIONS

Evaluations were completed on a sample area of 10’x80’ which was centered in the treatment plot. Prior to treatment, all woody stems in the sample area were recorded by species and height class. In October, 2010 (15 months after treatment), living stems of woody plants were tallied by species and height class.

DATA ANALYSIS

Cumulative heights were derived by multiplying the number of stems by their respective heights for each species. Percent changes were calculated for the principal species on each

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site and for the total species on each site. Percent values were subjected to arcsine transformation, but actual values are presented herein. Means separation was completed using Duncan's New Multiple Range Test at alpha=0.05.

RESULTS

The principal species on the Mississippi site were sweetgum, red oaks (southern red, water and cherrybark), persimmon, and winged elms (Table 2). The winged elm was not present in sufficient numbers for statistical evaluation of all treatments, but nine of the twelve treatments included sufficient numbers for comparison. MAT-28 applied alone does not control sweetgum or red oaks well. This had been observed in earlier studies and results of this study were consistent with the earlier findings. MAT-28 applied alone or with small amounts of imazapyr provided good to excellent control of persimmon. Control of winged elm was variable, but good control was observed in the lowest rate of MAT-28 applied alone. Control of the total stems on the site was strongly influenced by the results of the sweetgum response since that species was present in greater numbers than any other species (Table 2).

Control in Texas was better than in Mississippi with most treatments resulting in some reduction of cumulative heights. Control of both sweetgum and the oaks in Texas was variable and would generally be considered unacceptable for site preparation (Table 3). Even the mixes of Oust Extra, Chopper Gen2, and glyphosate commonly used for site preparations (Treatments 10 and 11) failed to provide good control on the Texas site. However, these two treatments provided very good (Treatment 10) to total (Treatment 11) control on the Mississippi site.

SUMMARY

Generally, MAT-28 applied alone in this study did not provide good control of hardwoods. Exact results varied by state, but the trends were similar. The control of winged elm is promising, but more research is needed to confirm that finding. Combining MAT-28 with Chopper GEN2 could prove to be an effective treatment, but that combination was purposefully omitted to facilitate crop tolerance testing later in these studies.

It appears evident that MAT-28 will not be a stand-alone treatment for forestry site preparation. Currently labeled products in the utility and rights-of-way markets use MAT-28 in mixes with other herbicides. The herbicide does have potential for use as a tank mix partner in forestry site preparation work.

Table 1—List of treatments applied in 2009 MAT-28 study

Treatment No.	Herbicide and Rate/Acre
1	MAT-28 (3.76 oz) + MSO 1% v/v
2	MAT-28 (5.64 oz) + MSO 1% v/v
3	MAT-28 (7.62 oz) + MSO 1% v/v
4	MAT-28 (3.76 oz) + Escort (1.0 oz) + Imi* (3.5 oz) + MSO 1% v/v
5	MAT-28 (5.64 oz) + Escort (1.5 oz) + Imi (5.2 oz) + MSO 1% v/v
6	MAT-28 (7.62 oz) + Escort (2.0 oz) + Imi (7.0 oz) + MSO 1% v/v
7	MAT-28 (3.76 oz) + Oust Extra (2.0 oz) + Gly (5 qts) + MSO 1% v/v
8	MAT-28 (5.64 oz) + Oust Extra (3.0 oz) + Gly (5 qts) + MSO 1% v/v
9	MAT-28 (7.52 oz) + Oust Extra (4.0 oz) + Gly (5 qts) + MSO 1% v/v
10	Oust Extra (4.0 oz) + GEN2** (32 oz) + Gly*** (5 qts) + MSO 1% v/v
11	Oust Extra (4.0 oz) + GEN2 (40 oz) + Gly (2 qts) + MSO 1% v/v
12	Untreated check

*75% WG formulation of Imazapyr
**Chopper GEN2
***Glyphosate (4 lbs. a.i./gallon)

Table 2—Percent change in cumulative heights for principal species and total hardwoods by treatment in 2009 aminocyclopyrachlor study (MS)

	Species[1]				
Treatment	SWG	REO	PER	WIE	Total[2]
	---------- percent ----------				
1	+458f[3 4]	+171d	23e	84.66	+351g
2	+160e	+450g	100.0a	+67d	+237f
3	+548f	+360f	66.7b	*	+285f
4	25.2c	+307f	25.0c	+33cd	+80e
5	+59c	11.5c	92.9a	25.0c	+26d
6	129	+164d	100.0a	+100.0a	+110e
7	37.7c	88.9b	100.0a	100.0a	54.5bc
8	52.2bc	+266e	+81d	*	24.1c
9	+24d	N.C.	66.7b	*	2.2cd
10	76.5b	79.2b	55.6b	100.0a	79.2b
11	100.0a	100.0a	100.0a	100.0a	100.0a
12	+140e	+266e	+4cd	+28e	+96e

[1] SWG = sweetgum, REO = red oaks, PER = persimmon, WIE = winged elm
[2] Total = all hardwood species (results strongly influenced by sweetgum response)
[3] Plus sign indicates an increase in cumulative heights
[4] Values in a column followed by the same letter do not differ at alpha = 0.05
* Insufficient stems for comparison

Table 3-Percent change in cumulative heights by treatment for hardwoods in 2009 aminocyclopyrachlor study (TX)

Treatment No.	Oak	SWG	Total
	---------- percent ----------		
1	11ab[2]	34b	+11c[3]
2	+5b	5ab	+1bc
3	+10b	+53c	+14c
4	26ab	1abc	17abc
5	8ab	24a	20abc
6	56a	27a	43a
7	17ab	52a	39a
8	43ab	29a	25ab
9	33ab	28a	44a
10	33ab	59a	46a
11	62	61a	42a
12	+83c	+48bc	+54d

[1] SWG = sweetgum, Total = all hardwood species
[2] Values in a column followed by the same letter do not differ at alpha = 0.05
[3] Plus sign indicates an increase in heights

USE OF AMINOCYCLOPYRACHLOR FOR FORESTRY SITE PREPARATION IN THE SOUTHEASTERN U.S.

Andrew W. Ezell, Ronnie Turner, and Jimmie L. Yeiser

ABSTRACT

It is not often that new chemistry is made available for use in forestry applications. Aminocyclopyrachlor is a new active ingredient which may have usefulness as a forestry herbicide. Research using this active ingredient began in 2005 and is continuing in university projects across the South. Both hardwood control efficacy and pine tolerance have been evaluated in these trials. A total of 60 different treatments have been evaluated for use in site preparation applications in Mississippi and Texas. This herbicide is effective on a number of species including some invasive exotics. It will probably not be a stand alone treatment, but could be useful in tank mix applications.

INTRODUCTION

Chemical site preparation continues to be the largest use of herbicides in forestry applications. While the number of acres varies annually, each year, more than one million acres of southern forest land receives chemical site preparation. Due to the long term economic considerations associated with site preparation, cost-efficacy of the treatments is a primary concern. For that reason, any new herbicide which has potential for such use is thoroughly investigated. New chemistry for forestry applications is reasonably rare, and the introduction of a new herbicide creates a great deal of interest.

Aminocyclopyrachlor was first evaluated for use in forestry work in 2005. For the past six years, a number of protocols have been installed at numerous locations across the South. In each of these, treatments were evaluated for effectiveness in controlling target species. Some of the studies included an evaluation of crop tolerance on planted pines.

MATERIALS AND METHODS

Since this paper is a summary of a number of field trials, broad overviews of the materials and methods used will be presented.

HERBICIDE

Aminocyclopyrachlor is a synthetic auxin (or auxin type) herbicide. It stops the growth of plants by interfering with hormonal balance necessary for normal shoot and root development. This interference is more intense and more protracted than molecules with a similar mode of action. The material has a very low acute mammalian toxicity with oral and dermal LD_{50} ratings of greater than 5000 ppm. The material is readily metabolized by soil microbes and the metabolites are not biologically active. Aqueous photolysis can also be a major degradation route.

APPLICATION METHODS

Aminocyclopyrachlor has been applied in more than 70 treatments in both forestry cutover and rights-of-way settings for purposes of discussion in this paper. All treatments were applied using CO_2 –powered backpack sprayers and pole extensions to simulate aerial application. Total spray volumes of both 10 gpa and 15 gpa were utilized. All treatments were replicated three times.

EVALUATION

Woody vegetation stems were recorded by species and height class prior to application and again at 12-14 months after treatment. Heights were summarized by species into cumulative heights (number of stems in a height class X height). Percent reduction in cumulative heights by species was then used to evaluate treatment efficacy.

RESULTS

For purposes of this overview, results will be presented for species or species groups which were well represented in the various studies.

Red Oaks—Control was highly variable at all rates of aminocyclopyrachlor applied alone. When mixed with Arsenal AC or Razor Pro, control was consistently greater than 75 percent. Species included southern red oak, water oak, cherrybark oak and blackjack oak. There have been reports that aminocyclopyrachlor applied alone did provide good control of northern red oak in North Carolina.

Blackgum—Aminocyclopyrachlor is very effective on blackgum. Excellent control was obtained with rates as low as 6-7 oz. of product per acre.

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Red Maple—Control was variable when aminocyclopyrachlor was applied alone, but excellent control was obtained in mixes which contained a low rate of Arsenal AC.

White Oaks (including Post Oak)—Very good to excellent control of this group was obtained from application rates as low as 4-5 oz. of product per acre applied alone or in mixes with imazapyr or glyphosate.

Hickory—Using 4-5 oz. of product per acre provided 70-80 percent control of hickory. The primary species were shagbark and mockernut hickories.

Persimmon—Aminocyclopyrachlor alone at 4-5 oz of product per acre provided greater than 90 percent control of persimmon.

Sumac (winged and smooth)—Aminocyclopyrachlor applied alone will provide excellent control of these species.

Eastern Baccharis—This invasive species is very difficult to control, but 4 oz. a.i. per acre of aminocyclopyrachlor provided 95-100 percent control. Mixing the product with Escort XP also provided excellent control.

Sweetgum—Aminocyclopyrachlor applied alone does not provide good control of sweetgum. Tank mixes with imazapyr or glyphosate provide very good to excellent control.

Green ash—Aminocyclopyrachlor applied alone does not provide control of green ash.

Pine tolerance—Loblolly, slash, and longleaf pine seedlings were all planted in plots treated with aminocyclopyrachlor. The first formulation tested did result in phytotoxic symptoms (needle discoloration and twisting) on the seedlings. However, the newer formulation is being tested for crop tolerance and initial results are most promising.

SUMMARY

Aminocyclopyrachlor is a new herbicide which could be useful in forestry applications. It will not be used for herbaceous weed control or woody release, but it has good potential for use in site preparation and possibly midrotation brush control (untested).

CONTROL AND MANAGEMENT OF EASTERN BACCHARIS IN A RECENTLY ESTABLISHED BOTTOMLAND HARDWOOD PLANTATION

Benton Gann, Lynne Thompson, and Jamie L. Schuler

ABSTRACT

Eastern baccharis (*Baccharis halimifolia* L.) is a frequent invader in bottomland hardwood plantations established in southeastern Arkansas. This dioecious shrub can affect the survival and growth of newly planted stems. This study evaluated the utility of various herbicides and mechanical control treatments to manage eastern baccharis in an established hardwood plantation. Of the four herbicide treatments used, a dormant season application of triclopyr was the most effective treatment. As a non-chemical treatment option, two annual dormant and growing season cuttings resulted in 43 and 26 percent mortality, respectively, of the eastern baccharis rootstock. No damage was visible to any of the planted hardwood stems after two growing season for any of the management options tested.

INTRODUCTION

The establishment of hardwood plantations has been used as a mechanism to restore many thousands of acres in the lower Mississippi Alluvial Valley (Allen and others 2001; Stanturf and others 2004). However, factors such as site-species relationships, alteration of hydrology, edaphic characteristics, herbivory, seedling quality, and others have been linked to poor establishment associated with these plantings. One of the most consistent factors that contribute to poor survival and/or growth of these hardwood plantations has been the failure to control competing vegetation (Allen and others 2001; Stanturf and others 2004).

Eastern baccharis, *Baccharis halimifolia* L., (referred to as baccharis hereafter) is a dioecious shrub reaching 10-12 feet in height and commonly found in coastal marshes, freshwater swamps and abandoned fields from Texas to Florida and north to Massachusetts (Kraft and Denno 1982, Boldt 1989). It can dominate areas with recent disturbance and is a significant invader on former agriculture lands in southern Arkansas that are being converted to hardwood plantations (authors' personal observation).

A number of herbicides (e.g., dicamba, glyphosate, and 2,4-D) have been used to control *Baccharis* spp. during the growing season (Westman and others 1975, Everitt and others 1978, Boldt 1989). However, most of the herbicides that would effectively control baccharis will also damage planted hardwood seedlings. One untested option for controlling baccharis in hardwood plantations is to utilize dormant season herbicide treatments. While baccharis is a deciduous shrub, its newer stem growth (e.g., <1 year old) tends to remain green during the winter and retains living foliage for a majority of the year (Miller and Skaradek 2002). Therefore, a dormant season foliar-acting herbicide might offer an approach to managing baccharis that minimizes impacts to non-target species (i.e., planted hardwoods). Since hardwood seedlings in southern Arkansas are typically dormant from December to mid-March, a dormant season application could be used to reduce the density of baccharis to the extent that the planted hardwoods would be released. Similar dormant season applications have been successfully used to control honeysuckle (*Lonicera* spp.) invasions in hardwood forests (Evans 1984, Regehr and Frey 1988, Nyboer 1992).

Despite their effectiveness, some landowners may not want to use herbicides to control baccharis. As an alternative, mechanical treatments (e.g., bush hogging) can be used to manage baccharis (Hoffman 1968, Everitt and others 1978, Hobbs and Mooney 1985). However, mechanical control methods are labor and equipment intensive, which makes them costly. In addition these treatments usually do not provide long-term control because cut stems readily sprout (DeLoach and others 1986, Boldt 1989). Nonetheless, information on sprouting frequency relative to stem size and/or age would be useful in order to best target treatment implementation.

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The objectives of this research were to (1) test dormant season applications of various herbicides to assess their efficacy for managing baccharis in established hardwood plantations, and (2) compare sprouting probabilities for baccharis stems cut during dormant and growing seasons.

METHODS

SITE DESCRIPTION

The study was located on former farmland in Chicot County, AR that was enrolled in the Wetlands Reserve Program. In 2002-03, bald cypress (*Taxodium distichum* (L.) Rich.), pecan (*Carya illinoinensis* (Wangenh.) K. Koch), green ash (*Fraxinus pennsylvanica* Marsh.), Nuttall oak (*Quercus texana* Buckl.), Shumard oak (*Q. shumardii* Buckl.), water oak (*Q. nigra* L.), and willow oak (*Q. phellos* L.) were planted at densities totaling 303 stems/acre. A field survey conducted in 2005 reported average hardwood seedling density of 153 stems/acre, including volunteers, and several thousand rootstocks per acre of baccharis (Smith and others, 2006, unpublished data). The soil is classified as Perry clay (Very-fine, smectitic, thermic Chromic Epiaquerts), which are very deep, poorly drained, and very slowly permeable soils that formed in clayey alluvium (USDA 2002). The annual mean temperature for Chicot County, Arkansas is 64ºF with a mean annual precipitation of 55.5 inches (NOAA 2002).

Herbicide Study

The effects of dormant season herbicide applications on baccharis and hardwood saplings were assessed on 20 plots (approximately 75 feet long by 20 feet wide) established in the six year-old bottomland hardwood plantation. Ten hardwood saplings and 15 dominant baccharis rootstocks were tagged per plot. Hardwood seedlings were predominately Nuttall oak and green ash with the occasional willow oak. The height and basal diameter of each tagged hardwood sapling were measured before treatments were applied.

Four chemical treatments consisting of Clearcast, Milestone, RazorPro, and Tahoe 4E (imazamox, aminopyralid, glyphosate, and triclopyr, respectively; Table 1) were applied in early March before planted seedlings broke dormancy. All treatments were replicated four times. Four additional plots were left untreated to serve as controls. Herbicides were applied using a CO_2 sprayer attached to a 20 foot boom with the predetermined herbicide and concentration mixed with the equivalent of 20 gallons/acre of water. The 20 foot boom consisted of 12 spray nozzles 20 inches apart to assure equal and uniform application of the chemical to each plot.

To determine the long-term effects of the herbicide treatments on the baccharis and hardwood saplings, a damage assessment was performed on the tagged baccharis and hardwood saplings in September 2010, which corresponded to the end of the second growing season following treatment. Plants were assigned one of five crown damage categories: 0 percent (undamaged), 1-34 percent (minor dieback), 35-65 percent (moderate dieback), >65 percent (severe dieback), and dead. Non-parametric ANOVA (Friedman's test) with a Tukey-type mean separation test was used to assess the effects of the herbicide treatments on sprayed hardwood and baccharis saplings. The basal diameter and height of the tagged hardwood saplings were also recorded in September 2010. The annual height and diameter increment among treatments were compared using ANOVA and Tukey's HSD test for mean separation testing. Survival data for the herbicide study were analyzed using an arcsine transformation. Significance testing was conducted at alpha=0.05.

MECHANICAL CONTROL

Eight plots containing 25 tagged shrubs each were established in 2009. All baccharis stems in four plots were cut during the dormant season in January 2009, while all stems in the remaining four plots were cut during the growing season in May 2009. An additional 6 foot wide buffer strip was created around each plot. Each cut stem was aged using a disk cut from the basal end. Each stem on the dormant and growing season plots was re-cut in 2010 during its respective season to assess the effect of repeated harvesting on survival. Survival was checked for each rootstock in September 2009 and 2010. A binary logistic regression was used to predict the sprouting probability of baccharis by age, season of cut, and the interaction of age and season using a significance level of alpha=0.05.

RESULTS

HERBICIDE STUDY

Two growing seasons after treatments were initiated, no visible damage was observed to any of the tagged hardwood stems. Bacccharis stems were highly impacted by the Tahoe treatment. Baccharis survival was 72, 77, 95, 97, and 12 percent for stems on the control, Clearcast, Milestone, Razor Pro, and Tahoe treatments (Table 2). The only differences among treatments were between the Tahoe treatment and all others.

The total height and basal diameters of the planted hardwood stems were not different among treatments (Table 2). However, the herbicide treatments were taller and had larger diameters than the control stems, possibly indicating a treatment effect in coming years.

MECHANICAL CONTROL

Average survival at the end of the first growing season was 72 and 58 percent for the dormant and growing season treatments, respectively. By the end of the second growing season, 43 percent of the original rootstocks for the dormant season treatment and 26 percent of the original rootstocks for the growing season treatment had re-sprouted and continued to survive. However, there were no statistical treatment or age effects on resprouting probabilities (Figure 1).

DISCUSSION

Control of broadleaf competition in established hardwood stands is one of the most challenging aspects of hardwood plantation management (Schuler and others 2004). The delayed or brief dormancy period exhibited by eastern baccharis provides an opportunity to manage this species in hardwood plantations in a way that is effective and efficient. The application of 6 quarts/ac of Tahoe 4E over the top of foliated baccharis during a period when the planted hardwood stems were dormant (e.g., early March), resulted in no obvious damage to the hardwood crop trees after two growing seasons, while the treated baccharis stems had 88 percent mortality (Table 2).

Differences in the effectiveness of the herbicides used may be due to differences in their modes of action or the application rates. For example, the active ingredients in Tahoe 4E and Milestone are both auxin growth regulators (Duke 1990, Gunsolus and Curran 1991, Bukun and others 2009); however, Tahoe was almost completely effective, whereas Milestone had essentially no effect on the treated baccharis. This difference could be due to the differences in compounds and their pathway through the plant, although the exact pathway has not been described for each chemical. Glyphosate is the active ingredient in RazorPro, and is an amino acid inhibitor. Some plants are able to deactivate this compound (Gunsolus and Curran 1991, Feng and others 2004). Another possibility is that the limited leaf function during the late winter/early spring may result in limited plant uptake. Clearcast is an imidazolinone herbicide that inhibits the acetolactate synthase in plants, which is similar to imazapyr products (Gunsolus and Curran 1991). Imazapyr-containing products are often used in pine forests to manage hardwoods, with excellent control of many species (Fortson and others 1996, Harrington and Edwards 1999). However, Clearcast did not exhibit any visible impact on the baccharis at the end of the growing season, which again could reflect the differences in the pathways that the herbicide takes in the plant.

MECHANICAL MANAGEMENT OF BACCHARIS

Since chemical treatments may not be options in certain areas or where personal and social pressures prohit their use, mechanical alternatives to herbicides are sometimes used (Zutter and others 1987, Willoughby and McDonald 1999). As with many woody species, eastern baccharis is capable of coppicing when harvested (Fig. 3). Although no differences were detected, numerically the highest mortality induced by the two harvesting events occurred with the oldest stems (Fig. 1). However, deferring treatments also prolongs competition. The lack of differences between seasons may be due to a drought that occurred during the second year of this study. Annual rainfall during the second year was about 35 inches, which was about 20 inches below the long-term average (NOAA 2002).

CONCLUSION

Baccharis in established bottomland hardwood plantations can be controlled by a broadcast herbicide application in the late winter/early spring (i.e., after baccharis begins to leaf out but before bud swelling occurs in the hardwood seedlings) of 6 quarts/acre of Tahoe 4E. Futher testing of this product may indicate reduced rates are equally effective. Similarly, increasing rates of RazorPro, Milestone, and Clearcast may show opportunities. Since most baccharis stems are only partially foliated during the dormant season, the higher rates of some herbicides or adjuvents might improve control of baccharis. The alternative control measure of severing the baccharis stems have been found effective, but in our study the differences between dormant and growing season treatments may have been impacted by droughty conditions.

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Table 1—Herbicides and application rates used in this study

Trade Name	Common Name	Rate (per acre)
Clearcast	imazamox	2 quarts
Milestone	aminopyralid	7 oz
Razor Pro + LI700 (surfactant)	glyphosate	4 quarts + 0.025% v/v
Tahoe 4E	triclopyr	6 quarts

Table 2—The diameter, total height of planted 8-year-old planted hardwoods and the survival of baccharis two years following herbicide applications.

	Planted Hardwood Stems		Baccharis
Treatment	Basal Diameter (inches)	Total Height (feet)	Survival (%)
Control	1.97	9.5	72
Clearcast	2.24	9.8	77
Milestone	2.13	10.1	95
Razor Pro	2.09	9.6	87
Tahoe	2.20	9.7	12

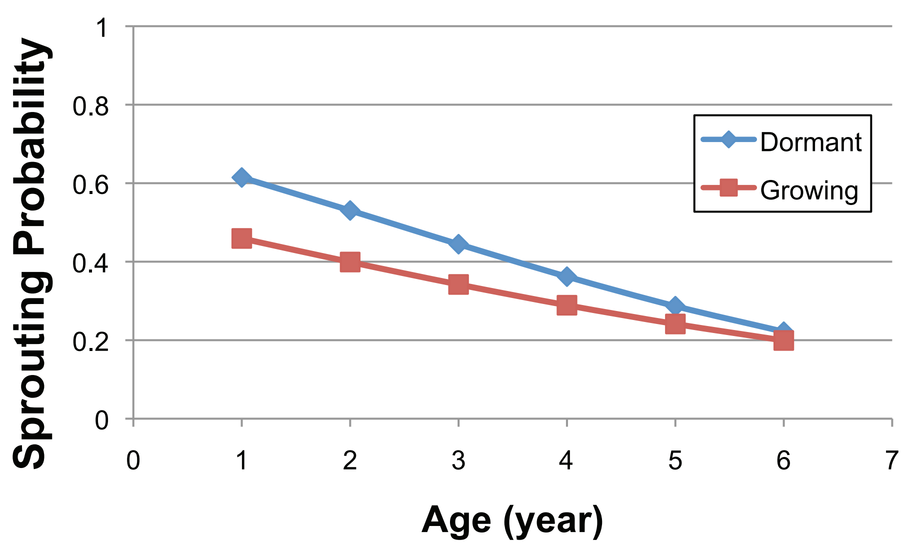

Figure 1—The predicted sprouting probabilities of eastern baccharis as a function of stem age for dormant and growing season harvests.

GEOSPATIAL RELATIONSHIPS OF TREE SPECIES DAMAGE CAUSED BY HURRICANE KATRINA IN SOUTH MISSISSIPPI

Mark W. Garrigues, Zhaofei Fan, David L. Evans, Scott D. Roberts, and William H. Cooke III

ABSTRACT

Hurricane Katrina generated substantial impacts on the forests and biological resources of the affected area in Mississippi. This study seeks to use classification tree analysis (CTA) to determine which variables are significant in predicting hurricane damage (shear or windthrow) in the Southeast Mississippi Institute for Forest Inventory District. Logistic regressions were run based on the terminal nodes of the CTA analysis to provide a greater detailed examination of the variables significant to damage. By studying tree species and areas that may be more prone to wind/hurricane damage, foresters and private land owners will have greater knowledge of how to effectively manage their timberlands. Two predominant species groups across the Southeast MIFI Forest District were examined in this analysis, including pine (*Pinus sp*.) and oak (*Quercus sp*.).

INTRODUCTION

Hurricane Katrina made landfall in Plaquemines Parish, Louisiana on August 29, 2005. With sustained winds recorded at 204.4 kmh, Hurricane Katrina was a Category 3 storm on the Saffir-Simpson scale at landfall (Knabb et al. 2006). Once over land, the storm quickly lost power and six hours after making landfall was reduced to a tropical storm just northwest of Meridian, Mississippi. In addition to hurricane-strength winds, the storm brought substantial amounts of rainfall over a very short period of time and a storm surge of up to 8.5 m across southern Louisiana and Mississippi (Graumann et al. 2005). This storm surge penetrated 10 km inland in many areas of southern Mississippi, and up to 20 km inland along bays and rivers (Knabb et al. 2006). Hurricane Katrina generated substantial impacts on the forests and biological resources of the affected area in Mississippi. According to Mississippi Institute for Forest Inventory (MIFI) and United States Forest Service Forest Inventory and Analysis (USFS FIA) assessments, over one half million hectares of forest land and approximately 39 million m^3 of timber were damaged across the Southeast Forest District of Mississippi due to Hurricane Katrina. Total damages/costs for the entire storm event were estimated to be $125 billion (Graumann et al. 2005). With so much data potentially available after severe weather phenomena it is important to understand which variables have the most importance in developing models to predict damage. This study uses CTA to examine the importance of variables addressing storm meteorology, stand conditions, and site characteristics for predicting damage to pine and oak tree species.

Previous research has focused on identifying biotic and abiotic factors that can predict the severity of wind-related damage. For example, following Hurricane Katrina, Kupfer et al. (2008) set out to map the hurricane-induced damage within the DeSoto Ranger District of the DeSoto National Forest located in southern Mississippi. Four damage classes were used (none, low, moderate, and heavy) to classify 450 plots within 153,000 hectares using a combination of air photo interpretation and field sampling. Predictive damage models were then developed using single tree classification tree analysis (CTA) and stochastic gradient boosting (SGB) which examined variables such as storm meteorology, stand conditions, and site characteristics for predicting forest damage. Damage was shown to be more strongly related to stand conditions and site characteristics and less related to measures of storm meteorology.

Wang and Xu (2008) conducted a similar study evaluating the effects of Hurricane Katrina in the Lower Pearl River Valley and the surrounding area in St. Tammany and Washington Parishes in Louisiana, and Hancock and Pearl River Counties in Mississippi. Fifty-three percent of the study area was forested lands including wetland forests, upland forests, and urban forests. A series of full and reduced logit models were developed to analyze the effects of forest characteristics and site conditions on the hurricane disturbance and to model probabilities that forests would be disturbed by hurricanes. Wang and Xu (2008) indicated that Hurricane Katrina damaged 60 percent of the forested land,

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with 18 percent highly, 35 percent moderately, and 7 percent lightly disturbed in the Lower Pearl River Valley. A large fraction of highly damaged forest and a small portion of moderately damaged forest were clustered in the Lower Pearl River Valley and south Hancock County. Lightly disturbed forests were randomly scattered as small patches in this region, whereas undisturbed forests clustered in the Lower Pearl River Valley, the lower portion of St. Tammany Parish, and the northwestern portion of Hancock County (Wang and Xu 2008). This is the same area that received the highest levels of storm surge inundation (Knabb et al. 2006).

Forests adjacent to streams and rivers in the study area showed a higher level of disturbance from the hurricane, indicating a high susceptibility of bottomland forests to the hurricane damage (Wang and Xu 2008). With increased distance away from river channels, the percentage of highly damaged forest declined (Wang and Xu 2008). These findings correspond with those from Kupfer et al. (2008) as well. An increase in distance from perennial streams resulted in less notable damage. It was shown that the most susceptible to damage were hardwoods located in bottomlands and along river channels (Kupfer et al. 2008).

These studies examine hurricane force damage to forests at the individual tree level, plot level, and at the landscape scale. Most previous research utilizes logistic and linear regression to correlate damage type and severity to biotic or abiotic factors. However, very few use CTA to determine significant predictor variables. Using the MIFI database and CTA in R (a free statistical software package), this study seeks to determine and test significant predictor variables for determining shear and blowdown damage in pine and oak species caused by Hurricane Katrina. Coupled with logistic regressions based on the terminal nodes of the pruned classification trees this will provide a detailed view at the variables significant in hurricane damage. Using these methods, this study seeks to test the following hypothesis: Hurricane damage will be more strongly correlated with stand characteristics than measures of storm meteorology.

MATERIALS AND METHODS

The study area for this research is the Southeast MIFI Forest District which contains 15 counties that suffered the most Hurricane Katrina damage within Mississippi. Forest plot locations were derived from the MIFI data and span the 15 counties included in the district. Following Hurricane Katrina, about 1,700 0.2-ha circular plots were randomly installed in forest strata within the Southeast MIFI Forest District to measure forest damage (shear and blowdown). The MIFI data included plot location (x,y coordinates of plot centers), tree species, individual tree diameter at breast height (cm), total height (m), damage type (shear or blowdown), and trees per hectare (tph). Other calculated variables include Lorey's mean height (m) and Quadratic Mean Diameter (cm). The species of interest were pine and oak; these species were chosen for their abundance throughout the study area and for their widespread spatial distribution throughout the southern and Atlantic coastal regions. Pine species included loblolly pine (*Pinus taeda*), slash pine (*Pinus elliottii*), longleaf pine (*Pinus palustris*), and shortleaf pine (*Pinus echinata*) which are found on a multitude of sites in the Coastal Plains and Lower Piedmont Plateau (Hodges et al. 2008) throughout Mississippi. The range of these pines is from southern New Jersey south to central Florida, west to southeastern Texas and southern Oklahoma. Loblolly pine is also almost exclusively planted for timber production in plantation settings, adding to the amount found within Mississippi. In comparison, oak species are slightly more limited in their natural range. Oak species included white oak (*Quercus alba*), Durand oak (*Quercus durandii*), southern red oak (*Quercus falcata*), cherrybark oak (*Quercus pagoda*), turkey oak (*Quercus laevis*), laurel oak (*Quercus laurifolia*), overcup oak (*Quercus lyrata*), blackjack oak (*Quercus marilandica*), swamp chestnut oak (*Quercus michauxii*), chinkapin oak (*Quercus muehlenbergii*), water oak (*Quercus nigra*), Nuttall's oak (*Quercus texana*), willow oak (*Quercus phellos*), Shumard oak (*Quercus shumardii*), post oak (*Quercus stellata*), black oak (*Quercus velutina*), and live oak (*Quercus virginiana*). Oak species are generally characterized by their tendency to grow in wet lowland to moist upland soils and on deep sand deposits in bottom lands. All of the previously mentioned oak species are found naturally throughout Mississippi (Hodges et al. 2008).

CTA was conducted for the two species groups using a binary classification (0 no damage, 1 damage) for each damage type and combined damage. First, all CTA were performed using the same predictor variables to create the over-fit classification and regression trees. CTA is a non-parametric statistical process and can be interpreted as those plots/stands with the highest proportion of damage would occur on the terminal nodes on the right side of the tree. Pruning of these trees was then done using the highest cross-validation error less than one standard error above the minimum cross-validation error (Steinberg et al. 1997). This was determined by analyzing the cross-complexity parameter (CP) table provided by R. This was also visually inspected by plotting the cross-validation relative error against the Cost-complexity Parameter (CP) value. The CP value is a measure of how much additional accuracy a split will add to the entire tree. As the CP value increases, a greater number of nodes are pruned away, resulting in a simpler classification/regression tree. Forward stepwise logistic regressions were run based on the terminal nodes of the pruned classification trees. This was done to provide a more detailed examination of the potentially significant variables when predicting tree damage.

RESULTS

The fully-grown Classification Tree for all oak species total damage included fourteen terminal nodes. The cross-validation plot indicated that a tree with four terminal nodes provided the greatest accuracy and results in a much simpler classification tree (Figure 1). The first split for the pruned classification tree for total damage in oak species indicated that a Lorey's mean height (LMH) of 15.54 m was the first splitting criteria with plots having a LMH less than 15.54 m splitting to the right, being more likely to be damaged, and plots with a LMH greater than or equal to 15.54 m splitting to the left, being less likely to be damaged. At the next split, plots/stands with a Quadratic Mean Diameter (QMD) less than 6.45 cm have a smaller proportion of damage than those plots with a QMD greater than or equal to 6.45 cm. The final splitting criteria was based on TPH, with those plots/stands having a TPH less than 3.14 have a lower proportion of damage than those with TPH greater than or equal to 3.14. When examining shear damage in oak species the cross-validation plot indicates a tree with only one node would provide the best fit. This shows a poor fit to the data and may be a result of an overall lack of shear damage in oak trees. The pruned blowdown classification tree uses slightly different split parameters when compared to the total damage classification tree (Figure 2). Following the right split, those plots with the highest proportion of blowdown damage had a LMH less than 12.90 m and QMD greater than or equal to 7.87 cm. The subsequent logistic regressions were run on each terminal node of the pruned classification trees, for this paper the logistic regressions for only the nodes with the highest proportion of damage will be reported. For oak total damage the only significant variable for node 4 (69 percent damage) was distance from Hurricane Katrina's track (km). This was also the case when examining the logistic regression for node 3 (67 percent damage) for oak blowdown damage. Both were negatively correlated, meaning as the distance from Hurricane Katrina's track increases, damage is likely to decrease (Table 1).

A slightly different pattern emerged when examining pine species damage. The pruned classification tree for all pine species total damage included three terminal nodes (Figure 3), with plots/stands with the highest proportion of damage (59 percent damage) being less than 93.35 km from the coast and less than 66.54 km from Hurricane Katrina's track. For these plots/stands near the track and near the coast the logistic regression showed the significant variables are QMD, LMH, Height Variation, TPH, and hard sustained wind speed (Table 2). The pruned classification tree for all pine shear damaged resulted in a classification tree with four nodes (Figure 4). Plots/stand with the highest proportion of shear damage had a QMD greater than or equal to 4.07 cm, a distance from the coast less than 70 km, and a distance from Hurricane Katrina's track less than 52.22 km. The logistic regression for terminal node four (61 percent damage) resulted in significant variables QMD, Height Variation, and TPH (Table 2). The pruned classification tree for pine blowdown damage was slightly more complex having five terminal nodes (Figure 5). This resulted in two terminal nodes having the highest proportion of damage, nodes four and five. Terminal node four (56 percent damage) included plots/stands with a TPH greater than or equal to 69.81, a LMH greater than or equal to 11.23 m, a QMD greater than or equal to 5.71 cm, and a LMH less than 14.37 m. Terminal node five (60 percent damage) included plots/stands with a LMH less than 11.23 m, a QMD greater than or equal to 5.71 cm, and a LMH less than 14.37 m. The logistic regressions for both of these terminal nodes showed LMH and Height Variation to be the most significant (Table 2).

DISCUSSION

This study set out to test if damage was more strongly related to stand characteristics than measures of storm meteorology. The resulting pruned classification trees were almost entirely limited to stand/plot characteristics; this confirms previous research and the hypothesis for this study. The classification trees for the oak species were entirely limited to TPA, LMH, and QMD. This shows a strong relationship between these variables and damage type. This was slightly unexpected, oak trees are known to be a more site specific species so local factors were expected to be more prevalent in their classification trees. While oaks are overall a more site specific species, all oak trees tend to grow in wet lowland to moist upland soils and on deep sand deposits in bottomlands. They are most commonly found along streams and in bottomlands. For both oak damage types, the logistic regressions resulted in distance from Hurricane Katrina's track being the only significant variable.

This was not the case when examining pine species damage. The classification trees for all pine species were limited to LMH, QMD, TPH, distance to the coast, and distance from Hurricane Katrina's track. This could be explained by the different pine species having more specific growing site characteristics. When examining the distribution of MIFI plots with loblolly pine trees present and the distribution of MIFI plots with damaged loblolly pine trees present there is a very widespread distribution within the study area. Every county had loblolly pine trees present, and every county had loblolly pine trees that received either shear or blowdown damage. The other pine species are much more limited in their range. Slash pine is a coastal species found in swamps and along streams growing in sandy soils, this is evident when mapping the distribution of this species throughout the study area. Slash pine is almost exclusively found in the southernmost counties of the study area. Longleaf pine has similar site characteristics as loblolly pine but is not as abundant throughout the study area. With a more limited spatial distribution among the pine species this may have added a greater complexity to the relationships between damage type and species group. The logistic regressions for pine damage resulted in LMH, QMD, TPH, Height Variation, and Sustained Wind Speed as significant variables. This shows more complexity in the relationship between damage type and pine trees.

This classification tree analysis was important because it begins to identify variables important in the prediction of Hurricane Katrina tree species damage. To develop a better fitting model, other modeling methods will be tested and examined, including logistic regression and neural networks. With a better understanding of how site characteristics influence damage severity and type we will be able to better predict potential damage. This will aide in recovery and salvage operations as well as allow managers to make better species selections based on the type of site available for planting. Previous research has found that recently thinned stands or stands with large open spaces are more susceptible to wind damage than those with a smooth forest landscape (Roberts et al., 2007; Zeng et al., 2009). While recent thinning or harvest activities were not taken into account for this study, silvicultural methods should be accounted for in future research.

Future research in this area should utilize other geostatistical processes to better model and predict forest damage. Specifically, linear regression modeling and regression tree analysis should be used to predict damage based on multiple co-variates as well as multiple logistic regressions. This will utilize biotic and abiotic factors that may influence damage type and severities for the species utilized in this study, as well as expand the research to other predominant species within the Southeast MIFI Forest District.

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Table 1—Oak species damage logistic regressions results

Oak Species		
Total Damage, Node 4		
Variable	Estimate	Pr>ChiSq
Intercept	1.648	<0.000
Track Dist.	-0.019	0.000
Blowdown Damage, Node 3		
Intercept	1.569	<0.000
Track Dist.	-0.025	0.003

Table 2—Pine species damage logistic regressions results

Pine Species		
Total Damage, Node 3		
Variable	Estimate	Pr>ChiSq
Intercept	-3.321	0.022
QMD	0.202	<0.000
LMH	-0.073	0.003
Height Variation	-0.252	<0.000
TPH	0.011	<0.000
Sustained Wind Speed	0.018	0.022
Blowdown Damage, Node		
Intercept	0.256	0.727
LMH	0.223	0.027
Height Variation	-1.099	0.009
Shear Damage, Nodes 4 & 5		
Intercept	-0.511	0.415
QMD	0.096	0.039
Height Variation	-0.209	0.004
TPH	0.008	0.002

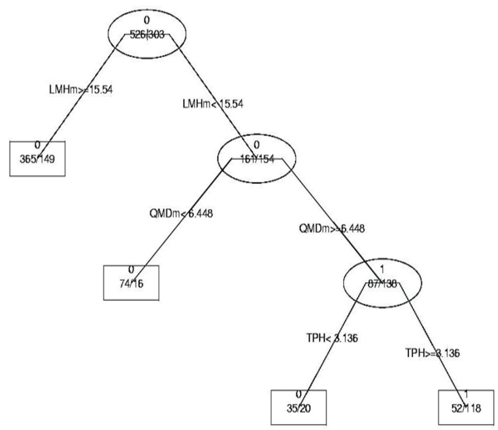

Figure 1—Pruned classification tree for all oak species damage.

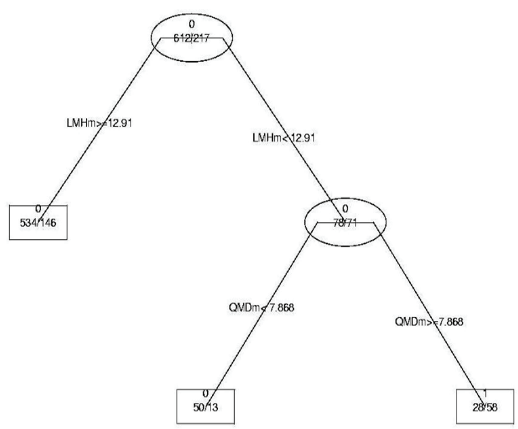

Figure 2—Pruned classification tree for all oak species blowdown damage.

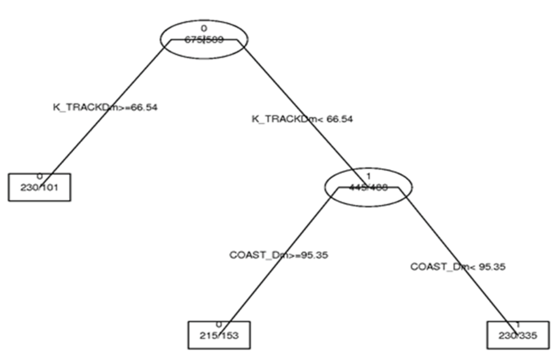

Figure 3—Pruned classification tree for all pine species damage.

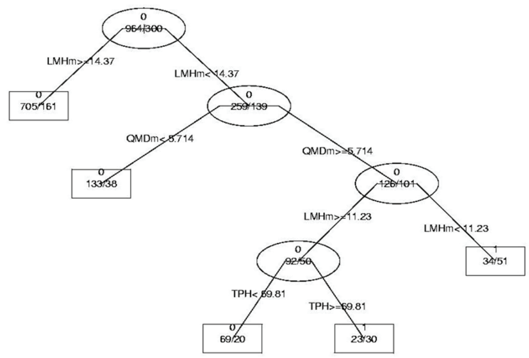

Figure 4—Pruned classification tree for all pine species shear damage.

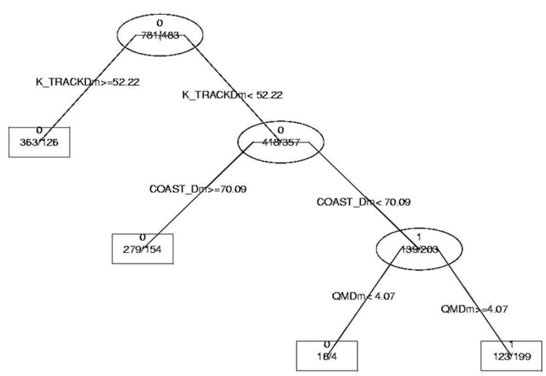

Figure 5—Pruned classification tree for all pine species blowdown damage.

SPATIAL ANALYSIS OF LONGLEAF PINE STAND DYNAMICS AFTER 60 YEARS OF MANAGEMENT

John C. Gilbert, John S. Kush, and Rebecca J. Barlow

ABSTRACT

There are still many questions and misconceptions about the stand dynamics of naturally-regenerated longleaf pine (*Pinus palustris* Mill.). Since 1948, the "Farm Forty," a forty-acre tract located on the USDA Forest Service Escambia Experimental Forest near Brewton, Alabama, has been managed to create high quality wood products, to successfully promote natural regeneration, and to minimize management costs. Management consists of periodic inventories, prescribed fire, and harvests, which have created an uneven-aged stand structure with a range of age classes. A GIS database was created by stem-mapping all pines greater than or equal to 3.1 inches dbh (diameter at breast height). This database contains information for over 5,000 trees and provides a unique opportunity to explore longleaf pine stand dynamics spatially. The variations in densities and size classes across the tract will be evaluated to provide information about how longleaf pine grows and the dynamics of long-term management.

INTRODUCTION

There are still many unanswered questions and misconceptions about the dynamics of naturally-regenerated, even-aged stands and uneven-aged management of longleaf pine (*Pinus palustris* Mill.). The longleaf pine ecosystem that once dominated the southern landscape has been decimated to small isolated patches scattered across the southeastern United States. Today, there is a growing interest in restoring functional longleaf pine ecosystems. Focusing on education and outreach opportunities for small-scale private landowners, who own a majority of the land and longleaf pine in the Southeast, is essential to the success of this movement (Miles 2009). Frequent fire and natural regeneration have sustained longleaf pine and are what perpetuated the climax forest across the landscape (Chapman 1932). More information about long term longleaf pine management and associated stand dynamics is essential for providing more opportunities and encouragement to landowners to not only restore longleaf pine but more importantly to maintain sustainable longleaf pine stands into the future.

To better understand longleaf pine stand dynamics and learn more about long-term management of longleaf pine, the "Farm Forty" was selected for study. The "Farm Forty" is a forty-acre tract located on the Escambia Experimental Forest, owned by T.R. Miller Mill Co. and managed by the U.S. Forest Service, near Brewton, Alabama. The "Forty" was established in 1948 as a demonstration area for the small private forest landowner (Boyer and Farrar 1981).

The preliminary inventory in 1947, outlined by Boyer and Farrar (1981) showed the stand was an under stocked second-growth longleaf pine forest averaging 35 to 40 years old, with 31 acres of longleaf pine and 9 acres of slash pine (*Pinus elliottii* L.). The management objectives for the tract were to create high quality wood products, to successfully promote natural regeneration, and to minimize management costs. Initially, the Forty was going to be managed with the goal of a 60 year rotation (Boyer and Farrar 1981). However, when the Forest Service moved to 120 year rotations for longleaf pine on their properties, the rotation for the Forty was extended (Barlow and others 2011). The site has been inventoried periodically with the management consisting of periodic harvests and prescribed burning. The results of the first 30 years of management and demonstration on the Farm 40 were reported by Boyer and Farrar (1981), and Barlow and others (2011) reported on the last 30 years, as well as summarizing the first 60 years.

Periodic harvests provided opportunities for regular income and to make stand improvements by removing lower quality trees and leaving higher quality trees. These thinnings were strategically planned to remove less growth and to create small gaps, which promoted natural regeneration for new age classes using the shelterwood method (Boyer and Farrar 1981). The shelterwood method, which consisted of selecting an area with potential cone-bearing longleaf pine trees, thinning this area to 30 square feet per acre of basal area, and then removing the overstory when a satisfactory amount of regeneration was present (Croker

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and Boyer 1975). Periodic prescribed burning every 2 to 3 years and switching from the dormant to the growing season has maintained the site and prepared the seedbed for regeneration (Boyer and Farrar 1981, Barlow and others 2011). The combination of periodic harvests using this regeneration method, periodic prescribed burning, and extending the rotation has created a sustainable uneven-aged stand structure on the Forty with a range of age classes including seedlings to trees over 100 years old (Barlow and others 2011). It is a living demonstration for what a small scale private landowner can do with 40 acres and has been showcased during field days, which were often annual during the first 30 years, where products from the harvest were displayed for visitors to see in context to the residual stand (Croker 1987). With over 60 years of extensive management records and demonstrations to private landowners, the Forty provides a unique opportunity to utilize spatial technology to better understand longleaf pine stand dynamics and the effects of long-term management. Opportunities through spatial analyses offer the ability to take an in-depth look at species and size distributions, regeneration potential, current gap dynamics, and future harvest locations across the Forty.

METHODS

To evaluate the current stand dynamics of the Forty after 60 years of management, a GIS (geographical information system) database was created. ESRI's ArcGIS 9.3.1 was used for all of the spatial data creation and analysis. The first steps in creating the database were to compile information and create layers for past inventories, harvests, and prescribed burning records. An existing stand map created by Boyer in 1977 was also digitized and added as spatial layers. GPS (Global Positing System) coordinates were collected for the Forty's corners, roads, and streams. These layers were then used to update the stand map from 1977 and to see how the Forty has changed over the past 30 years. To complete a detailed spatial analysis of the stand, all pines greater than or equal to 3.6 inches dbh (diameter at breast height) were stem-mapped. The stem-mapping was completed by setting strategic points across the Forty and recording sub-meter GPS locations for each point. A survey laser was setup at each point and used to calculate the azimuth and distance from the points to the surrounding trees while a dbh and species was also being recorded for each tree. The coordinates for each tree were calculated, and a tree layer shapefile was created for all of the trees. A soils layer, aerial photograph, and topographic maps were also clipped to the boundary of the Forty and added to the database.

With the tree layer, a spatial analysis looking at tree size and species distributions could be completed. The next step was to evaluate the regeneration potential for longleaf pine. For adequate natural regeneration across the site using the shelterwood method, there needs to be at least 30 square feet per acre of productive longleaf pine seed trees scattered evenly across the site, which are generally 30 years old or greater and 10 inches dbh and greater (Croker and Boyer 1975). This is very important considering the short seed dispersal range of longleaf pine. About 71 percent of longleaf pine seed falls within 66 feet of the parent tree with a maximum distance of 100 feet (Boyer 1963, Croker and Boyer 1975). To evaluate the potential for longleaf pine regeneration by looking at possible seed dispersal patterns, a layer was added by creating multiple ring buffers of 66 feet and 100 feet around all longleaf pines 10 inches dbh and greater. The seed production of longleaf pine generally increases until the trees are 15 inches dbh (Croker and Boyer 1975). An additional layer was created by adding the 66 and 100 feet buffers around longleaf pines 14 inches dbh and greater because these are the trees often left by managers as the parent trees. The areas outside of the buffers were evaluated by overlaying the tree layer to see what size trees and species were present. These layers provided information about regeneration potential for longleaf pine by looking at possible seed dispersal patterns, but density information is also needed to evaluate the potential for future harvests and natural regeneration using the shelterwood method.

The 1977 stand map differentiated the age classes and species mix across the Forty. The Forty was plotted on graph paper on a 20 by 20 grid where each square represented 0.1 acre. Since harvests generally created small gaps on the Forty and were often single tree or group selection, the next step was to create spatial layers to divide the Forty into 0.1, 0.4, and 1.6 acre units. A layer was created to divide the Forty on a 20 by 20 grid of 0.1 acres per unit for 400 units representing a gap removing possibly only one tree or more trees. For a small group selection where a few trees might be harvested, a layer was created for a 10 by 10 grid of 0.4 acres per unit for 100 units. Creating a layer for a 5 by 5 grid of 1.6 acres per unit with 25 units represents a larger gap where numerous trees might be removed. The tree layer was then clipped to each of these layers, and trees per acre and basal area per acre were calculated for all pines, longleaf pine, and potential cone-bearing longleaf pine in each unit. Using the criteria from Croker and Boyer (1975), basal area per acre values were classified by regeneration potential into categories of less than 30, 30 to 45, 45 to 80, and greater than 80 square feet per acre. Trees per acre values were calculated and used to identify areas where high basal area values were the result of many small trees or a few large trees. Side-by-side comparisons could then be made for all pines, longleaf pine, and potential cone-bearing pines for each of the grid patterns representing various harvest sizes. Roads, streams, and tree locations by size and species were added to the layouts for more information to aid decision making. The comparisons could be used to evaluate the locations of existing gaps and identify potential areas for harvests and natural regeneration using the shelterwood method by looking at basal area, trees per acre, species, and the location and size of trees across the Forty.

RESULTS AND DISCUSSION

A total of 5,197 trees were stem-mapped on the Forty. Longleaf pine accounted for 89 percent or 4629 trees. Average dbh of the longleaf pine was 7.8 inches and with a maximum of 22.3 inches. Other pines represented 11 percent including 555 slash pines and 13 loblolly pines (*Pinus taeda* L.). The average dbh for slash pine was 13.5 inches with a maximum of 29.5 inches. The average dbh for loblolly pine was 12.4 inches with a maximum of 28.2 inches. The stem-map shows that the site is predominantly longleaf pine, with scattered loblolly pine and slash pine dominating the northeast corner of the Forty. The stem-map also shows that slash pine is intermixed with longleaf across the eastern side of the Forty. Since the stem-map shows the location of all pines on the Forty within the specified criteria, it provides opportunities to plan future harvests to provide periodic income and to promote natural regeneration, while monitoring areas down to the individual species.

Using buffers around potential cone-bearing longleaf pine to look at the regeneration potential for the Forty, gaps in the potential seed dispersal distances were mainly in the areas around the slash pine documented in 1977 and in regeneration areas where recent overstory removal cuts were completed and the regeneration had not reached 3.6 inches dbh. Areas around the stream and in the north portion of the Forty were also highlighted as potential regeneration problems, which were impacted by Hurricane Ivan (Barlow and others 2011). Longleaf pines smaller than the stem-map criteria were located near or in these areas and may provide a seed source in the future, but close monitoring and evaluation is needed in these areas in the future. These results show the success and sustainability of past management on the Forty, with opportunities to continue managing longleaf pine into the future. To start identifying areas with suitable parent trees for future harvests, layers showing buffers around longleaf pine 14 inches dbh and greater were also used. Areas where these buffers overlap provide a starting point, but the areas need to be classified using the basal area recommendations for the shelterwood method.

The 0.1, 0.4, and 1.6 acre grids were used to show densities for all pines, longleaf pines, and potential cone-bearing trees, where basal area values were used to identify areas of interest for thinnings to promote longleaf pine natural regeneration. Comparing basal area values for all pines to longleaf pine for each grid showed that slash pines were inflating the basal areas along the eastern side of the Forty. The trees per acre calculations also showed areas where basal areas were high due to large amounts of small trees in the older regeneration areas and due to areas with clusters of large trees. These layers can be helpful when looking at the Forty as a whole and when trying to understand the stand dynamics down to size and species level, but using these layers alone to make management decisions for longleaf pine natural regeneration can provide unrealistic estimates and cause regeneration failures. The basal area calculations for potential cone-bearing longleaf pine provided better estimates for future harvests when looking at single tree, small group, and large group selections.

When the Forty was divided by the 1.6 acre grid for large group selections, there were 20.8 acres in the less than 30 square feet per acre class, 9.6 acres in the 30 to 45 square feet per acre class, and 9.6 acres in the 45 to 80 square feet per acre class. There were no units where basal area was greater than the 80 square feet per acre class. After removing the areas dominated by slash pine and that were damaged by Hurricane Ivan, the units with less than 30 square feet of basal area were mainly areas that had already been naturally regenerated and contained trees less than the stem-map criteria. The next step was to look for opportunities for small group selections and single tree selections. Using the 0.4 acre grid for small group selections, there were 21.6 acres in the less than 30 feet square feet class, 10.4 acres in the 30 to 45 square feet per acre class, 6.4 acres in the 45 to 80 square feet per acre class, and 1.6 acres in the greater than 80 square feet per acre class. When using the 0.1 acre grids to look at single tree selections, 22.4 acres were in the less than 30 feet square feet class, 7.2 acres in the 30 to 45 square feet per acre class, 7.1 acres in the 45 to 80 square feet per acre class, and 3.3 acres in the greater than 80 square feet per acre class. The layers for small group and single tree selection thinnings provide a better look at how longleaf pine grows by highlighting areas supporting over 150 square feet per acre that could be missed by focusing on a larger area. Some areas had three 14 inch dbh longleaf pines in a 0.1 acre unit, and there was a maximum basal area of 137.4 square feet per acre on a 0.1 acre gap.

There are opportunities across the Forty for numerous large group, small group, and single trees selection thinnings with even more opportunities for various combinations. Comparing all three grid layers provides more information about longleaf pine stand dynamics by looking at the variations in density across the Forty. In an uneven aged stand like the Forty, basal areas and trees per acre values need to be used with caution because of dense clusters and large diameter trees to prevent future regeneration failures from management decisions. Isolated patches of longleaf pine without 30 feet square feet of basal area should be checked for adequate regeneration and closely monitored in the future. Using all tree grid layers and adding the tree layers showing size classes and species can help provide more accurate information for decision making. These thinning opportunities can be strategically planned to continue providing regular income and to promote natural regeneration, as managers have done in the past.

CONCLUSIONS

The results of the GIS database for the Forty reinforce that this type of management with longleaf pine can be successful for a private landowner with 40 acres. It has the benefits of providing periodic income with low management costs, sustainability, opportunities for multiple use management, and requires strategic planning for harvests. The Forty has been managed for over 60 years with over 20 periodic harvests, including annual harvests for field days (Boyer and Farrar 1981, Barlow and others 2011). The stem-map and evaluations of the Forty show what the managers have been doing on the ground is successful and sustainable. This effort provides scalable management techniques that can be applied to larger landscapes or smaller stands. It requires visiting the stand, looking for regeneration, thinning carefully, and strategically planning harvests.

The data reminds users to use basal area and trees per acre with care when managing. Large trees can skew these numbers that can create unrealistic management activities on the ground that can result in regeneration failure for longleaf pine. The database and layouts can be utilized for future management by providing a type of decision support tool for future harvests, regeneration areas, and monitoring. The stem-map can also be used in future marking during harvests to target the slash and loblolly pine and continue to promote longleaf pine regeneration in these areas. It will be important to update the database over time. As the 5-year inventories are completed, the stem-map and database can be updated. Adding more detailed information about age distributions and regeneration would also be very beneficial to the database and spatial analysis of the Forty.

Since stem-mapping 40 acres is not an option for most landowners and land managers, the database and associated maps can also serve as education and extension tools showing the benefits and success of long-term management of longleaf pine for private forest landowners, researchers, and conservation professionals. The Forty and the layouts provide visual examples for small-scale private landowners showing longleaf pine management options, stand dynamics, and the benefits of natural regeneration. In 2009, the 60^{th} anniversary of the Farm 40 was celebrated with a highly successful forestry field day for landowners and forestry professionals. It was also featured in a Gold Award winning video titled *60 years on the Farm 40: Longleaf pine management for the private landowner*. The Farm Forty will continue to be a living demonstration and provide small-scale private landowners with ideas for successful opportunities with longleaf pine on their properties.

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FREQUENCY AND SEASON OF PRESCRIBED FIRE AFFECT UNDERSTORY PLANT COMMUNITIES IN LONGLEAF PINE STANDS

James D. Haywood

ABSTRACT

Prescribed fire research on the Kisatchie National Forest in Louisiana spanned the last 7 decades and led to a greater understanding of fire behavior and the importance of fire in longleaf pine (*Pinus palustris* Mill.) stands. Early research focused on management of the bluestem (*Andropogon* spp. and *Schizachyrium* spp.) range for livestock forage. Because of its tolerance to fire, range burning favored longleaf pine over other woody plants making the establishment of pure longleaf pine stands possible once feral hogs were controlled and other livestock placed under management. Through its continued application, fire greatly influenced the production and composition of the overstory and midstory plant communities, and both the frequency and season of prescribed burning affected herbaceous plant production. The importance of frequency and season of prescribed burning is discussed using both past and recent research results.

INTRODUCTION

The bluestem (*Andropogon* spp. and *Schizachyrium* spp.) range extended from northwestern Florida and southern Alabama to eastern Texas, and occupied primarily the Gulf Coastal portion of the longleaf pine (*Pinus palustris* Mill.) -- slash pine (*P. elliottii* Engelm.) timber type (Grelen 1974). It included about four million hectares in 1935. By the 1930s, uncontrolled harvesting had denuded most of the original longleaf pine within the bluestem range of the West Gulf Coastal Plain. The remaining vegetation was being burned too frequently, heavily grazed by cattle, foraged by feral hogs (*Sus scrofa*) and other livestock so that tree reproduction could not establish naturally (Hopkins 1947, 1948, Wade and others 2000). For example, a feral hog (first introduced 470 years ago by DeSoto) could strip the root bark from 200 to 400 uprooted longleaf pine seedlings per day. The problem was so severe in the West Gulf region that Hopkins (1947, 1948) recommended slash pine as a replacement for longleaf pine because slash pine roots were less desirable to hogs. Longleaf pine management became possible once feral hogs were controlled and other livestock placed under management. Because of the history of range use for forage, however, much of the range remained under livestock management in the West Gulf region, although range grazing has now largely ceased across the South (Grelen 1978).

Even after livestock damage was no longer considered as serious a problem, artificial reforestation efforts across the South focused on establishing loblolly (*P. taeda* L.) and slash pine rather than longleaf pine because foresters mistakenly believed that longleaf pine could not be artificially regenerated (Croker 1989). Nevertheless, longleaf pine still recovered naturally where advanced regeneration and seed trees were present on some forestlands (Haywood and others 2001), albeit on only a fraction of longleaf pine's native sites (Landers and others 1995, Outcalt and Sheffield 1996, Brockway and others 2005).

Research in the bluestem range began on the Kisatchie National Forest during the mid-1940s and originally emphasized the effects of prescribed burning on range resources and herbage quality (Campbell and others 1954; Duvall 1962; Duvall and Whitaker 1964; Grelen and Epps 1967a, 1967b). Cattlemen burned the range to remove litter and suppress brush development so that the production and quality of fresh herbage, primarily grasses, could be increased (Duvall 1962, Duvall and Whitaker 1964). Burning was done in March to obtain fresh herbage at the beginning of the growing season. However, grass quality decreased through the growing season (Campbell and others 1954), and so, May burning was practiced as a way to once again obtain fresh herbage of better quality than the herbage that began growth in March (Grelen and Epps 1967a, 1967b). Rotational burning, that is a portion of the range was burned in March or May every three years, was practiced and the cattle moved between ranges to access the best quality herbage (Duvall and Whitaker 1964).

In these early range studies, longleaf pine regeneration tolerated fire and it became the dominant woody plant (Grelen 1975, 1983b). This occurred partly because during its unique grass-stage period longleaf pine seedlings growing in full sunlight reach sufficient girth to tolerate high temperatures because large tufts of needles protect the terminal bud when fire moves quickly through grass cover. Once longleaf pine seedlings emerge from the grass stage, they are more susceptible to heat injury until about 2 m tall (Bruce 1951). Nevertheless, the majority of longleaf pine

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seedlings survive while the other woody species are top killed by fire (Duvall 1962; Haywood 2009, 2011).

Prescribed fire applied repeatedly over a number of years profoundly changed forest structure and the productivity of the understory on the Palustris Experimental Forest (Grelen 1983a; Haywood 2009, 2011; Haywood and Grelen 2000; Haywood and others 2001). Both the frequency at which fires were applied, whether annually, biennially, or triennially, and the season of burning, whether in March, May, or July, were believed to be important, but demonstrating these differences required installing and monitoring field studies over many years.

STUDY FINDINGS

Herein, the results from five long-term studies are presented that support the belief that the frequency and season of burning affected overstory development, herbaceous plant production, and stocking of understory woody vegetation.

DIRECT SEEDED LONGLEAF PINE STUDY

The first study compared vegetative composition in unburned plots to plots where prescribed fire was applied over a 20-year period in a direct seeded stand of longleaf pine (Haywood and Grelen 2000). The alternative burning regimes included biennial or triennial applications of fire in either March or May. At study initiation, vegetation on the seeded site was primarily native perennial grasses, mostly bluestems, periodically prescribed burned for open-range grazing. Following seeding, longleaf pine seedlings were abundant across the area. All overtopping pines and hardwoods were girdled to form an even-aged stand of longleaf pine regeneration; however, pines outside of the study area remained as a natural seed source.

Not applying fire or any other vegetation management treatment over a 20-year period allowed volunteer loblolly pines to dominate the overstory and hardwoods to form a midstory that resulted in the near exclusion of longleaf pine trees (Table 1, Haywood and Grelen 2000). In addition, litter accumulation on the unburned plots and the greater amount of overstory cover smothered and shaded out the understory vegetation on the unburned plots. Higher overstory basal areas have been associated with less herbaceous plant production in other work as well (Grelen and Enghardt 1973; Grelen and Lohrey 1978; Wolters 1973, 1982).

Biennial burning in March resulted in the lowest longleaf pine basal area among the prescribed fire treatments, which was significantly less on plots biennially burned in March than on plots either biennially or triennially burned in May (Table 1, Haywood and Grelen 2000). The detrimental effect of biennial prescribed burning in March on the basal area of longleaf pine compared to prescribe burning in May is supported by others work. For example, Grelen (1975) reported that when prescribed fire was applied in March, it resulted in smaller longleaf pine saplings than if fire was applied in May. Haywood (2009) also reported that prescribed burning in March resulted in slower sapling and pole-size longleaf pine height and volume per tree growth than prescribed burning in May. Because biennial burning in March resulted in the least longleaf pine basal area, it also resulted in the most understory plant production, which was an outcome reported in other research as well (Grelen and Enghardt 1973; Grelen and Lohrey 1978; Wolters 1973, 1982).

PLANTED SLASH PINE STUDY

The second study began in a 4-year-old slash pine plantation in which the understory was dominated by bluestem grasses and the most abundant woody plants were wax myrtle (*Morella cerifera* (L.) Small) and southern red oak (*Quercus falcata* Michx.) (Grelen 1983a). Prescribed fire treatments, annual, biennial, or triennial burning in March or May, were applied over the next 8 years on some plots with others not being burned. Repeated fires kept brush suppressed, and Haywood and others (2000) found that annual burning suppressed the stature of wax myrtle more than biennial burning, and shrub stature was greatest when prescribed fires were applied triennially.

By stand age 12 years on the unburned plots, fire-intolerant species flourished. Blackberry (*Rubus spp*.) grew into impenetrable thickets in places, and natural loblolly pines grew as fast as the planted slash pines (Grelen 1983a). The brush suppressed herbaceous plant production on the unburned plots compared to plots annually or biennially burned in March or annually burned in May (Table 2).

On all of the prescribed burned plots, grass was the dominant understory taxon (Grelen 1983a)—primarily little bluestem (*Schizachyrium scoparium* (Michx.) Nash) and slender little bluestem (*Schizachyrium tenerum* Nees), several other bluestem (*Andropogon spp*.) grasses, many miscellaneous grasses, and a myriad of forb species. Annual burning in March resulted in significantly more herbaceous plant production than either triennial March burning or burning in May regardless of frequency (Table 2). However, the amount of herbaceous plant production was more associated with individual tree stature than with slash pine basal area, and basal area did not differ significantly among treatments (Grelen 1983a).

NATURALLY REGENERATED LONGLEAF PINE STUDY

In the third study, longleaf pine trees originated from natural regeneration. In 1962, all pine and hardwood trees and shrubs above 30-cm tall were severed and removed across the study site to help create uniform cover conditions over the entire area (Haywood and others 2001). However, scattered longleaf and loblolly pines outside the study area were seed sources. Prescribed fire was discontinued on some plots in 1961. The unburned plots were mowed and raked in 1962 and 1963 as part of a simulated grazing study, but no further treatments were applied after 1963. Plots used for the three prescribed fire treatments were biennially burned 20 times from 1962 through 1998 in March, May, or July.

After 37 years, the herbaceous plant community was nearly eliminated on the unburned plots due largely to a well-developed hardwood midstory, a large number of hardwood trees and shrubs in the understory, and accumulated litter that smothered the herbage (Table 3, Haywood and others 2001). Although pine basal area on all four treatments was comparable, on the unburned plots, loblolly pine comprised 40 percent of the basal area originating from seed from adjacent trees after the study began. There were no volunteer loblolly pines or midstory hardwoods on the three prescribed fire treatments.

Among the three months in which prescribed fire was applied, March, May, or July, there were no significant differences in herbaceous plant production (Haywood and others 2001). Plots burned in July had fewer understory trees and shrubs of shorter stature than plots burned in March. Understory woody vegetation on plots burned in May was similar to July burned plots. Haywood and others (2000) had similar results in which burning in July reduced wax myrtle stature compared to burning in March, and May burning was intermediately effective.

DELAYED BURNING IN A LONGLEAF PINE PLANTATION

The fourth study was initiated in a longleaf pine plantation beginning in the seventh growing season after planting (Haywood 2009). The understory was dominated by bluestem grasses with low scattered brush. Beginning in the seventh growing season, prescribed fire was applied biennially to plots in March, May, or July. Additionally, biennial chemical woody plant control was applied to another set of plots, and there was an untreated check.

By the fourteenth growing season, the herbaceous plant community had collapsed on the untreated and chemical woody plant control plots (Table 4, Haywood 2009). An 8-year accumulation of litter in the absence of burning was the likely reason for the decrease in herbaceous plant cover, although the greater longleaf pine basal area, i.e. stand density, on the untreated and chemical woody plant control plots than on the three prescribed fire treatments was undoubtedly a contributing factor (Grelen and Enghardt 1973; Grelen and Lohrey 1978; Wolters 1973, 1982). In addition, the percentage of tree and shrub cover in the midstory and understory of the untreated plots had a further adverse effect on percentage of grass cover when compared to the chemical woody plant control treatment. Woody vine cover was greater on the two unburned treatments than on the three prescribed fire treatments because vines commonly found in the Southeast are susceptible to heat injury.

Nevertheless, chemical or mechanical woody plant control as a supplement to prescribed burning might allow for a longer frequency between prescribed fires, but prescribed fire will still be necessary to remove litter in longleaf pine plant communities especially when large areas of forests have to be burned each year. For example, the Southern Region of the US Forest Service prescribed burned 375,000 hectares per year from 2001 through 2009 (Personal Communication. 2011. William E. Bratcher. Fire/Lands Team Leader, Kisatchie National Forest, 2500 Shreveport Highway, Pineville, LA 71360), and such a task would not be possible by mechanically removing litter because of cost and terrain restraints.

Regardless of the benefits of fire in maintaining a herbaceous plant cover, the loss in longleaf pine growth on the prescribed fire treatments was a concern (Table 4). However, fire intensities were high regardless of when the burns were conducted and averaged 700 kJ/s/m of fire front across all prescribed fires (Haywood 2009), which was four times more intense than the 173 kJ/s/m threshold recommended for low intensity fires by Deeming and others (1977). Luckily, fires are not always this intense in native grass cover (Haywood 2011).

July burning was associated with greater grass and forb cover than burning in either March or May (Table 4). Although not statistically significant, plots burned in March had the lowest longleaf pine basal area of the three fire treatments, but the cover of grasses and forbs was similar to plots burned in May.

Overall, applying prescribed fire in May was a medium treatment that produced a good combination of outcomes when considering longleaf pine development, grass and forb cover, and control of woody vines and brush. Earlier work by Grelen (1975, 1983b) also reported that May (spring) was a better time to burn than March (late winter) or July (summer) in terms of longleaf pine seedling growth because of its morphological stage of development. Sword Sayer and Haywood (2009) found that longleaf pine seedlings were in good physiological condition to recover quickly from needle loss due to scorch from May applied fires, and Haywood (2009) reported that fire intensities were lower in May than if prescribed fires were applied in March or July.

EARLY BURNING IN A LONGLEAF PINE PLANTATION

In the fifth study, prescribed fire was first applied in May of the second growing season after longleaf pine seedlings were planted, and fire was reapplied another three times

(Haywood 2011). The intensive vegetation management treatment included both pre- and post-plant herbaceous and woody plant control practices. After 10 years, the untreated plots had significantly less longleaf pine basal area but more tree and shrub cover in the understory than the prescribed burned or intensive vegetation management treatments (Table 5). Therefore, unlike the fourth study, the prescribed burned plots had greater pine basal area than the untreated plots (Tables 4 and 5). One reason was probably the lower fire intensities at study 5 than 4, in which the fire intensities averaged 512 kJ/s/m of fire front study and were only three times more intense than the 173 kJ/s/m threshold recommended by Deeming and others (1977). The vegetation management treatment had the greatest longleaf pine basal area, but prescribed burning in May resulted in the greatest herbaceous plant cover and the fewest woody vines (Table 5). Thus, applying prescribed fire in May was again a medium treatment that produced a good combination of outcomes when considering longleaf pine development, grass and forb cover, and control of woody vines and brush.

CONCLUSIONS

Burning annually in March produced more forage than burning less frequently in March or burning in May regardless of frequency because more frequent burning kept litter from accumulating and smothering fresh herbage (Duvall 1962) and March burning allowed herbage to grow for the entire growing season (Tables 1 and 2). Conversely, percentages of grass and forb cover were significantly greater on plots burned in July than earlier in the growing season in Haywood's (2009) work (Table 4). However, percent cover and production are different variables and can not necessarily be compared nor do they always result in the same conclusions (Haywood 2010).

Overstory stand development, which was expressed as basal area per hectare, also influences herbage production (Grelen and Enghardt 1973; Grelen and Lohrey 1978; Wolters 1973, 1982). In Haywood and Grelen's (2000) work, the low basal area of overstory longleaf pine was partly responsible for the high production by understory vegetation (Table 1). Pine overstory basal areas did not significantly differ among burning treatments in Haywood and other's (2001) work, and there were also no significant differences among March, May, or July burns (Table 3).

These five studies directly apply to longleaf pine plant communities in the West Gulf region, and may be applicable in grass communities outside of the West Gulf region as well. It is difficult to statistically prove treatment differences in herbaceous production and percentage of cover in prescribed fire studies because natural variation often masks apparent treatment effects. By synthesizing information from these five studies, it was shown that frequency and season of prescribed burning affect understory production. The more frequent the burning, the more productive the understory herbaceous plant community will be. Two factors that affect this outcome are overstory basal area and the density and stature of understory woody plants, and long-term fire use especially influences understory and midstory woody vegetation. March burning was associated with more woody understory plants than May or July burning, which is counterproductive if herbaceous vegetation is the primary concern. Burning in July resulted in less longleaf pine basal area than burning in May. Therefore as a compromise treatment, burning in midspring rather than late winter or summer should result in acceptable longleaf pine growth, herbaceous plant production, and control of understory and midstory woody vegetation.

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Table 1—Stand characteristics after 20 years of prescribed burning; initially, the site was direct seeded in November 1968, prescribe burned 16 months later in 1970, and the overtopping trees were felled in early 1973 to form an even-aged stand of longleaf pine regeneration (Haywood and Grelen 2000)

Treatments	Understory production[a]	Basal areas Longleaf pine	Basal areas Loblolly pine	Basal areas Hardwoods
	(kg/ha)	(m^2/ha)	(m^2/ha)	(m^2/ha)
Unburned after 1970	< 1 b[b]	1.3 c	32.9 a	3.0 a
Biennial March burns	2027 a	9.1 bc	0 c	0.1 b
Triennial March burns	245 b	18.0 ab	0 c	0.4 b
Biennial May burns	550 b	21.3 a	1.9 b	0.2 b
Triennial May burns	339 b	24.4 a	0.2 c	0.7 b

[a] Understory vegetation was all herbaceous vegetation and woody plants less than 2.5 cm in diameter at 1.4 m above the ground.
[b] Based on Duncan's Multiple-Range Tests, columnar means followed by the same letter are not significantly different.

Table 2—Stand characteristics after 8 years of prescribed burning; the site was a 4-year-old slash pine plantation when prescribed burning began (Grelen 1983a)

Treatments	Understory condition	Herbaceous production	Pine basal area
		(kg/ha)	(m^2/ha)
Unburned	brush	205 c[a]	21.6 a
Annual March burns	grass	1123 a	17.2 a
Biennial March burns	grass	817 ab	19.3 a
Triennial March burns	grass	389 bc	20.0 a
Annual May burns	grass	651 b	22.7 a
Biennial May burns	grass	575 bc	22.3 a
Triennial May burns	grass	462 bc	21.3 a

[a] Based on Duncan's Multiple-Range Tests, columnar means followed by the same letter are not significantly different.

Table 3—Stand characteristics after 37 years of prescribed burning in a natural stand of longleaf pine, prescribed fire ceased on the unburned plots in 1961, but the other plots continued to be burned from 1962 through 1998 (Haywood and others 2001)

		Overstory basal areas		Understory	
Treatments	Herbaceous production	Pine	Hardwoods	Trees & shrubs	Average height
	(kg/ha)	(m^2/ha)	(m^2/ha)	(stems/ha)	(m)
Unburned after 1961	12 b[a]	18.4 a	8.3	19,800 ab	0.91 a
Biennial March burns	940 a	22.3 a	…	37,900 a	0.63 a
Biennial May burns	1016 a	30.2 a	…	7300 c	0.33 b
Biennial July burns	1380 a	15.1 a	…	10,900 bc	0.38 b

[a] Based on Duncan's Multiple-Range Tests, columnar means followed by the same letter are not significantly different.

Table 4—Stand characteristics after four biennial prescribed fires or biennially applied chemical weeding treatments in a 14-year-old longleaf pine plantation; treatments began in the seventh growing season and ended in the thirteenth growing season (Haywood 2009)

		Percent cover[a]			
Treatments	Longleaf pine basal area	Grasses	Forbs	Woody vines	Trees and shrubs
	(m^2/ha)	(%)	(%)	(%)	(%)
Untreated	24.1 a[b]	2 d	1 c	13 a	53 a
Biennial weeding	23.4 a	4 c	1 c	11 a	5 c
Biennial March burns	13.8 b	35 b	3 b	2 b	17 b
Biennial May burns	16.4 b	32 b	3 b	1 b	10 bc
Biennial July burns	15.5 b	44 a	9 a	1 b	8 bc

[a] Percentages were arcsine square root transformed before analysis.
[b] Based on Duncan's Multiple-Range Tests, columnar means followed by the same letter are not significantly different.

Table 5—Stand characteristics after four biennial prescribed fires applied in May or intensive vegetation management with herbicides in a 10-year-old longleaf pine plantation; the first burns were applied in the second growing season and ended in the ninth growing season and vegetation management began before planting and continued through third growing season after planting (Haywood 2011)

Treatments	Longleaf pine basal area	Percent cover[a]			
		Grasses	Forbs	Woody vines	Trees and shrubs
	(m^2/ha)	(%)	(%)	(%)	(%)
Untreated	7.1 c[b]	7 b	1 b	10 b	91 a
May prescribed fires	11.6 b	38 a	4 a	4 c	24 b
Intensive vegetation management	22.4 a	3 b	1 b	23 a	27 b

[a] Percentages were arcsine square root transformed before analysis.
[b] Based on Duncan's Multiple-Range Tests, columnar means followed by the same letter are not significantly different.

ICE DAMAGE EFFECTS ON THINNED LOBLOLLY PINE (*PINUS TAEDA*) STANDS IN SOUTHEASTERN OKLAHOMA

Thomas Hennessey, Robert Heinemann, Randal Holeman, Rodney Will, Thomas Lynch, Douglas Stevenson, Edward Lorenzi, and Giulia Caterina

Loblolly pine plantations in southeastern Oklahoma and Arkansas are periodically subjected to damaging ice storms. Following one such event, damage to a 25-year-old, previously thinned stand was assessed and quantitative relationships were developed to guide stand management in ice storm-prone areas.

Our objective was to assess the impact of ice-loading on stand structure and survivability, and to determine the predictive power of pre-storm stand parameters to estimate potential susceptibility of plantations to ice damage.

The loblolly pine stand was measured for the following: (1) pre-storm tree height (feet), (2) pre-storm dbh (inches), (3) pre-storm height (feet) to base of live crown, (4) pre-storm percent live crown, (5) post-storm dbh (inches), (6) post-storm tree mortality, (7) post-storm tree diameter (inches) at point of bole breakage, (8) post-storm height (feet), (9) post-storm tree height (feet) at point of bole breakage, (10) post-storm height (feet) to base of live crown, *(11)* post-storm percent of crown missing or damaged,(12) post storm percent of live crown, (13) post storm tree lean, and (14) post storm insect damage (present or absent). Parameters 1, 2, 4, 5, 8, 10, 11, and 12 are predictors that were assessed in the development of a regression equation to predict potential damage by ice to thinned stands.

Loblolly pine pre-storm tree dbh, height, and percent live crown were useful to predict post ice storm tree height loss (Table 1). The prediction equation (Height Loss Due to Ice Damage = - 26.40 + Pre-storm dbh (1.82) + Pre-storm Percent Live Crown (-3.26) + Pre-storm Height (- 0.14)) (R^2 = 0. 213 (F = 17.90, df (3, 198), $p<0.0001$)) could be used to estimate potential loss of tree height and in turn the amount of standing timber volume lost due to ice damage. This equation had the maximum R^2 among all equations with three independent variables.

The regression analysis suggested that the pre-storm tree diameter is the strongest predictor (t = 4.60, $p<0.0001$) of potential height loss due to ice damage (Table 2). With this in mind, another regression analysis was performed regressing post-storm tree height loss to pre-storm dbh. Height Loss Due to Ice Damage = - 36.80 + Pre-storm dbh (1.68) (R^2 = 0. 209 (F = 53.13 df (1, 200), $p<0.0001$)). Therefore, the height loss could be predicted from pre-storm dbh alone (t = 7.29, $p<0.0001$). This equation is much simpler and of particular value when pre-storm tree height and pre-storm percent of live crown were not known.

In this study, trees with larger dbh's tended to lose more height due to ice-loading. Shorter trees with a smaller live crown ratios were more likely to be damaged.

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Table 1—Pre- and post-storm loblolly pine metrics

Variable	% CROWN DAMAGE	N	MEAN	STD DEV	MAX	MIN
Pre-Storm Height Year 2000 (Feet)	No Crown Damage	202	75.6	4.7	88.5	54.5
Pre-Storm Diameter Year 2000 (Inches)	No Crown Damage	202	13.4	3.1	24.7	6.6
Pre-Storm Percent Live Crown Year 2000	No Crown Damage	202	27.8	8.0	48.7	14.3
Post Storm Height Year 2001 (Feet)	No Crown Damage	48	76.2	7.5	89.8	58.9
	1% TO 25%	46	76.2	4.9	88.1	63.0
	26% T0 50%	58	73.4	7.0	94.4	56.3
	51% TO 75%	18	62.1	10.2	74	41.9
	76% TO 99%	8	62.7	8.7	71.1	48.2
	100 % CROWN LOSS	24	37.4	14.9	56.8	14.8
Post Storm Diameter Year 2001 (Inches)	No Crown Damage	48	9.1	2.7	17.6	5.7
	1% TO 25%	46	14.0	3.2	21.5	1.5
	26% T0 50%	58	14.5	3.6	25.5	7.9
	51% TO 75%	18	13.5	2.7	17	8.2
	76% TO 99%	8	11.8	2.9	19.1	9.2
	100 % LOSS OF CROWN	24	9.2	2.0	13.5	6.2
Total Height Loss From Damage (Feet)	No Crown Damage	48	0	0	0	0
	1% TO 25%	46	7.2	5.8	19.17	0
	26% T0 50%	58	12.7	5.5	25.0	0
	51% TO 75%	18	15.1	5.4	23.0	8.3
	76% TO 99%	8	15.7	4.3	22.9	11.1
	100 % LOSS OF CROWN	24	39.9	13.3	66.0	21.0

Table 2—Regression analysis of predictors of tree height loss.

R-Squared	Coefficient of Variance	Root MSE	Mean Height Loss
0.210246	-68.17096	10.21518	-14.98465

Parameter	Estimate	STD Error	t Value	Pr >	t	
Intercept	-26.39867788	12.13364051	-2.18	0.308
Pre Storm Diameter	1.81907633	0.39553198	4.6	<.0001
Pre Storm Percent Live Crown	-3.25611597	11.35658543	-0.29	0.7746
Pre Storm Height	-0.138337156	0.15756510	-0.88	0.3809

MANAGEMENT INTENSITY AND GENETICS AFFECT LOBLOLLY PINE CROWN CHARACTERISTICS

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ABSTRACT

The development of elite loblolly pine (*Pinus taeda* L) genotypes may lead to reduced planting densities as a means of reducing establishment costs. However, this can lead to undesirable crown and branch characteristics in some genotypes. Selecting appropriate genetic material, combined with appropriate silvicultural management, is essential to realizing potential genetic gains. A study was established in 2008 to examine the performance of two loblolly pine varieties, a "crop tree" ideotype and a "competitor" ideotype, at different initial tree spacings and management intensities. After two growing seasons, genetics were already affecting crown morphology. The crop tree ideotype was, on average, taller, had longer and wider crowns, greater crown volume, and less acute branch angles. Management intensity had greater impact on crown characteristics than genotype. Intensive management resulted in trees that averaged over 1.1 ft (~24%) taller with wider crowns (0.7 ft, 30%), longer crowns (0.9 ft, 32%), and greater crown volume (5.5 ft^3, 133%) relative to non-intensive management. Differences due to management intensity were related to reduced crowding from competing vegetation and lower incidence of damage from pine tip moth and sawfly.

INTRODUCTION

Due to increasing population, demand for wood products continues to increase. Numerous improvements have been made in the management of loblolly pine, and large increases in growth have been reported in recent years (Borders and Bailey 2001). Such improvements have come about due to improvements in management practices, seedling quality, mechanical and chemical site preparation, density management, and fertilization (Jokela and others 2004).

Researchers have also used genetic tree improvement as a means for increasing productivity of loblolly pine forests, resulting in a steady progression of improved yields over the past five decades. Genetic manipulation of trees through breeding and selection has improved wood quality, growth rates, and disease resistance of loblolly pine (Fox and others 2007). These improvements were attained by utilizing offspring from high quality female parent trees that have been tested in open-pollinated half-sib family blocks (McKeand and others 2006). Further improvements have been made using controlled pollination, a technique allowing selection of both parents which results in potentially superior full-sib offspring for planting. While controlled pollination was originally used in the breeding and testing phases of tree improvement programs, the forest industry has now adopted Mass Controlled Pollination (MCP) techniques as a means of producing full-sib seedlings. MCP allows the capture of a greater amount of genetic variation, theoretically, resulting in faster growth rates, better tree form, and increased disease resistance on an operational scale (Bramlett 1997).

Clonal forestry has the potential for even greater genetic gains (Mckeand and others 2003), and may be obtained by the utilization of somatic embryogenesis (Pullman and others 2002). Somatic embryogenesis method uses the results from full-sib progeny tests to determine which specific parents will be crossed to recreate a similar selected full-sib family. From a specific cross, embryos are harvested, and developed into plants that can be clonal tested. Each individual embryo is a clone (today known as a variety) (Wright and Dougherty 2006). A number of varieties can then be included into a set of varietal tests to determine selections for operational deployment. Like any other genetic tests these varietal can be specifically selected for characteristics that coincide with a targeted product. For example, phenotypic characteristics desirable for sawtimber might include superior stem form, good self-pruning ability, and wood characteristics needed for quality structural grades (Wright and Dougherty 2006). The development of elite loblolly pine varietals may lead to reduced planting densities thus reducing establishment costs. Combining appropriate select genetic material, with a corresponding level of silvicultural management, is essential to realizing potential genetic gains (McKeand and others 2003).

A study was established in 2008 to examine the performance of two loblolly pine varieties, one selected as a sawtimber "crop tree" ideotype and the other as a "competitor" ideotype, at different initial tree spacings and management intensities. The overall objective of the study was to compare the performance of the two ideotypes across different stem densities and management intensities. The specific objective of this analysis is to compare treatment effects on stem and crown form of two contrasting loblolly pine varieties.

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METHODS

The study is located on Mississippi State University's Coastal Plain Branch Experiment Station near Newton, Mississippi (32˚20'19"N 89˚05 51"W). Soils on the site are classified as a Prentiss, very fine sandy loam with an approximate site index for loblolly pine of 88 feet at base age 50. The site had previously been in agricultural production resulting in somewhat compacted soils. The site received a broadcast application of Glyphosate (64 ounces per acre) in September 2007, and was sub-soiled to a depth of approximately 14 inches in October of 2007. The site received a second broadcast application of Glyphosate (32 ounces per acre) in March of 2008 prior to being hand planted with containerized seedlings in late April/early May of 2008.

Treatments consisted of two levels of management intensity, two genetic varieties of loblolly pine, and three initial planting spacings. The two levels of management intensity included a standard intensity (low) and a high intensity (high). In addition to the chemical site preparation and sub-soiling described above, both high and low intensity plots received herbaceous competition control in year 1 through a broadcast application of Oustar® (10 ounces per acre). Additional management input applied to high intensity plots included tipmoth control in the form of a single SilvaShield™ tablet (Bayer Environmental Science) in the planting hole at time of planting, PTM™ insecticide (BASF Corp.) injected 3-6 inches deep into the soil adjacent to each tree (0.05 ounces per tree) in years 2 and 3 for additional tipmoth control, herbaceous competition control in year two (1 ounce per acre of Escort®, 16 ounces per acre of Arrow®, 32 ounces per acre of Goal®), and mowing competing vegetation in year 3.

Two varietal genotypes of loblolly pine were included in the study based on their putative divergent crown architectures. The varieties, produced by ArborGen, LLC, included one considered to be a competitor ideotype (comp) characterized by a wider crown form, and another considered to be a crop tree ideotype (crop) with a more narrow, compact crown form. The three initial tree spacings were 6 x 14 ft (519 tpa), 9 x 14 ft (346 tpa), and 16 x 14 ft (194 tpa).

The study was set up as a 2x2x3 factorial design with split plots. Main effects treatments included the two levels of management intensity and the two genetic varieties, with main effects treatment plots split by the three initial planting spacings. Trees within the spacing subplots were planted in 64-tree blocks (8 x 8 trees) with the inner 36 trees constituting the measurement plots. Each treatment combination was replicated four times.

Initial heights were recorded following planting in May 2008. Age-one heights were recorded in December 2008. Year-two measurements, taken at the end of the 2009 growing season, consisted of ground line stem diameters, height to the base of the live crown, and total height on all trees. Crown and branch measurements were recorded on trees within an inner 16-tree (4 x 4 tree) measurement plot. Branch angle, branch length, and branch diameter one inch from the main stem were recorded on the two longest branches in the first primary whorl from the base of the tree. Height was measured using a height pole and recorded to the nearest one tenth of a foot. Branch diameter was measured using a caliper and recorded to the nearest one tenth of an inch. Branch angle was measured using a protractor to judge the angle of the branch adjacent to the main stem. Branch angle was recorded to the nearest five degrees. Crown diameter was the average of measurements taken in two directions. For this analysis, we tested for spacing, management intensity and varietal differences in crown characteristics following the second growing season. All reported differences are based on a critical value of alpha=0.05.

RESULTS AND DISCUSSION

Results for year-two crown widths show there were significant differences by variety and management intensity, but not by spacing. Mean crown width of the crop tree ideotype (2.7 feet) was nearly one half of a foot greater than the competitor ideotype (2.3 feet) (Figure 1). Mean crown widths on the high intensity management plots were 0.8 feet wider than on the low intensity management plots (Figure 2).

Significant differences in mean branch length occurred with management intensity. Mean branch length on high intensity plots averaged 2.1 feet compared to 1.5 feet on low intensity plots (Figure 3). The crop tree ideotype did have slightly longer (0.1 feet) mean branch lengths than the competitor ideotype but the difference was not significant.

Branch diameters also differed significantly by management intensity, with mean branch diameters on high intensity management plots (0.36 inches) larger than on low intensity plots (0.30 inches) (Figure 4). The crop tree ideotype again had slightly larger mean branch diameters than the competitor ideotype but the difference was not significant (Figure 5).

High intensity plots where expected to have wider crowns, longer branches, and larger branch diameters than low intensity plots, as higher intensity management typically produces more growth compared to low or non-managed sites. Crown widths, branch lengths, and branch diameters on high intensity plots were all significantly greater than on low intensity plots. This was likely due to reduction of competing vegetation and lower incidence of damage from pine tip moth and sawfly in high intensity management plots allowing for greater crown development.

Analysis of branch angles in year two showed a significant difference by genetic variety. The mean branch angle of the crop tree ideotype was 49˚ while the competitor ideotype had a mean branch angle of 46˚ (Figure 6). There were no differences in mean branch angle by management intensity or initial spacing.

The results of crown and branch measurements indicate genetics are already playing a role in crown characteristics. The crop tree ideotype was, on average, taller, had longer and wider crowns, greater crown volume, and wider branch angles than the competitor ideotype. Initial observations concerned us if the crop tree ideotype selected was actually performing as a crop tree. However, according to Cannell (1978), the crop tree ideotype being tested here is performing as a crop tree. Crop trees are efficient users of locally available resources and do not compete strongly with neighboring trees. These characteristics enable the crop tree ideotype to produce greater yields than trees of a competitor ideotype in intensively managed monocultures. In fact, the crop tree ideotype in this study outperformed the competitor ideotype by 15 percent for mean height at the end of the year 2 (Roberts and others [in press], these proceedings). These early results indicate that the varietal material retains its inherent ability to exhibit those selected stem and crown characteristics regardless of spacing.

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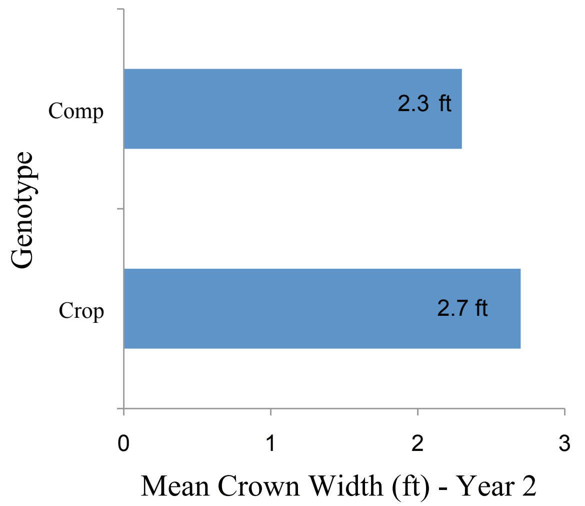

Figure 1—Mean year-2 crown widths for contrasting loblolly pine crown ideotypes planted in a spacing by management intensity trial in central Mississippi.

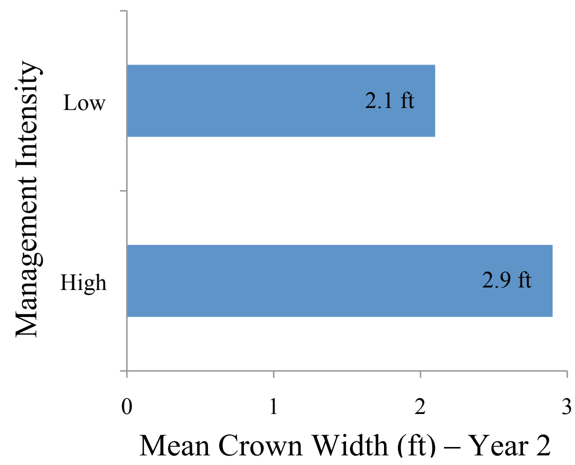

Figure 2—Mean year-2 crown widths for loblolly pine varietal seedlings managed at different management intensities in central Mississippi.

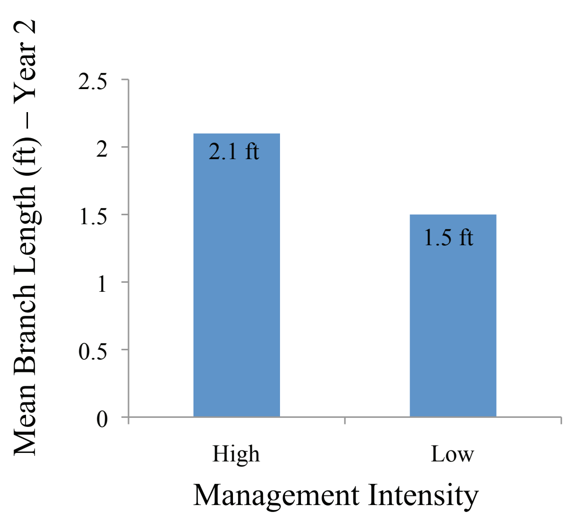

Figure 3—Mean year-2 branch lengths for loblolly pine varietal seedlings managed at different management intensities in central Mississippi.

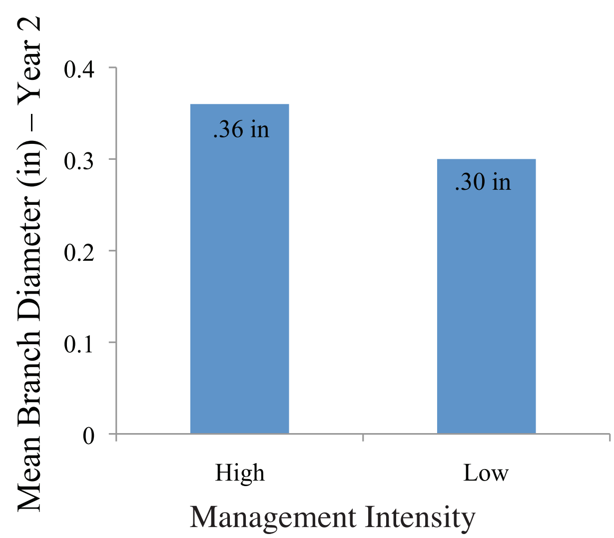

Figure 4—Mean year-2 branch diameters for loblolly pine varietal seedlings managed at different management intensities in central Mississippi.

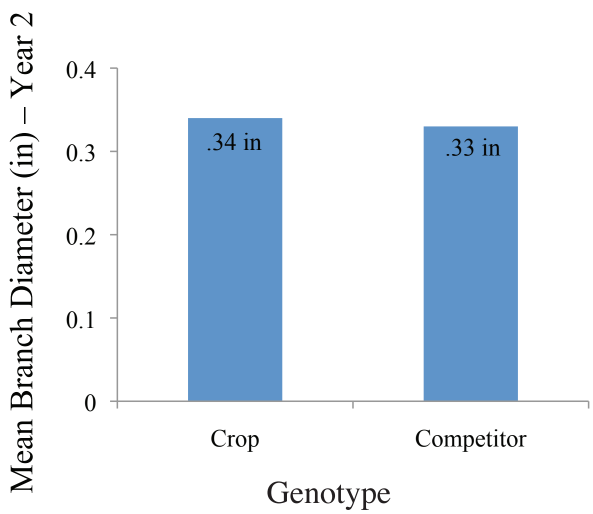

Figure 5—Mean year-2 branch diameters for contrasting loblolly pine crown ideotypes planted in a spacing by management intensity trial in central Mississippi.

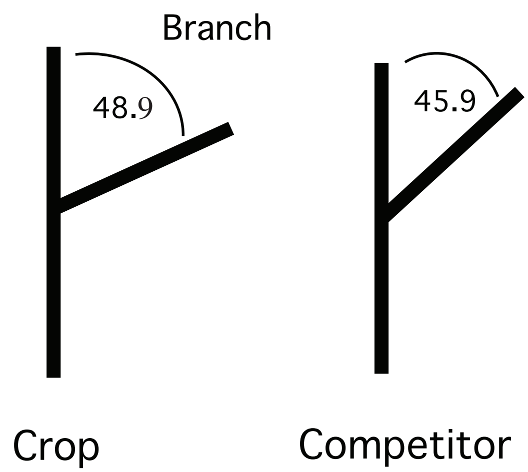

Figure 6—Mean year-2 branch angles for contrasting loblolly pine crown ideotypes planted in a spacing by management intensity trial in central Mississippi.

EVALUATING DIFFERENT PLANTING STOCKS FOR OAK REGENERATION ON HURRICANE KATRINA DISTURBED LANDS

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ABSTRACT

Three oak planting stocks were evaluated to determine their influence on survival and initial growth. Planting stocks utilized included conventional containerized seedlings in 240 centimeter^3 (cm^3) containers, 1-0, bareroot seedlings, and Root Production Method (RPM™) seedlings in 11.4 liter (L) containers. Initial height, groundline diameter (GLD), and survival were assessed after planting and at the conclusion of the first growing season. Species planted were swamp chestnut oak (*Quercus michauxii* Nutt.) and Nuttall oak (*Q. texana* Palmer). Study sites were located in southern Mississippi on lands disturbed by Hurricane Katrina. Statistical comparisons of growth and survival among species and planting stocks were performed. RPM™ and bareroot seedlings exhibited similar growth and survival, and both were greater than conventional containerized seedlings. Bareroot seedlings could be the most economically feasible planting stock to utilize for artificial oak regeneration.

INTRODUCTION

Oaks are valuable to southern forests for timber production and wildlife habitat (Moree and others 2010, Ezell and others 1999). However, the oak component of many bottomland hardwood stands in the southern United States has been decreasing for many years (Nix and Barry 1992, Nix 1988, Chambers and others 1986, Johnson 1984,), and oaks are often lacking following harvest (Loftis 1988, Beck and Hooper 1986). Successfully regenerating a stand following harvest is one of the challenges of hardwood silviculture (Belli 1999). Many hardwood regeneration managers utilize natural regeneration to adhere to landowner objectives (Coder 1994). However, natural regeneration alone is not always practical in situations where oak regeneration is desired (Dey and others 2008). Naturally regenerated oaks are often unable to compete with faster-growing competitors (Kellison 1993) because oak seedlings are poor competitors with herbaceous vegetation which grows rapidly in bottomland systems throughout the South.

Planting poor quality seedlings can also complicate artificial oak regeneration (Duryea 1985). Dey and Parker (1997) reported that planting high quality seedlings is an essential element of any artificial regeneration prescription. Seedlings with larger initial diameters and more fully developed root systems have shown greater survival and growth rates (Kormanick and others 1998, 1995). Larger seedlings also tend to perform better against competing vegetation (Dey and others 2008).

Proper planting is fundamental to ensure seedling survival. Both hand planting and machine planting can be effective if experienced, conscientious personnel oversee the planting job (Gardiner and others 2002). Improper planting such as J-rooting or shallow planting, increases the chance of mortality for a seedling. Thus, using high quality seedlings provides no advantage if a poor planting job is implemented.

Numerous research projects have been conducted to address the previously mentioned regeneration problems, but little research has been conducted comparing the survival and growth of various oak planting stocks. Also, Hurricane Katrina created a need for hardwood regeneration on thousands of acres. Therefore, this research project had the potential to provide valuable information to land managers considering planting hardwoods.

MATERIALS AND METHODS

Two study areas were utilized in this project. The first area, the Gordon Tract, is located approximately 26 kilometers (km) southwest of Poplarville, MS in the floodplain of the Pearl River. The study area encompasses approximately 1.6 hectares (ha) within an area that received a salvage harvest due to damage from Hurricane Katrina. The soil series is Latonia fine sandy loam (coarse-loamy, siliceous, semiactive, thermic Typic Hapludults) with 0 – 2 percent slopes. Average annual precipitation is 152 cm, average temperature in winter is 12°C, and average temperature in summer is 27°C. The second study area, the Brooke Tract, is located approximately 21 km northeast of Picayune, MS and also encompasses approximately 1.6 ha. This

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site also received a salvage harvest due to damage from Hurricane Katrina. The soil series is Harleston (coarse-loamy, siliceous, semiactive, thermic Aquic Paleudults) with slopes 0 – 2 percent. Average annual precipitation is 145 cm, average winter temperature is 11°C, and average summer temperature is 27°C.

Two species, Nuttall oak and swamp chestnut oak with three planting stocks: 11.4 L RPM™ seedlings, conventional containerized seedlings with a 240 cm^3 container, and high-quality 1-0, bare-root seedlings, for a total of six species/planting stock combinations were utilized in this study. A randomized complete block design, with three replicates was employed in this study. A total of 3,600 seedlings were planted. Each site had a total of 1800 seedlings planted consisting of: 300 bare-root swamp chestnut oak, 300 bare-root Nuttall oak, 300 RPM™ swamp chestnut oak, 300 RPM™ Nuttall oak, 300 containerized swamp chestnut oak, and 300 containerized Nuttall oak. Each replicate consisted of 100 seedlings per species/planting stock combination. Each six species/planting stock combinations was randomly assigned within each replicate. Seedlings were planted on 3.05 meter (m) x 3.05 m spacing. All seedlings were hand planted with planting shovels in February 2009. Bare-root and conventional containerized seedlings were planted by Mississippi State University personnel and RPM™ seedlings were planted by a crew hired by the Forrest Keeling Nursery in Elsberry, MO.

Both mechanical and chemical techniques were utilized during site preparation. The Gordon Tract received mechanical site preparation only. The landowner was responsible for having all woody harvest debris pushed out of planting areas following the salvage harvest using a bulldozer. Both chemical and mechanical site preparation techniques were utilized on the Brooke Tract. A broadcast application of Accord XRT® (9.3 L per ha) and Garlon 4® (2.3 L per ha) was applied during the first week of November 2008. Chemical site preparation was deemed necessary due to the presence of undesirable woody species. The landowner was responsible for site preparation which was completed using a sprayer affixed to an agricultural tractor. The planting site was burned three weeks after herbicide application. After burning, the landowner pushed residual brush out of the planting site with a bulldozer.

All bare-root seedlings received a post-plant, pre-bud break herbicide treatment of Oust XP® (140.0 grams (g) per sprayed ha) February 29, 2009 applied as a 1.5 m band over the top of the seedlings. The herbicide was applied with 11.4 L backpack sprayers. Caution was taken to only apply the herbicide when there was little to no wind to avoid drift. A Solo® backpack sprayer was used for herbicide application at a rate of 93.5 L per sprayed hectare.

Measurements were recorded after planting and at the conclusion of the first growing season. Height was measured to the nearest centimeter on bare-root and conventional container seedlings using height sticks. Height of RPM™ seedlings was measured to the nearest tenth of a foot using height poles and converted into centimeters. GLD was measured to the nearest tenth of a millimeter (mm) using digital calipers. Seedling survival was based on visual inspection.

Statistical Analysis System (SAS) software version 9.2® was used for statistical analyses. Statistical analyses were performed using PROC SORT, PROC MEANS, and PROC GLM. Least square means was used to perform means separation among treatments. Arcsine transformation was used to normalize survival data. Actual means are presented for purpose of interpretation. Differences were considered significant at $\alpha = 0.05$.

RESULTS

RPM™ swamp chestnut oak seedlings (13.4 cm) had the most height growth, while conventional containerized Nuttall oak seedlings (-16.8 cm) had the least on the Gordon Tract (Table 1). Both species of RPM™ seedlings had the most height growth on the Brooke Tract (Table 2). RPM™ seedlings (11.0 cm) had the most height growth, while bare-root seedlings (-0.2 cm) were significantly greater than conventional containerized seedlings (-11.8 cm) on the Gordon Tract (Table 3). Again, RPM™ seedlings (13.5 cm) exhibited the most height growth, while bare-root seedlings (7.1 cm) were significantly greater compared to conventional containerized (-4.4 cm) seedlings on the Brooke Tract (Table 4).

Nuttall oak seedlings of all planting stocks had significantly more GLD growth compared to swamp chestnut oak seedlings (Table 1) resulting in no significant differences among the planting stocks on the Gordon Tract (Table 3). While Nuttall oak had the most GLD growth for all planting stocks, it was only significantly greater than conventional containerized seedlings on the Brooke Tract (Table 2). RPM™ seedlings had significantly greater GLD growth compared to conventional containerized and bare-root seedlings on the Brooke Tract (Table 4). Conventional containerized seedlings had significantly less GLD growth compared to bare-root seedlings.

There were no significant differences in survival between species for RPM™ and bare-root seedlings on the Gordon Tract (Table 1). Nuttall oak had significantly higher survival than swamp chestnut oak for only conventional containerized seedlings on the Brooke Tract (Table 2). RPM™ and bare-root seedlings did not differ significantly but both had significantly higher survival than conventional containerized seedlings on both tracts (Tables 3 and 4).

DISCUSSION

Previous research comparing RPM™ seedlings and bare-root seedlings has been variable. Several previous studies have documented RPM™ seedlings to have greater height growth than other planting stocks. Shaw and others (2003) reported RPM™ pin oak (*Quercus palustris* Münchh.) and swamp white oak (*Quercus bicolor* Willd.) seedlings to have greater first-year height growth compared to bare-root seedlings in Missouri. Dey and others (2003), as well as, Kabrick and others (2005) also reported RPM™ pin oak and swamp white oak seedlings had greater first-year height growth compared to bare-root seedlings in Missouri. However, several Missouri studies have reported RPM™ hardwood seedlings to have less third-year height growth than bare-root seedlings (Dey and others 2003, 2006, Kabrick and others 2005).

Previous studies have shown containerized oak seedlings to have greater height growth compared to other planting stocks. Teclaw and Isebrands (1993) reported northern red oak containerized seedlings had greater height growth than bare-root seedlings after two and three growing seasons. Burkett and Williams (1998) reported small containerized Nuttall oak seedlings had greater first-year height growth compared to bare-root seedlings in Mississippi, Louisiana, and Texas. Williams and Stroupe (2002) reported small containerized water oak (*Quercus nigra* L.) and willow oak (*Quercus phellos* L.) seedlings had greater first-year height growth compared to bare-root seedlings in Texas. However, Kormanik and others (1976) reported bare-root cherrybark oak (*Quercus pagoda* Raf.) seedlings had greater height growth compared to small containerized seedlings for the first four years after outplanting in Georgia.

GLD growth results were not surprising as Nuttall oak is known to exhibit excellent early growth (Miwa and others 1992, Williams and others 1992). However, the lack of significant difference in GLD growth among planting stocks on the Gordon Tract was surprising (Table 3). Larger planting stocks have been shown to exhibit more early growth than smaller planting stocks as discussed previously. GLD results on the Brooke Tract might be more typical for the three planting stocks observed in this study as the largest planting stock had the most GLD growth and the smallest planting stock had the least.

The application of Oust XP® is a possible explanation for bare-root seedling survival compared to conventional containerized seedlings. Herbaceous weed control has been proven to be effective at increasing early survival of bare-root oak seedlings (Ezell and Hodges 2002, Ezell and Catchot 1998) due to reduced competition for soil moisture. Containerized oak seedlings have been shown in previous studies to have excellent early survival without herbaceous weed control (Miller 1999). Though survival of conventional containerized seedlings was significantly less than RPM™ or bare-root seedlings, 71-85 percent survival is considered acceptable for most land managers.

With the smallest and shallowest root system of the three planting stocks used in this study, conventional containerized seedlings were possibly not able to compete with herbaceous competition for soil moisture as well as the bare-root and RPM™ seedlings. Previous studies have shown that water deficit can be a primary contributor to early mortality of newly planted seedlings (Kramer 1986, Kozlowski and Davies 1975). Russell and others (1997) concluded that competing vegetation is the primary cause of oak seedling mortality due to competing vegetation can capture much of the available soil moisture (Newton and Comeau 1990). Though no rain gauges were installed on the sites, monthly precipitation data from the nearest weather station were noted. The weather station was located approximately 25.7 km from both the tracts, and recorded precipitation levels 6.4 cm below average for April, 8.9 cm below average for July, and no precipitation recorded for the months of June and September. It is possible that the lack of rainfall combined with the associated lack of soil moisture was a major contributor to first-year seedling mortality in this study. With the documented lack of rainfall during first growing season, the results of this study indicate that small containerized seedlings may be susceptible to a lack of soil moisture combined with herbaceous competition. Previous studies have shown conventional containerized oak seedlings to exhibit greater survival than bare-root seedlings without herbaceous weed control. Williams and Craft (1997) reported first-year survival of Nuttall oak seedlings to be greater for containerized seedlings (84%) as compared to bare-root seedlings (38%) in Mississippi without weed control. Miller (1999) reported containerized oak seedlings to exhibit greater survival than 1-0 bare-root seedlings without application of herbaceous weed control. Burkett and Williams (1998) reported 96 percent first-year survival of containerized Nuttall oak seedlings, whereas 1-0, bare-root seedlings averaged 45 percent survival without weed control. In the same study Burkett and others (2005) reported third-year survival of 1-0, bare-root seedlings (45%) to be greater than containerized seedlings (39%). Williams and Stroupe (2002) reported 81 percent first-year survival of bare-root seedlings and 83 percent for containerized seedlings of water and willow oaks in Texas.

CONCLUSIONS

This study found that high quality 1-0, bare-root seedlings that are properly handled can perform as well or better than more expensive containerized planting stocks. Further research is needed to determine if current growth patterns will continue for several growing seasons in order to assess the full potential of these three planting stocks. Several years of growth and survival observations would be helpful in determining which of these planting stocks will perform the best. Although economics of each planting stock were not evaluated in this study, bare-root was the least expensive ($0.25/seedling) planting stock, followed by conventional containerized ($1.50/seedling), with RPM™ seedlings ($15.00/seedling) being the most expensive. Given that the bare-root seedlings performed as well or better than either RPM™ or conventional containerized seedlings, this study indicates that bare-root seedlings could possibly be the most feasible choice when deciding which planting stock to utilize for optimizing early growth and survival.

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Table 1—Average first year height growth, groundline diameter growth, and survival by planting stock and species on the Gordon Tract

Planting Stock/Species		Height Growth	GLD Growth	Survival
		-----cm-----	-----mm-----	-----%-----
RPM™[1]				
	NUO[2]	8.5b[3]	3.96a	98.7a
	SCO	13.4a	3.18b	96.7ab
BR				
	NUO	-1.4c	4.38a	93.3ab
	SCO	1.0c	2.41c	91.7ab
CC				
	NUO	-16.8e	3.91a	81.9bc
	SCO	-6.7d	2.49c	71.3c

[1]RPM™ = root production method, BR = bare-root, CC = conventional containerized
[2]NUO = Nuttall oak, SCO = swamp chestnut oak
[3]Values in a column followed by same letter do not differ at α = 0.05

Table 2—Average first year height growth, groundline diameter growth, and survival by planting stock and species on the Brooke Tract

Planting Stock/Species	Height Growth	GLD Growth	Survival
	-----cm-----	-----mm-----	-----%-----
RPM™[1]			
NUO[2]	12.7a[3]	4.13a	95.7a
SCO	14.3a	3.94ab	98.7a
BR			
NUO	4.7c	3.70ab	97.0a
SCO	9.5b	3.60b	96.0a
CC			
NUO	-1.8d	1.89c	85.3b
SCO	-7.0e	1.01d	73.2c

[1]RPM™ = root production method, BR = bare-root, CC = conventional containerized
[2]NUO = Nuttall oak, SCO = swamp chestnut oak
[3]Values in a column followed by same letter do not differ at $\alpha = 0.05$

Table 3—Average first year height growth, groundline diameter growth, and survival by planting stock on the Gordon Tract

Planting Stock	Height Growth	GLD Growth	Survival
	-----cm-----	-----mm-----	-----%-----
RPM™[1]	11.0a[2]	3.57a	97.7a
BR	-0.2b	3.40a	92.5a
CC	-11.8c	3.20a	76.6b

[1]RPM™ = root production method, BR = bare-root, CC = conventional containerized
[2]Values in a column followed by same letter do not differ at $\alpha = 0.05$

Table 4—Average first year height growth, groundline diameter growth, and survival by planting stock on the Brooke Tract

Planting Stock	Height Growth	GLD Growth	Survival
	-----cm-----	-----mm-----	-----%-----
RPM™[1]	13.5a[2]	4.04a	97.2a
BR	7.1b	3.65b	96.5a
CC	-4.4c	1.45c	79.3b

[1]RPM™ = root production method, BR = bare-root, CC = conventional containerized
[2]Values in a column followed by same letter do not differ at $\alpha = 0.05$

WHOLE CANOPY GAS EXCHANGE AMONG ELITE LOBLOLLY PINE FAMILES SUBJECTED TO DROUGHT STRESS

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Future climate change simulations predict that the southeastern United States will experience hydrologic patterns similar to that currently found in the Western Gulf Region, meaning, that planted elite loblolly families may be subject to drier, hotter summers (Ruosteenoja et al. 2003, Field et al. 2007). Currently, there is little research on how these fast-growing loblolly families will perform under severe, summertime drought conditions. The summer of 2010 was extremely dry in northern Louisiana. From March to October precipitation totals were 46.3 cm (54%) below the 30 year average making this one of the driest summers on record (NOAA 2010). The objectives of this study were to determine how severe drought stress effected total tree leaf area, specific light saturated photosynthesis (A_{Sat}), and canopy level light saturated photosynthesis (A_{Can}) among four fast-growing loblolly families.

Four seed sources of loblolly pine (Pinus taeda L.) were planted in 0.15-acre plots at the LSU AgCenter Hill Farm Research Station in northwest Louisiana in January 2005. Each seed source was replicated 12 times in a randomized complete block design. All seed sources were from the eastern portion of the loblolly pine range. Two of the seed sources were of open-pollinated half-sib families (7-56 and 8-103), and two seed sources were clones (CL93 and CL9).

Gas exchange measurements were taken monthly from May to September 2010 using an open-flow, infrared gas analyzer equipped with 2 x 3 cm cuvette with a blue–red LED light source (Li-Cor 6400, Lincoln, Nebraska). Specific light saturated photosynthesis (A_{Sat}) measurements were taken on excised needles from the upper half of the tree. Measurements were made on previous year's latest fully elongated needles "OLD", and current year's first flush of needles "NEW". For this experiment these values were averaged into a single value. Total leaf area was estimated from allometric equations developed from destructive harvest of 24 trees harvested in September 2009. Allometric equations between height, diameter, and leaf biomass were created. Specific leaf area was used to convert total leaf biomass to total leaf area. These values were used to scale A_{Sat} rates to the canopy level C assimilation (A_{Can}).

Specific A_{Sat} did not differ among families, except for on the September sampling date when conditions were at their driest (Figure 1). Leaf area was consistently different among the families with 7-56>CL9>8-103>CL93. Clone 93 maintained the lowest canopy level A_{Can} rates throughout the summer (Figure 1). This resulted in CL 93 accumulating comparatively less stem volume than the other three families. The percent change in stem volume is 21.7, 18.8, 17.7, and 7.2 percent, respectively for families 7-56, CL9, 8-103, CL93.

Severe drought stress did not significantly affect total tree leaf area; however, there was a significant reduction in both A_{Sat} and A_{Can} throughout the measurement period. The performance of high value families diminished with increasing drought stress. This is most apparent in A_{Can} and stem volume comparisons, where CL93 yielded the greatest negative response. Considerations should be made when weighing the cost of establishing high value seedlings, particularly if summer droughts are predicted to become increasingly more common.

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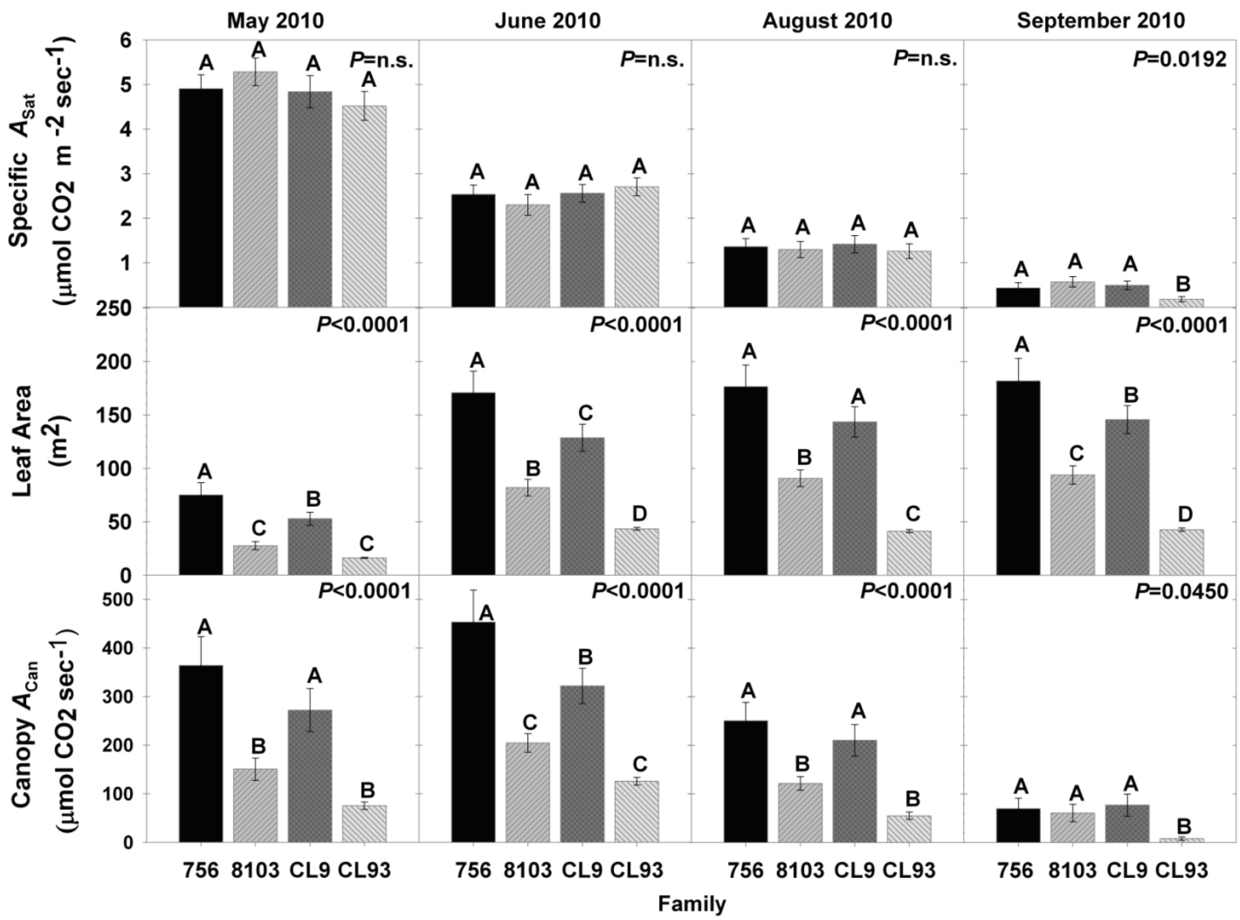

Figure 1—Mean specific light saturated photosynthesis (A_{Sat}; Top Panel), total leaf area (Middle Panel), and Canopy level photosynthesis (A_{Can}; Bottom Panel) for each Pinus taeda family measured on four separate sampling dates. Letters represent Fisher's LSD mean separation procedure (P<0.05; n=12). P-values were determined for each sampling date using ANOVA.

EVALUATION OF SHORT-ROTATION WOODY CROPS TO STABILIZE A DECOMISSIONED SWINE LAGOON

K.C. Dipesh[1], Rodney E. Will[1], Thomas C. Hennessey[1] and Chad J. Penn[2]

ABSTRACT

Fast growing tree stands represent an environmentally friendly, less expensive method for stabilization of decommissioned animal production lagoons than traditional lagoon closure. We tested the feasibility of using short-rotation woody crops (SRWCs) in central Oklahoma to close a decommissioned swine lagoon by evaluating the growth performance and nutrient uptake of two SRWCs. After backfilling a de-watered swine lagoon with soil, we planted sycamore (*Platanus occidentalis*) in 2008 and cottonwood (*Populus deltoides*) in 2009 at 2240 trees ha^{-1}. After three growing years, sycamore averaged 4.5 m and 4 cm in height and diameter respectively, whereas the two-year-old cottonwood averaged 5.8 m and 4.8 cm in height and diameter respectively. Cottonwood produced 16 Mg/ha of dry biomass and contained 193 kg/ha of Nitrogen (N) and 31 kg/ha of Phosphorous (P). Sycamore produced 8.5 Mg/ha of dry biomass and contained 72 kg/ha of N and 14 kg/ha of P.

INTRODUCTION

Livestock production has been one of the major agribusiness activities in the United States. Larger operations of swine, poultry, and cattle are being increasingly established over the past two decades (Thorne 2007). Liquid manure from the operations is stored in the lagoons. The lagoons contain the two most important nutrients in excess, Nitrogen (N) and Phosphorous (P), but also can be a source of pollution during run-off and/or leaching to the nearby water sources (Bicudo and others 1999) and may cause serious damages like hypoxia or anoxia to the aquatic life, for example, the dead zone of Gulf of Mexico (Rabalais and others 2002). Therefore, lagoon decommissioning has been a subject of great concern (Leffert and others 2008, Thorne 2007). Plants can be the best option for stabilizing the decommissioned lagoons since plants can prevent or at least reduce pollution and remove, degrade, or contain chemical pollutants, located in the soil and water (Chappell 1997, Doty and others 2007, Eapen and D'Souza 2005, Oyang and others 2002, Rockwood and others 2004, Schnoor and others 1995). Plants offer a lower cost and environmentally friendly technology with the benefit of woody biomass production (Eapen and D'Souza 2005, Leffert and others 2008, Paulson and others 2003, Rockwood and others 2004). Plants with fast growth, deep roots, and high water usage are very effective in the process (Nyer and Gatliff 1996). Short-rotation woody crops (SRWCs) can be an excellent option because these crops have the benefits of fast growth and high biomass production. SRWCs, for example, loblolly pine has relatively high ability to take-up, metabolize, and sequester nutrients (Will and others 2006). Similarly, SRWCs also have high transpiration, e.g., more than 38 cm of water per month per unit of ground surface area (Samuelson and others 2007). Sycamore (*Platanus occidentalis*) is one of the model species of SRWCs (Tuskan 1998) and can tolerate metal contaminated sites (Pulford and Watson, 2003). Cottonwood (*Populus deltoides*) also is an excellent candidate species due to its rapid growth rate and high nutrient requirement (Gochis and Cuenca 2000). *Populus* spp. growth responds positively to water from animal waste lagoons (Leffert and others 2008, Robinson and others 2000, Vose and others 2000). Thus, sycamore and cottonwood are suitable candidates for the dual purpose of lagoon stabilization and biomass production. The goal of this study was to test the feasibility of using SRWCs in central Oklahoma to close a decommissioned swine lagoon by evaluating the growth performance and the rate of nutrient removal by sycamore and cottonwood.

METHODS

STUDY AREA

The study area is located in Stillwater, OK, and owned by Oklahoma State University. Average annual rainfall in this area is 93 cm and average annual temperature is approximately 16°C. Average growing season ranges from 225-230 days.

The 2-acre decommissioned lagoon that had been in operation for more than 50 years was prepared for planting by pumping the liquid out from the lagoon in November 2007. Once the sludge was exposed, the berm of the lagoon was mixed with the sludge material to create a level surface. A cap of mineral soil (10-30 cm deep) was placed over the sludge soil mixture compacted. In spring 2008, and unimproved bare-root sycamore seedlings (George O. White nursery, Licking, MO) were planted, whereas a mix of 25

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different 50-cm cottonwood cuttings from OK/TX selections from the same nursery were planted in spring 2009. Each species was planted in 4 separate randomly assigned plots at a1.8 m X 2.4 m spacing to achieve a planting density of 2240 trees per hectare. Immediately after planting, oxyfluorofen (Goal, DowAgroScienes) was sprayed to reduce competition. Directed sprays of glyphosphate were initiated in June to further reduce competition from weeds. Drip irrigation was provided as needed during the growing season.

DATA COLLECTION

Tree sampling—During October and November 2010, when the leaves were still on the trees (following two growing seasons for cottonwood and three growing seasons for sycamore), eight trees of each species were selected for harvest to ensure adequate representation of all tree sizes. Branches, leaves and stem (including bark) were separated and oven dried at 66^{o}C until constant weight. Different allometric equations were developed for separate biomass components for each species. However, bark biomass was estimated based on the total stem biomass. We assumed 20 percent of the total stem biomass was bark for cottonwood (Guidi and others 2008) and 10 percent of the total stem biomass was bark for sycamore (Cobb and others 2009). To account for leaf abscission before harvest, we estimated the proportion of leaf drop at time of harvest using data from five litter traps per plot. Litterfall was collected each month and the proportion of total litter that fell before harvest was calculated. Based on that estimate, we multiplied the standing foliage biomass of sycamore and cottonwood by 1.42 and 1.41 respectively.

The product of diameter at breast height (d) squared and height (h) was the best predictor for aboveground biomass based upon R^2 value. Hence, we measured d and h of all the remaining trees in December 2010 to estimate the dry biomass of the remaining trees.

Nitrogen and phosphorous uptake—Leaf, stem wood, stem bark and branch wood samples of air dried biomass components were collected for nutrient analysis at the time of harvest. Leaf samples were randomly selected from a minimum of 5 trees per plot. Wood samples and bark samples were taken from the top, middle and bottom portion of the harvested tree stems. No nutrient analysis on branch bark was carried out. The samples were sent to the SWFAL (Soil, Water and Forage Analytical Laboratory, Oklahoma State University) to determine N and P concentration. N and P contents were calculated by multiplying the biomass of each component by the concentration.

RESULTS AND DISCUSSIONS

ALLOMETRIC EQUATIONS

Ninety-seven percent of the sycamore and 90 percent of the cottonwood survived through the 2010 growing season. Allometric equations developed for both species are shown in Figure 1. The percent of variation explained by d^2h varied between 67 and 98 percent for the various biomass components. Similarly, studies have found d^2h to be the best predictor of aboveground biomass (e.g. Cole and Ewel 2006, Senelwa and Sims 1998, Verwust 1991)

ABOVEGROUND BIOMASS

Both species grew rapidly. Cottonwood trees were larger and taller than sycamore even though the sycamore trees were a year older. Wittmer and Immel (1978) also found faster growth for cottonwood. Fast growth in cottonwood has been attributed to its higher photosynthesis rate (Nelson 1984). Table 1 summarizes the average height, diameter and biomass partitioning of both species. The 3-year old sycamore attained the maximum height of 6.45 m and maximum diameter of 8.5 cm, whereas, average sycamore height and diameter were 4.47 m and 4.05 cm respectively, greater than the average reported by most other studies (e.g. Brinks and others 2011, Wittmer and Immel 1978). However, Davis and Trettin (2006) reported height of 5.45 m and diameter of 5.9 cm after the third growing season in a sycamore plantation. Our study showed that cottonwood attained the maximum height of 8.6 m and maximum diameter of 10.9 cm, whereas average height and diameter were 5.85 m and 4.85 cm respectively. A study done in 2-year-old cottonwoods in Missouri River floodplains showed that the average height and diameter reached 4.37 m and 3.8 cm respectively (Pallardy and others 2003). Higher yields in our study probably reflected the abundance of nutrients in the decommissioned swine lagoon and perhaps the advantage of better clonal stock.

On average, cottonwood had 16 Mg/ha of aboveground biomass, almost double that of sycamore, which produced 8.5 Mg/ha. SRWCs can produce more than 20 Mg of dry wood/ha/yr (Stolarski and others 2008, Szczukowski and others 2005). We expect the growth rates of our stands to increase during the next several years, the stands are now fully occupied and perhaps approach the 20 Mg/ha/yr growth rate. Pallardy and others (2003) reported the maximum of 16.1 Mg/ha of dry matter with an average being 11.7 Mg/ha in a two-year old cottonwood planted in the Missouri River floodplains. Heilman and Stettler (1985) reported 16.7 Mg/ha in two-year cottonwood stands. On the other hand, biomass for 3-year old sycamore was lower than what Wood and others (1976) reported. There are two possibilities for this: two of the sycamore plots had water logged conditions during some part of the growing seasons which may have reduced the growth and Wood and others (1976) study included fertilization and spacing treatments. The higher biomass for cottonwood than sycamore in our study was because of higher growth rate despite the younger age and lower survival. Moreover, most of the cottonwoods had multiple stems growing from the cuttings which led to the higher biomass. Also, the cottonwood clones had been selected for fast growth while the sycamore seedlings were unimproved.

Sycamore partitioned 44 percent of its aboveground biomass to stem-wood, 5 percent to bark, 22 percent to foliage and 29 percent to branch. Wood and others (1976) also reported that foliage biomass made up about 20 percent and that branch biomass accounted for 25 percent of the total yield in three-year old stands. Cobb and others (2008) reported a range of 64 to 78 percent stem biomass in 6-year-old sycamore stands with different treatments. Similarly, bark biomass was 6 percent, branch biomass content was about 15 percent of the total, whereas foliage biomass ranged from 8 to 21 percent and depended upon irrigation and fertilization. Compared to Cobb and others (2008), lower stem biomass partitioning in our study is due in part to the younger age of our stands; younger trees allocate more carbohydrate towards leaf area development and have not had time to accumulate large amounts of woody biomass.

Cottonwood biomass comprised 38 percent stem biomass, 9 percent bark biomass, 24 percent foliage biomass and 29 percent branch biomass. Our findings were similar to those of Coleman and others (2004) except that stem biomass was higher than ours because stem biomass included bark biomass in their results. A study by Baker and Blackmon (1976) in a 1-year old cottonwood also showed a similar trend of branch biomass, but foliage biomass was higher than our study implying that younger stands allocate their biomass towards leaf production. Similarly stem biomass (34 percent) (bark biomass not separated) was also lower because of age. Foliage biomass represents the current year growth only whereas stem biomass growth is the accumulation of woody biomass over time.

NUTRIENTS CONTENT

Each biomass component except stem-wood had higher N concentration (Harner and Stanford, 2003) in cottonwood than sycamore (Table 2). This higher concentration can probably contribute to the rapid growth of poplar trees (O'Neill and Gordon 1994). Foliar N concentration was highest of all biomass components, 2.5 percent in cottonwood and 1.9 percent in sycamore. Total N content in cottonwood was 193 kg/ha whereas P uptake was 31 kg/ha. Sycamore stands contained 72 kg/ha of N and 14 kg/ha of P. Our estimates of total N and P uptake do not include foliage uptake during previous growing seasons. To estimate total uptake from the site, the current values should be adjusted upwards based on estimated foliage production of previous years. Our study shows higher N content in the plant components on a per hectare basis when compared with most other studies of similar aged stands implying the abundance of N and fast growth at our site. N-uptake rate increases with increased available N (Coleman and others 2004). A study by van Miegroet and others (1994) found a range of 112-197 kg N/ha in three-year old sycamore, but this study included the direct use of N fertilizers at different amounts.

Once harvested, all aboveground woody biomass components and the nutrients in them are taken out from the lagoon. The foliage biomass was slightly below one-quarter of the total in both species and had a high N and P content; nutrients in the foliage can be removed by raking or blowing leaf litter off the site.

CONCLUSION

Our study illustrates that SRWCs can take up large quantities of N and P from the decommissioned lagoons and thus possibly reduce loss due to runoff and leaching. SRWCs planted in a decommissioned swine lagoon performed better than most other studies in terms of biomass and nutrient (N and P) uptake. Two-year cottonwood outperformed 3-year-old sycamore producing 16 Mg/hectare biomass. Similarly, 3-year-old sycamore also performed well, although exhibiting only half the production of cottonwood biomass. In addition, nutrient uptake was higher in cottonwood than sycamore due to both higher nutrient concentrations and greater biomass production. Growth rate and nutrient uptake should continue to increase in the coming years.

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Table 1—Average tree size and biomass for three-year-old sycamore and two-year-old cottonwood trees growing on a decommissioned swine lagoon in central Oklahoma. Values in the parenthesis represent the standard deviation.

			Biomass (kg)/tree			
Species	Height (m)	Diameter (cm)	Stem-wood	Bark	Leaf	Branch
Sycamore	4.47 (0.76)	4.05 (1.25)	1.89 (0.66)	0.19 (0.07)	0.87 (0.57)	1.12 (0.4)
Cottonwood	5.85 (1.21)	4.85 (1.78)	2.89 (1.79)	0.72 (0.45)	1.87 (0.93)	2.29 (1.84)

Table 2—Nitrogen (N) and Phosphorous (P) percentages in the aboveground biomass components of the species.

	Stem-wood		Bark		Leaf		Branch	
	N	P	N	P	N	P	N	P
Sycamore	0.49	0.16	0.79	0.13	1.86	0.2	0.57	0.14
Cottonwood	0.34	0.11	1.08	0.18	2.50	0.29	1.29	0.23

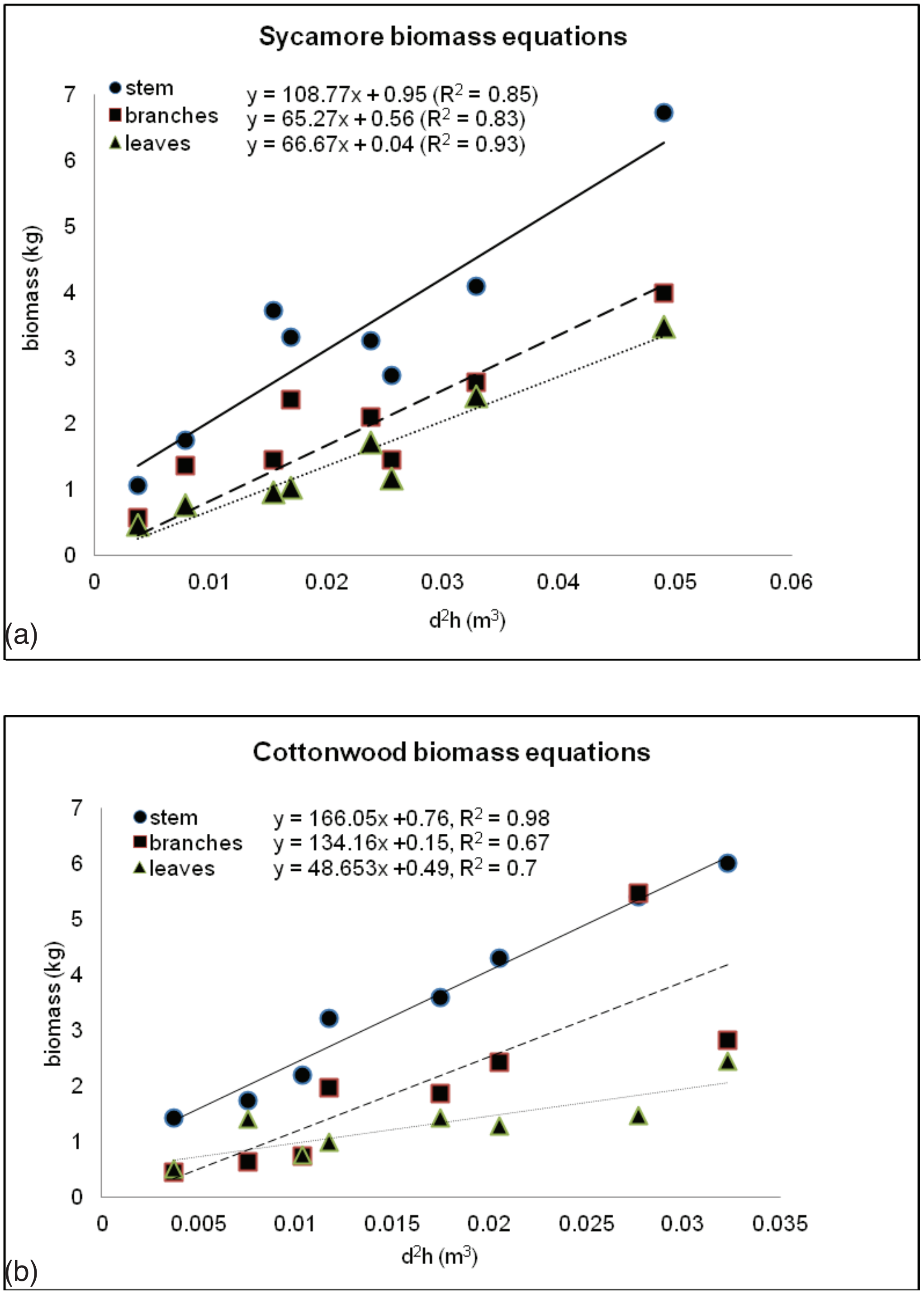

Figure 1—Allometric equations for each aboveground biomass components of (a) three-year-old sycamore and (b) two-year-old cottonwood trees growing on a decommissioned swine lagoon in central Oklahoma. Stem biomass includes both the stem-wood and bark biomass.

PLANTING DENSITY AND SILVICULTURAL INTENSITY IMPACTS ON LOBLOLLY PINE STAND DEVELOPMENT IN THE WESTERN GULF COASTAL PLAIN THROUGH AGE 8

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Commercial plantation growers need to know how planting density and cultural regime intensity affect loblolly pine plantation productivity, development and value to make sound management decisions. This knowledge is especially important given the diversity of traditional products, such as pulpwood, chip-n-saw, and sawtimber, and potential products, such as bioenergy feedstock and carbon, from plantations. While there has been considerable research reported on general effects of planting density alone and of cultural intensity alone, relatively limited research has been reported on how plantation performance may be affected by combinations of planting density and cultural intensity across a range of planting densities and silvicultural regimes on representative soils (Carlson and others 2009, Quicke and others 1999, Rahman and others 2006, Zhao and others 2011).

A regional trial was established to examine planting density and cultural intensity effects and interactions in the Western Gulf Region (Arkansas, Louisiana, Texas, and Mississippi) from 2001 to 2003 by a consortium of large commercial growers and Texas A&M University. The Plantation Management Research Cooperative (PMRC) assumed responsibility for this study in 2008. A total of 18 installations were located on soil groups defined for the study based on drainage class and surface horizon depth. Each installation included 10 plots, each plot representing a unique combination of planting density and cultural intensity. Five levels of planting density (200, 450, 700, 950, and 1200 TPA) were tested in combination with two levels of silvicultural intensity, intensive and maximum. The intensive regime included mechanical site preparation specific to soil groups, tip moth control during the first two growing seasons, and competition control and fertilization during the first growing season. The maximum regime included intensive culture treatments plus additional competition control and fertilization treatments.

At age 8, averages across all plots were 92 percent survival, 33 feet height, 35 feet dominant height, 6 inch DBH, 112 square feet of basal area per acre, 1940 cubic feet of total stem outside bark volume per acre, 49 tons of total stem outside bark green weight per acre, 256 stand density index, 0.30 relative spacing, 20 feet of live crown, 60% live crown ratio, and 5 percent Cronartium infection rate.

Density dependent mortality was not pronounced although the slight reduction in percent survival with increasing age on maximum culture plots at 700 to 1200 planting densities suggests that intra-specific competition had begun.

Planting density and cultural regime had marked impacts on age 8 individual tree and stand attributes. Average tree diameter increased with decreasing planting density. Per acre basal area, volume and green weight, and stand density index increased with increasing planting density. Average height and dominant height for the 200 planting density were generally about 2 ft less than for the 450 planting density. Maximum culture increased average tree height and DBH and per acre basal area, volume, and green weight as well as stand density index. Relative spacing decreased with increasing planting density and was not significantly affected by cultural regime. At age 8, effects of planting density on tree and stand attributes were generally consistent across cultural regimes and effects of cultural regime on tree and stand attributes were generally consistent across planting densities. Soil group, as defined for this study, did not significantly affect plantation attributes at age 8. Live crown length was most affected by planting density, being about 9 ft longer on the 200 planting density than the 1200

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planting density. Live crown length was affected to a lesser degree by cultural regime, being only one foot longer on maximum culture plots than on intensive culture plots. Incidence of Cronartium on stems throughout the study was low, averaging 5%. Incidence was significantly elevated (9%) on low planting density (200) maximum culture plots.

Cultural regime and planting density combinations offer loblolly pine plantation managers opportunities to significantly influence individual tree and stand level attributes as warranted by objectives and markets. Greater intensity of culture offers opportunities to increase per tree and per acre growth rates over a range of densities while increased planting density provides opportunities to increase per acre production in the period prior to significant density dependent competition.

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SEDIMENT YIELD ALONG AN ACTIVELY MANAGED RIPARIAN BUFFER

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ABSTRACT

High quality water is generally associated with forested watersheds. However, intensive forestry activities within these watersheds can negatively affect water quality. In order to mitigate negative effects of forestry operations on water quality, best management practices (BMPs) are recommended. In this study, effects of silvicultural treatments on water quality are examined by comparing a treatment watershed with an unharvested control watershed. Forested areas created less sediment than open areas. In addition, a partial cut within streamside management zone (SMZ) increased sediment yield.

INTRODUCTION

Clean, drinkable water is becoming one of the most important natural resources for the future. Forested watersheds are the main sources of clean water. In order to insure the sustainability of products and benefits from forested watersheds, some intensive management practices may be essential (Grace 2005). But, these operations can adversely affect water quality without well-designed logging roads and the implementation of mitigating measures such as buffer zones (Saleh 2004). Best management practices (BMPs), such as streamside management zones (SMZs), have appeared to be effective for mitigating the effects of forestry operations on water quality (Norris 1993, Wynn and others 2000, McBroom and others 2007).

A SMZ is one of the most commonly employed nonstructural BMP types. SMZs consist of a strip of land that is managed to protect the surface water and riparian values from silvicultural operations (Alabama Forestry Commission 1999). Although SMZ's need not be excluded from silvicultural activities, these buffers should be carefully designed, and any silvicultural activity within them must be closely supervised and managed. Thinning operations within SMZs will reduce fire and insect hazards, provide some economic return, and improve the effectiveness of SMZs (McBroom and others 2007).

In this study, we intended to regenerate a mature SMZ stand and create an uneven-aged forest with multiple canopy tiers using single tree selection based on the Proportional-B method. During this process, the effects of partial cutting on sedimentation were observed by comparing the study watershed with an unharvested reference site. In addition to determining harvesting effects on sediment yield, the effects of different land uses and a recent clearcut on sedimentation were evaluated; the effect of forest cover on sediment was quantified, and the efficacy of the SMZ at reducing sediment yield from potential source areas was determined.

METHODS

STUDY SITE

The study was conducted on the Mary Olive Thomas Demonstration Forest which is owned and managed by the Auburn University School of Forestry and Wildlife Sciences. Most of the area has slopes of less than 6%; however, steeper slopes are present on some parts of the tract. Pacolet series is the predominant soil type on the property except for narrow bands of Taccoa sandy loam along streams and main drainages (McNutt and others 1981). The average annual rainfall is 148 cm, and 50% of the rainfall occurs during the growing season from April to September. The average daily temperature is 7 °C in winter and 27 °C in summer. The average relative humidity is about 50% in mid-afternoon, and is higher at night. The timber on the property is primarily Loblolly pine (*Pinus taeda L.)*. However, the SMZs (including the study area) are dominated by deciduous species. Average site index for loblolly pine is about 26 m (base age 50 years) on the property. The SMZ stands are well stocked, and are typically wider than required (approximately 20 m) by State of Alabama guidelines (AL Forestry Commission 1999).

Two small adjacent watersheds, treatment (Tw) and control (Cw), were chosen for the study (Figure 1). Each watershed was divided into three sections (Tw1-Tw2-Tw3, and Cw1- Cw2-Cw3 respectively) based on land use or forestry treatment. An intact SMZ borders the stream the entire length of the watershed from sample point T1 south to T3, and from sample point C1 south to point C3. North of T1 on the treatment watershed is an open area, mostly pasture with a pond in the middle of the section. The central

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portion of the study area, Tw2, is entirely forested. On the control watershed (Cw), section Cw1 (north of C1) is mostly residential area with a pond in the middle of the section. The mid- portion of the study area, Cw2, is entirely forested. The property north of T1 and C1 is not owned by Auburn University and no sampling or data collection was conducted in these areas. In Tw3 and Cw3, there is a clearcut area between the two SMZs. The clearcut was harvested in early 2008, site prepared with herbicide in late summer, windrowed with a root rake in the fall 2008 and planted during 2008-09 dormant season (Figure 1). One monitoring station was established on each section (T1, T2, T3, C1, C2, and C3) to sample stream stage. The first stations (T1and C1) were located on the north boundary of the forested area to observe how much water entered the forested area from the pasture and residential area. The second group of stations (T2 and C2) was located at the upstream edge of the clearcut area so that it would be possible to evaluate the effect of intact forest cover on water changes in the stream in comparison to T1. The third stations (T3 and C3) were located at the downstream end of the watershed to evaluate the effects of a clearcut area on water quality through an intact SMZ (Figure 1).

HYDROLOGIC SAMPLING

Water stage measurements were monitored using Solinst Levelogger Gold Model 3001 pressure transducers installed at each monitoring station. In addition to continuous water stage measurements by transducers, stream discharge was measured during storm events (whenever possible, while it was still raining) at each monitoring station. The proximity of the sites to Auburn University allowed for the capture of most rain events (rain events with lighting activities were avoided). Water levels were associated with discharge measurements taken during each site visit to determine water level-discharge relationships. These relationships were used to calculate continuous discharge (for each 15 minute period) by creating rating curves between water levels and discharge data from each station. Water samples were also taken at each monitoring station during rain events. Total suspended sediment (TSS) concentrations were determined from water samples using the SM 2540 D (total suspended solids dried at 103-105 °C) method. The TSS concentrations were also used to estimate sediment loads for each 15 minute period using LOADEST software. LOADEST requires a time series of streamflow, and constituent concentration (sediment concentration) at a time of a day to assist the user in developing a regression model for the estimation of constituent load (calibration) (Runkel and others 2004).

HARVEST OPERATION

The harvest operation was designed to create an uneven-aged SMZ with multiple canopy layers by allocating growing space among three canopy tiers (overstory, midstory, and understory) based on the Proportional-B method. This method is well suited for use within a SMZ as it ensures a continuous canopy cover, maintains full site utilization with approximately 80% of stand basal area allocated to the sawtimber size classes, and allows sufficient growing space for the recruitment of new cohorts as needed (Loewenstein 2005). Cutting and skidding operations were completed during about two weeks, in October, 2009. The harvest was conducted in dry weather to avoid compaction and rutting of the soils. Trees were removed from the SMZ with a rubber-tired John Deere 540 GIII Model Skidder.

STATISTICAL ANALYSIS

Treatment effects for watersheds were determined using the paired watershed approach based on streamflow (Hewlett 1969). Pre-harvest data were used as a basis for developing calibration regression equations between the treatment and control watersheds using paired monitoring stations (e.g. T1 with C1, T2 with C2, and T3 with C3). Post-treatment comparison relies on the high correlation that normally exists between water discharge from treatment watersheds and control watersheds when there is no harvest on either watershed. Given this relationship, the change in water characteristics attributable to the harvest operation could be determined. PASW Statistics 18.0 software was used to determine significant differences between observed and predicted means on the treatment watershed by the Independent-Samples T-Test for all mean comparisons.

RESULTS and DISCUSSIONS

In general, before the harvest operation, the pastoral area generated more sediment yield per unit area during storm events. Because sediment yield from the pasture is higher, this suggests that open areas generate more sediment yield than forested areas during storm events. The forested middle section generated the least sediment per unit area showing the importance of forested areas at reducing sediment yield on the treatment watershed (Figure 2). The sediment rate from section Tw2, which is intact forest, is lower than Tw3, which contains the clearcut and road crossing. We expected that sediment yield from the clearcut would be mitigated by the existing SMZ, but it appears that it was not sufficient to trap all of the sediment yield from both the clearcut area and the roads. It should be noted that we were unable to separate the sediment yield of the road from that of the clearcut. On the control watershed a similar situation was observed; sediment yield per unit area during rainfall events is higher from Cw1 than from further downstream.

In contrast with the pre-harvest results, post-treatment data on the treated watershed shows that the sediment pattern changed after the harvest. Section Tw3 generated significantly higher amounts of sediment per hectare than did the upstream sections (Figure 3). Section Tw2 generated remarkably higher amounts of sediment per hectare after harvest. Section Tw1 produced the least sediment yield per unit area, a complete reversal of the pre-harvest trends. On the control watershed, the sediment pattern did not change (as expected) since this watershed was not affected by harvesting (Figure 3).

Models derived from the calibration data were used to predict response on both treatment and control watersheds for the post-harvest period. Observed and predicted data were compared to determine harvest effects on sediment. There was no change in the sediment yield from section Tw1 on a unit area basis (Figure 4). When looking at the sediment yield on a per unit area basis, the post-harvest effect is quite distinct on Tw2, suggesting that the partial cut within the SMZ caused disturbance of the duff layer and/or vegetation, therefore allowing soil movement (erosion) and an increase in sediment yield during rainfall events (Figure 4). During rainfall events, between 10-15 times more sediment than predicted was generated in Tw2. Sediment yield significantly increased following harvest from Tw3 ($p=0.012$) (Figure 4). As on section Tw2, differences were most notable during rainfall events with sediment yields of 3-4 times what was predicted (Figure 4). Although less obvious, the magnitude of increased sediment yield during dry periods is greater than during storm events.

CONCLUSIONS

Forested watersheds and forested areas on a watershed both play important roles in protecting and maintaining both water quality and quantity. However, any silvicultural operations in forested watersheds must be carefully managed and supervised in order to protect and maintain water quality. During the pre-harvest period, upstream sections Tw1 (pastoral) generated much more sediment yield than downstream forested sections. It is also likely that sediment yields were affected by the ponds in the middle of section Tw1. We cannot determine the actual sediment yield from the upstream section (Tw1) because during all times except rain events, the pond acts as a settling basin. Also, during a rain event, we cannot know how much of the sediment generated from these sections is from that particular event or how much is stored sediment from previous erosion. The least amount of sediment was created by the forested middle section which differed from the downstream forested section in that there was an intact clearcut. The furthest downstream section Tw3, which contained a stream crossing and a two year-old clearcut, created much more sediment than forested section Tw2. This suggests that the SMZs were not sufficient to trap all of the sediment from the clearcut area and forest road, even though the SMZs were often much wider than the minimum guidelines. It may be also suggested that a SMZ may not function at desired level under certain conditions no matter how wide it is.

Following the partial cutting treatment of the SMZ in watershed Tw, it was observed that there was a significant increase in sediment load from the treated sections (Tw2 and Tw3) caused by increased erosion from soil exposed by skidding operations. Higher amounts of sediment were observed on these sections in comparison to the pre-harvest calibration period. Some of this increase is explained by the reduced canopy cover due to the dormant season, and by an increased number of rain events. However, no significant change was observed between the pre-harvest and post-harvest period on the section Tw1. Sediment trends did not differ from the calibration period following harvest on the control watershed.

This study shows the importance of forest cover at reducing sediment yield. The study also shows that season affects sediment and water yield as well. It may be suggested that clearcutting causes at least a temporary increase in sediment load, even with properly managed BMP's and SMZ's. If effective forest road BMPs are not in place then simply focusing on SMZs to reduce sediment yield may not be sufficient. This study also shows the importance factoring in upstream land use and land cover conditions when designing SMZs for sediment trapping.

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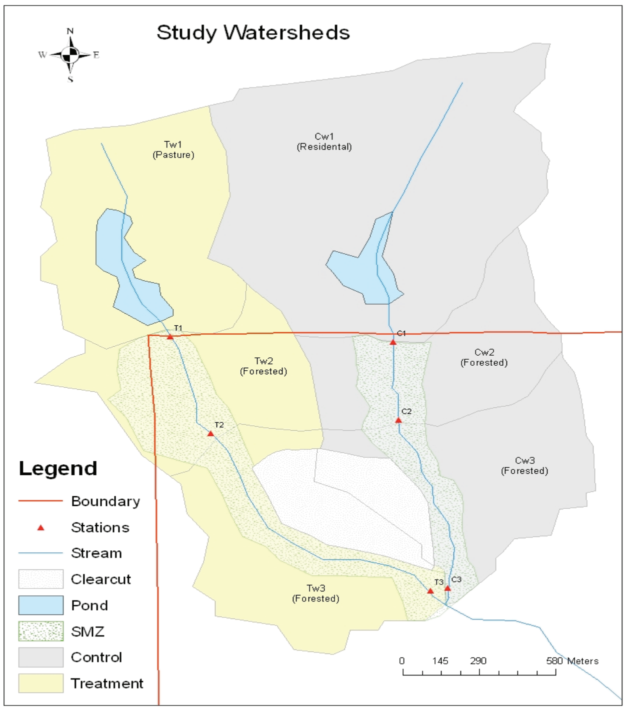

Figure 1—Map of the study watersheds.

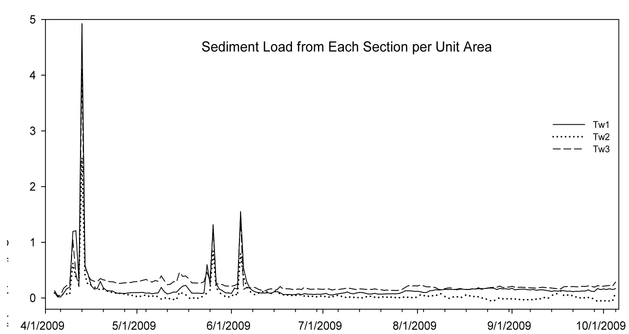

Figure 2—Pre-harvest sediment yield pattern.

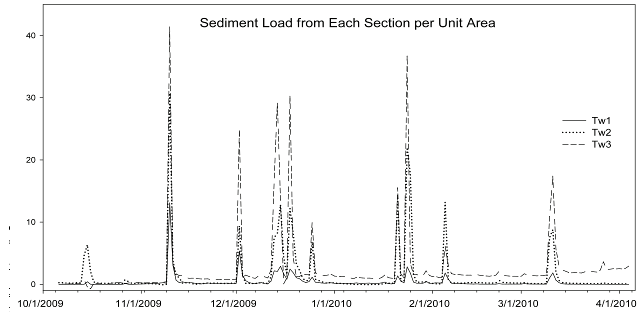

Figure 3—Post-harvest sediment yield pattern.

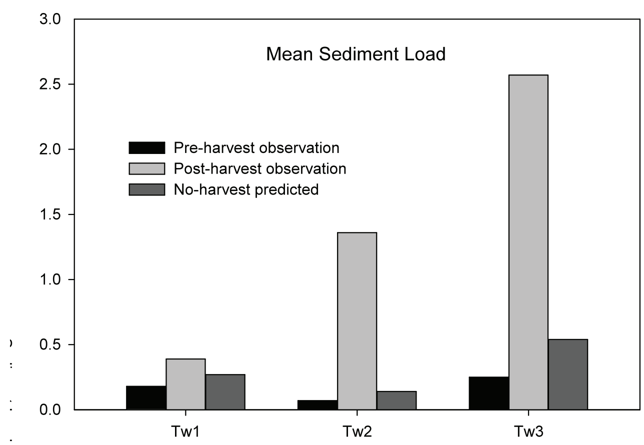

Figure 4—Mean sediment load of each section after harvest operation.

RELEASE OF NITROGEN AND PHOSPHORUS FROM LOBLOLLY PINE FOREST FLOOR IN A POST-HARVEST MICROCLIMATE

L. Chris Kiser and Thomas R. Fox

Loblolly pine (*Pinus taeda* L.) plantations grown on nutrient deficient soils in the southeastern U.S. require nitrogen (N) and phosphorus (P) fertilization to increase growth (Albaugh et al., 2007; Fox et al., 2007). Fertilization increases growth by increasing foliar nutrients and leaf area (Albaugh et al., 1998) which also results in higher litterfall mass. Nutrients sequestered in foliage eventually accumulate in the forest floor. As a loblolly pine stand ages forest floor mass increases (Switzer and Nelson, 1972). Nitrogen and P content also increase (Switzer and Nelson, 1972) due to an accumulation of N and P as the litter decomposes (Piatek and Allen, 2001; Sanchez, 2001) suggesting a forest floor sink. In fertilized systems, the forest floor sink is magnified due to higher inputs from litterfall and increased foliar N and P concentrations (Will et al., 2006). When a stand is harvested, forest floor decomposition increases due to changes in environmental conditions. Since next rotation seedling nutrient demand is not great enough to capture nutrient released through forest floor decomposition (Fox et al., 2007), a significant amount of site nutrient capital could be lost. Our objectives were to: (1) determine whether fertilization results in a forest floor N and P sink and (2) quantify N and P release from decomposing forest floor material in a post-harvest microclimate.

This study was conducted at the Southeast Tree Research and Education Site (SETRES). The site is a 25-year old loblolly pine plantation growing on an infertile, excessively-drained, sandy soil (Wakulla series, Psammentic Hapludult). The experimental design is a 2^2 factorial with 4 blocks. Treatments include fertilization (no addition and optimal nutrition) and irrigation (no addition and optimal soil water content). Treatment levels include a control, irrigation, fertilization, and fertilization x irrigation. Fertilization is conducted by applying a balance of macro- and micro-nutrients to provide optimal nutrition. Irrigation is conducted by maintaining a soil water content >40% field capacity during the growing season. Total N and P additions from 1992 to 2008 were 1378 and 168 kg/ha, respectively. The forest floor and mineral soil were sampled in March 2008 and analyzed for N and P. Treatment effects were determined with a general linear model. In May 2009, forest floor Oi and Oe horizons were collected in each plot, approximately 100 g were placed in a litterbag (20x40 cm; 2 mm opening). Initial masses were determined and litterbags were placed on the mineral soil surface in an open-sky area adjacent to the experimental plots replicating the layout of the plots. Four replicate litterbags were prepared for each of the 16 plots resulting in 64 total litterbags. One litterbag representing each of the 16 plots was destructively sampled every 3 months for 1 year. At each sampling interval, remaining mass and N and P concentration was determined. The proportion of N and P released was determined for each sampling interval (Schlesinger and Hasey, 1981) and the decay rate constant (k; per month) and mean residence time (MRT) of 99% mass loss were calculated (Olson, 1963). Treatment effects were determined with repeated measures ANOVA.

Fertilization did not increase mineral soil N but increased mineral soil P by 57 kg/ha. Fertilization increased forest floor Oi and Oe horizon N by 200 kg/ha and P by 10 kg/ha. These results indicated a forest floor sink for added N and a forest floor and mineral soil sink for added P. In the post-harvest replicated decomposition experiment, fertilization and irrigation did not affect the decay rate constant (k) or proportion of N and P released. The overall decay rate constant for all the data ($k = 0.411$; R^2=0.95) indicated a MRT of 12.2 months. Nitrogen and P content released was increased by fertilization ($p<0.0001$) (Figure 1). Approximately 255 kg/ha and 13 kg/ha of N and P, respectively, were released from fertilized forest floor within 1 year.

The forest floor Oi and Oe horizons retained 15% of N added through fertilization. This represents a significant amount of site N capital on an infertile site. The amount of N released from the decomposing forest floor exceeds the capacity of newly planted pine seedlings to take-up N which could result in a loss of N from the site.

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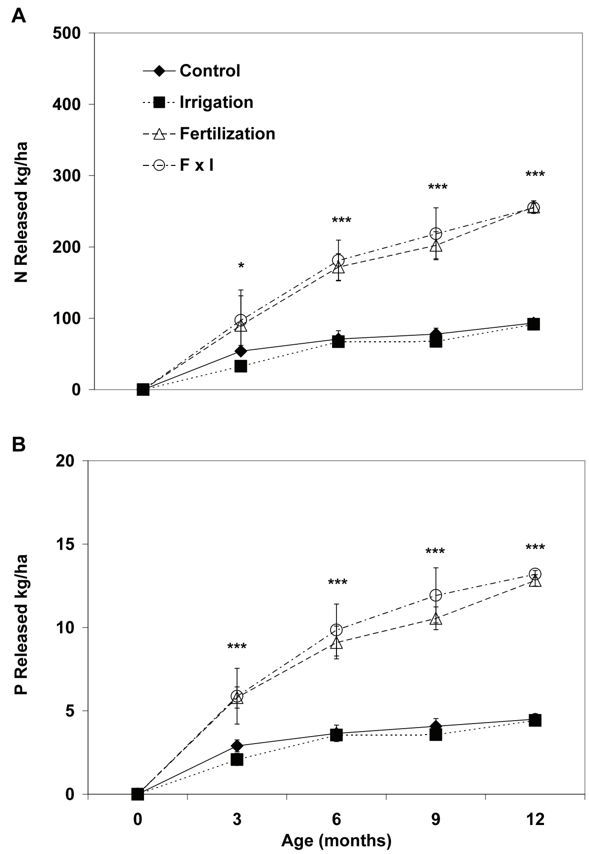

Figure 1—Mean nitrogen (A) and phosphorus (B) content released from forest floor Oi and Oe horizons. Significant fertilization x month interaction effect denoted by * ($p<0.05$), *** ($p<0.0001$). Error bars represent 1 standard deviation.

ARE WE OVER-MANAGING LONGLEAF PINE?

John S. Kush, Rebecca J. Barlow, and John C. Gilbert

ABSTRACT

Longleaf pine (*Pinus palustris* Mill.) is not loblolly (*Pinus taeda* L.) or slash pine (*Pinus elliottii* L.). There is the need for a paradigmatic shift in our thinking about longleaf pine. All too often we think of longleaf as an intolerant species, slow-grower, difficult to regenerate, and yet it dominated the pre-settlement Southeastern forest; how can that be? Wahlenberg, in his 1946 book about longleaf pine, wrote that mismanagement of longleaf pine has been the rule rather than the exception, due to the ignorance of the unique life history and incomplete knowledge of factors determining the life and death of seedlings and hence the succession of forest types. Using data from the Regional Longleaf Growth Study and from what had been a virgin stand of longleaf pine, the Flomaton Natural Area, this presentation will focus on examining data from areas that have been/were allowed to grow "unmanaged", i.e. no timber cutting. How did longleaf pine stay on the landscape before we almost managed it out of existence?

INTRODUCTION

Longleaf pine (*Pinus palustris* Mill.) ecosystems are considered to be in a perilous condition. A report by the U.S. Department of Interior lists the longleaf pine ecosystem as the second-most threatened ecosystem in the U.S. (Noss 1989). The original longleaf pine forest was self-perpetuating where seedlings always had to be present. It reproduced itself in openings in the overstory where young stands developed. These openings would have ranged from a few tenths of an acre due to the loss of a single tree to a lightning strike or wind fall, a few acres due to insects or a larger scale wind event, to large openings of several thousands of acres due to tornados or hurricanes. Regardless of the event size, longleaf pine was able to regenerate these openings. The result was a park-like, uneven-aged forest, composed of many even-aged stands of varying sizes.

The character of the ecosystem is best maintained with natural regeneration, with optimum use of silvicultural treatments simulating the processes that have long maintained longleaf ecosystems over the millennia. However, no phase of longleaf pine management presents more complex and critical problems than does its reproduction. Solutions depend on understanding the prerequisites of the process, the characteristics of seed-bearing trees and longleaf pine seed crops, and the possible causes of failure after seed fall. Predicting seedling performance under varying levels of overstory competition is important for understanding the consequences of silvicultural systems.

Many of the factors governing the ability of longleaf pine to reproduce are obscure, and the innumerable ecological influences are so interrelated as to make their interpretation difficult. A major regeneration problem is irregular seed production. Seed crops considered adequate for regeneration occur at 5- to 7-year intervals, on average, with exceptions. Longleaf pine is generally considered the most intolerant of the southern pines (Baker 1949). It is intolerant of competition from any source especially overstory competition. Survival and growth are closely related to longleaf pine's two unique silvical characteristics: its grass-stage and its high tolerance of fire. The grass-stage usually lasts 4-5 years but may range from 2 to 20 years. If competing species are allowed to grow freely, they will completely dominate the site while longleaf seedlings are still in the grass-stage. Once this has occurred, the longleaf pine stand can never regain dominance without some type of intervention. Unsatisfactory regeneration in longleaf pine forests may be attributed largely to the lack of management or unwise management.

It was recognized at the turn of the 20th century that natural regeneration of longleaf pine would be difficult because of human activities and its own life history. Problems with the regeneration of longleaf pine were noted by Schwarz (1907) when he wrote "Longleaf pine has an astonishing power of resistance to fires, except during its very early life, points to the possibility of possible renewal, in spite of the many destructive human agencies that are constantly threatening it." Wells and Shunk (1931) wrote this about the demise of longleaf pine: "In its pristine condition with millions of trees measuring a yard or more in basal diameter, the Pinus palustris ecosystem unquestionably presented one of the most wonderful forests in the world. And today hardly an

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acre is left in North Carolina to give its citizens a conception of what nature had wrought in an earlier day. The complete destruction of this forest constitutes one of the major social crimes of American history."

Wahlenberg (1946) in his landmark text "Longleaf pine: Its use, ecology, regeneration, protection, growth, and management" devoted three chapters to the topic of longleaf pine regeneration, nearly one-quarter of the book. In his introduction he stated "Where formerly it had complete possession of the land, it has often failed to reproduce; this failure has resulted in deterioration of land values in many localities." The two major problems he identified for the frequent failure were: 1: fire, whether too frequent, killing recent regeneration, or too infrequent resulting in competition from other species; and 2: logging practices that left little or nothing on the ground or no seed trees. He summed this up by saying "Mismanagement of longleaf pine has been the rule rather than the exception, due to ignorance of the unique life history and incomplete knowledge of factors determining the life and death of seedlings and hence the succession of forest types."

There has been renewed interest in longleaf pine over the past 10-15 years for a variety of reasons. It is valued as a straight-growing tree of higher value than other southern pines. It is relatively resistant to insects and wind, as well as being very tolerant of fire. Several threatened and endangered species are often associated with frequently burned longleaf pine ecosystems, such as the red-cockaded woodpecker and gopher tortoise. For wildlife, in general, the understory groundcover and "open pine" habitat of these frequently burned ecosystems are highly valued. Most recently, there is "America's Longleaf Initiative" and its impossible goal of increasing longleaf pine 3.4 million acres today to 15 million over the next 15 years (America's Longleaf Initiative 2009).

Longleaf pine is classified as a very shade intolerant species, but it has none of the characteristics associated with early successional species. It is not a prolific seed producer, the seed is not disseminated great distances, and its early growth is not rapid. Regeneration of longleaf pine occurs erratically. Excellent mast years occur once every 4–7 years, with variations locally. Is longleaf pine as intolerant as we are led to believe which would lead to our mismanagement of the species? We will examine data from parts of three studies to look at this question. Data from unthinned plots (unmanaged stands) from a long-term growth and yield study and from a virgin stand of longleaf pine as well as two comparative studies will be presented.

RESEARCH STUDIES

REGIONAL LONGLEAF GROWTH STUDY

In 1964 the U.S. Forest Service established the Regional Longleaf Growth Study (RLGS) in the east Gulf Region (Farrar 1978). The original objective of the study was to obtain a database for the development of growth and yield predictions for naturally regenerated, even-aged longleaf pine stands. Plots were installed to cover a range of ages, densities, and site qualities. At the time of establishment, plots were assigned a target basal area class of 30, 60, 90, 120, or 150 square feet/acre. The RLGS is inventoried every 5 years. It is now in its 45th year re-measurement. Several plots have been left unthinned to follow stand development over time. The data from these unthinned plots will be used to discuss longleaf pine stand dynamics.

FLOMATON NATURAL AREA

Private, state, and federal land managers have recently undertaken ecological restoration of the longleaf pine forests in the southeastern United States. Restoration to this point has lacked information on reducing litter accumulations, herbaceous species establishment, changes in overstory structure, and the fate of longleaf pine regeneration during the restoration process. One area where the impacts of ecological restoration on longleaf pine forests were being studied was the Flomaton Natural Area (FNA). The FNA was a 60-acre, virgin stand of longleaf pine that underwent more than 45 years of fire suppression. In 1995, a major restoration project was undertaken with the re-introduction of fire (Kush and Meldahl 1996). For the next decade the FNA was monitored and managed as an old-growth longleaf pine habitat. The stand was burned again in 1996, 1997, 1999, 2001, 2002, and 2003. A fuelwood operation was also conducted in 1996, in which all hardwood trees were mechanically removed.

ESCAMBIA EXPERIMENTAL FOREST

Dr. William Boyer has said for years that "longleaf pine will catch up" (Personal Communication. William Boyer. Several times over the past two decades. Principal Silviculturist, U.S. Forest Service, Devall Street, Auburn, AL 36830). One of the many reasons for his statement came from two of the many studies of unpublished material in his file cabinets from work he conducted on the Escambia Experimental Forest (EFF) located south of Brewton, AL. In one study, Dr. Boyer examined the role overstory competition played in the release of seedlings in the understory. The second study compared a longleaf pine plantation to a nearby naturally regenerated stand. The planting of longleaf pine coincided with a longleaf pine seed crop on the EEF.

RESULTS

REGIONAL GROWTH STUDY

A series of RLGS plots were established on the EEF in 1985 from the 1969 seed crop. Several of these plots were left unthinned. At the time of establishment, these unthinned plots had just over 3,500 trees/acre that were at least 0.6-inches diameter at breast height (DBH) at age 16 years. The basal area of these plots averaged 81 square feet/acre. At age 31, density had dropped to 1850 trees/

acre while basal area had increased to 171 square feet/acre. Hurricane Ivan struck these plots in 2004 and resulted in a nearly 2 percent loss in density and subsequent drop in basal area between ages 31 and 36 years old. At the last re-measurement, now 41 years old, these plots still had just over 1,000 trees/acre and a basal area of 162 square feet/acre.

At age 16 over 80 percent of the trees were in the 1- and 2-inch DBH classes. When DBH was plotted versus trees/acre at age 16, the result was the typical "reverse-J" shape that is often associated of uneven-aged stands. As time progressed, this curve has flattened out to have more of a traditional even-aged distribution approaching a "bell shaped curve". At age 41, there are still 1- and 2-inch DBH trees but there are also several trees that are 10- and 11-inches in DBH.

FLOMATON NATURAL AREA

Kush and others (2004) presented the results from six years of monitoring longleaf pine regeneration and development of seedlings in several gaps. Unfortunately, observations from the FNA came to an end a few years ago (Kush 2009). One final observation came from a tree that had a DBH of 36.2 inches and was 340 years old when it was killed by a "trash fire". A disk was cut from near the base of the tree and growth rings were measured. The tree had a DBH of 4.2-inches when it was 115 years old in the year 1767. Something happened around that time which released the tree. It was putting on its most growth between the years 1925 and 1950 when it was 273 years old.

ESCAMBIA EXPERIMENTAL FOREST

In the first study, longleaf pine total seedling height was examined by years since released from a shelterwood overstory. Portions of the overstory were removed every year for eight years and seedlings from each of the eight areas were tracked. At the end of the first eight years, seedlings which had their overstory removed at 1- and 2-years were above DBH. Those released between 3- and 7-years were out of the grass-stage. The seedlings that had just had the overstory removed at age eight were still in the grass stage. These trees were re-measured 21 years later and there were no differences in total height. Trees released at age one were 62 feet tall and those released at age eight were 58 feet tall. The trees in between those years fell between the two heights.

In the second study, volume growth was tracked over time comparing the site prepped longleaf pine plantation to a nearby naturally regenerated stand. At age 14, the plantation had nearly three times the volume of the natural stand, nearly 900 cubic feet/acre compared to 280 cubic feet/acre. The two stands were followed over time. By age 36 the trees in the natural stand were taller than the trees in the plantation. At age 39, the plantation and natural stand had nearly 4,200 cubic feet/acre in volume.

DISCUSSION

There may be little interest by any landowner or land manager to allow longleaf pine stands to develop at the high densities of over 3,500 trees/acre at age 16. The point is that you can do it. In many cases with longleaf pine that is just how nature managed it. When a gap was created in a forest, there were seedlings there to fill in the gap. The first 41 years of those unthinned plots from the RLGS demonstrate that longleaf pine does not stagnate in such dense stand conditions. Insects and/or diseases are not a problem in longleaf pine as they would most likely be with the either loblolly (Pinus taeda L.) or slash pine (Pinus elliottii L.).

The FNA demonstrated that we could get longleaf pine regeneration where none had existed. At the time restoration efforts were initiated in the FNA, there were no longleaf pines smaller than 3-inches DBH. Seven years into the effort there were no longleaf pine trees smaller than 4-inches DBH. However, there were longleaf pine seedlings in the understory and that several of them already out of the grass-stage (Kush and others 2004). In addition, the disk from a 340 year old tree showed that longleaf pine is not a slow grower at old ages and it does respond to release. These are characteristics most often associated with what are called tolerant species.

The studies from the EEF reinforce the above results. Whether seedlings were released at age 1 or age 8 from their overstory competition, by age 29 there was no difference in total height. Is this a characteristic of an intolerant species? A naturally regenerated stand of longleaf pine caught in total volume and surpassed in total height a longleaf pine plantation by age 36. If you have an existing stand of longleaf pine, does the added expense of site preparation and buying tree seedlings pay off? Longleaf pine is not an intolerant species that grows quickly from the start and you can plan on being able to thin at an early age. This work from the EEF shows that longleaf pine just starts to really grow when it is 20-40 years old. It is at age 35-40 when longleaf pine will be large enough in DBH to make utility poles. These 10-12-inch DBH poles are currently worth nearly twice the dollars sawtimber is given the same weight.

CONCLUSION

We are losing the best quality longleaf pine stands in structure and ground cover through the loss of natural stands of longleaf pine on privately-held lands. We need to maintain what existing stands are left, and yes, we need to give landowners and land managers reasons to plant longleaf pine. However, more importantly, we need to get information to the people who have longleaf pine to help them understand how to maintain it and their options for the future.

There is a paradigmatic shift going on in forestry in the southern United States. Landowners and land managers are looking for different management options. A majority of landowners no longer have income as the major reason for managing their forests. Alternative revenue streams from non-traditional forest values such as wildlife and hunting leases, pine straw harvesting, agroforestry, and "maybe" a potential for carbon credits are now of interest. Longleaf pine may let landowners and land managers explore more land management options than the other southern pines, especially where prescribed fire is a management tool.

Longleaf pine is not for everyone, but just as important, it must be remembered that longleaf pine is not loblolly nor is it slash pine and should not be grown like it is. If you want a tree that has early, rapid growth and grows fast at wide spacing's, then plant loblolly or slash pine. Some questions which are important to consider when making decisions: is longleaf pine intolerant? Ask Chapman (1932). Why is there a need to get the tree out of the grass-stage quickly if it "catches up"? Why does longleaf pine need to be planted at low densities? If you get a fast-growing, limby tree, why the additional expense of planting longleaf? And at low densities, will longleaf keep its form, and will it be wind firm?

The above questions to think about are tree specific, but what about at the forest/ecosystem level? Can we have red-cockaded woodpeckers or gopher tortoises without longleaf pine? Yes. Can we have groundcover species, such as wiregrass, without longleaf pine? Yes. Can we have "open pine" habitat sought by many without longleaf pine? Yes. Can we have a longleaf pine forest/ecosystem without longleaf pine? No!

Are we over-managing (mismanaging) longleaf pine? What Wahlneberg wrote in 1946 still holds true today. We continue to ignore the characteristics which make longleaf pine unique among the southern pines. It is not loblolly or slash pine and should not be grown as such. We need to do a better job of educating landowners and land managers about its unique life history. Finally, we should grow longleaf pine like nature did if we truly value the longleaf characteristics we say we do.

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ASSESSING THE LEANING, BENDING, AND SINUOSITY OF SAPLING-SIZE TREES

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ABSTRACT

Many factors result in trees with non-straight stems. An important prerequisite to investigating the causes of stem deformity is an ability to assess stem displacement. An ideal system would be easy to implement, be objective, and result in an index that incorporates the essential characteristics of the stem deformity into a dimensionless number. We tested a number of indices that could be measured and calculated from a photo taken from the side showing the tree's greatest deformity. Image analysis software was used to measure the characteristics that define the stem displacement and calculate an index of deformity. This system was tested on trees completing their fifth growing season in a long-term study of the effects of container cavity size and copper root pruning on longleaf pine (*Pinus palustris* Mill.) planted on moderately well-drained, gently sloping soils in central Louisiana.

INTRODUCTION

A field experiment of the effects of container cavity size and root pruning with copper on longleaf pine was established in November, 2004 in central Louisiana (N31°09.7342' ,W092°40.0396'). Sapling stems were first observed to be leaning after hurricane Gustav (September, 2008) and again in August, 2009. Some of the trees recovered from leaning, some did not, and some became sinuous during their recovery. A method was needed to quantify the degree of leaning so that it could be correlated with other tree characteristics.

There is no shortage of ways to quantify stem displacement, such as leaning, bending, and sinuosity, but there does not appear to be a standard way. In a study of crooked stem form with loblolly pine (*P. taeda* L.), Goddard and Strickland (1964) examined but dismissed the ocular estimates of Barber (1961), the binary classification of Mergen (1955), and the three crook categories of Littlefield and Eliason (1956). They modified the method of Perry (1960) for their estimates of stem crookedness (Goddard and Strickland 1964). Hans (1972) developed an instrument for assessing stem straightness and reported his results in three numbers: maximum deviation, angle, and number of bends. Cooper and Ferguson (1981) used subjective visual scores. Shelbourne and Namkoong (1966) used a photogrammetric technique to measure many variables associated with stem straightness. Adams and Howe (1985) dismissed photographic techniques as being too expensive and developed a simple index based on displacement. Cremer (1998) provided an in-depth analysis of stem recovery from bending using just the angle at the base of the stem and along the main displaced segment of the stem.

MATERIALS AND METHODS

After Hurricane Gustav in September, 2009, we began to photograph saplings from a long-term study of the effects of container cavity size and copper-caused root pruning on longleaf pine grown in containers before outplanting in November, 2004 on moderately well-drained, gently sloping soils in central Louisiana (Sword Sayer and others 2009). Digital photographs of each tree were taken from an angle perpendicular to the plane of greatest stem displacement. Twelve trees with various degrees of displacement were selected for this study. One of the selected trees was documented through time. A vertically held scale pole was included in each photograph. We used the photos as taken, but did examine the possibility of rectifying them to remove parallax effects. Measurements listed below were done using Sigma-Scan® from Jandel. Some of the measurements and calculations were directly from the literature, while others were new ideas. We also asked 10 people to rank 12 trees for stem displacement, on a scale of 1 to 5, based on the photographs taken. A straight tree is a 1 and a toppled tree very close to ground is a 5.

The measurements done on photographs of these trees are illustrated in figure 1: (a) the length of the shortest line from the base to the tip of the stem (fig 1A); (b) the area enclosed by the shape of the stem and the shortest line from the base to the tip of the stem (fig 1A); (c) the smallest rectangular area that fully encloses the main stem which may or may not include branches (fig 1B); (d) the height of the stem (fig 1C); (e) the area of the deflection between the shape of the stem and a vertical line centered at the base of the stem and extending to the tip of the stem (fig 1C); (f) the maximum deflection horizontal distance between a vertical line centered at the base of the stem and the point on the stem furthest from this vertical line (fig 1D); (g) the height of the maximum deflection point (fig 1D); (h) the height of the first deflection point on the stem (fig 1E); (i) the length of the stem following the shape of the stem (fig 1F); and (j) the angle between the stem base and the maximum

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deflection point on the stem (fig 1F); (k) the number of separate shortest line areas obtained by measurement (b) (fig 1A); (l) the number of separate deflection areas obtained in measurement (e) (fig 1C). The labels for k and l do not appear on the figure. In figure 1A, the left tree has one and the right tree has two shortest line areas. Both trees in figure 1C have two deflection areas. The height of first deflection point for the left tree in figure 1E is zero. Note that the rectangular area (measurement c) encloses the whole stem while the shortest line area (measurement b) and the deflection area (measurement e) extend only to the center of the stem.

Using the measurements a through l, twelve possible stem displacement indices were calculated and evaluated. Measurements g and h were ultimately not used in any of the indices presented here.

No. 1- Sinuosity index as defined by Wikipedia (2011) is the actual path length (the stem length, measurement i) divided by the shortest path length (measurement a).

No. 2- Since with the No. 1 index a leaning but otherwise straight tree would have a value of one, the same as that of the non-displaced tree, this index is the stem length (measurement i) divided by stem height (measurement d).

No. 3- Goddard and Strickland (1964) defined "Crook Index" as the number of crooks (measurement l) multiplied by the deviation of the largest crook (the maximum deflection distance, measurement f).

No. 4- Temel and Adams (2000) used a sinuosity index that is the number of crooks multiplied by the deviation of the largest crook (measurement f) and then divided this number by the stem radius. They only calculated their index for the second interwhorl from the top of the tree and used the radius of this segment. Since we calculated an index for the whole tree, we used the stem radius at 4.5 feet as our divisor.

No. 5- Temel and Adams (2000) worked only within the interwhorl; so, they did not account for taller versus shorter trees. We employed a modification where the index was further divided by tree height (measurement d).

No. 6- Cremer (1998) evaluated the tilt and posture of trees that are simply angles of lean on various parts of the stem. We evaluated the angle to the largest deviation from vertical on the stem (measurement j).

No. 7- The remaining indices are simply ideas that seemed reasonable to try. The first is the sum of all of the deflection areas (measurement e) divided by height (measurement d).

No. 8- A variation of the No. 7 index is to divide the area of the smallest rectangle possible (measurement c) by stem height (measurement d) and by diameter at breast height.

No. 9- The index is derived from multiplying the shortest line area (measurement b) by the number of bends (measurement k).

No. 10- A different variation of the No. 9 index is to divide the shortest line area (measurement b) by stem height (measurement d).

No. 11- Angle seems to be one of the characteristics that the eye of the observer is drawn to; yet, it does not account for multiple bends. Therefore, two additional modifications of the No. 6 index were attempted. The first is to multiply the angle of maximum deflection (measurement j) by the number of separate areas created by the shortest line(measurement k).

No. 12- The second is to multiply the angle of maximum deflection (measurement j) by the number of separate deflection areas created by a vertical line (measurement l).

RESULTS AND DISCUSSION

The advent of digital photography and computer image-analysis software have made photographic techniques practical for research studies, even if they may not be as useful in large-scale surveys. They have the advantage of minimizing complex measurements in the field while providing a permanent record of the measured trees. Photography is a useful tool in sinuosity measurements. It allows documentation of all characteristics, even those that were not thought of at the initial measurements. It allows access to points on the tree that would be difficult or unsafe to get to with a ladder or lift. The form of the tree is also less affected by the measurement process.

On the negative side, measurements are only two-dimensional and some parts, like the stem base and bud tip, may be hard to see. Proper scaling can be a problem. While not done in our earliest attempts we have found it important to guarantee that the base of the tree is visible and that the scale pole is in the same plane as the subject tree. It is probably best to record easily obscured measurements like diameter at breast height in the field rather than from the photograph. On average, the photo measurements were still less than 0.01 foot different in diameter and the length measurements were on average less than 0.22 feet different from field measurements. Given these small differences, it was decided that image rectification was an unnecessary step.

Figure 2 shows the 12 trees which were ranked subjectively for stem lean, bend, and sinuosity. Their digital measurements are summarized table 1. The same measurements were also done on a single tree through time in figure 3 but the data are not shown. Using the measurements obtained digitally, twelve possible sinuosity indices for the 12 trees in figure 2 are presented in table 2. Indices for a single tree through time are presented in table 3.

Two overarching criteria were used for the purposes of evaluating indices. The first is how well an index agreed with the subjective ranking that a reasonable person would give to a tree and is evaluated with table 2. The second criterion is how well the index showed the recovery from stem displacement by a tree through time as shown with table 3.

Subjective rankings are faster and by definition agree with what we feel is the correct rating. What they lack is repeatability between different observers and the ability to detect very subtle changes. Most of the objective measures tested have some good features. Ultimately we decided that for our use, No. 8 index, which is reported in tables 2 and 3 and based on the smallest possible rectangular area (measurement c), along with height (measurement d) and dbh, is the best. Henceforth we will refer to this method as the rectangular area index (RAI).

One important characteristic of the RAI is that it is dimensionless. Even though all of our calculations were done in feet because of the scale of the height pole, the index would be the same if we used the metric system or any other units. Only three other indices are dimensionless, No. 1, No. 2, and No. 4 (Tables 2 and 3). Indices No. 1 and No. 2 do not have a great range of values; thus trees of various degree of stem displacement have very similar indices. Furthermore, changes in a tree through time are more difficult to detect as shown in table 3. The No. 4 index has much potential since it appears to work well and is previously published (Temel and Adams 2000). However, in applying it to whole trees, there was disagreement among users as to the appropriate way to count the number of crooks. Obtaining the measurements for the RAI is a very basic process with little room for user variation so it is easy to repeat with different users.

In conclusion, none of the indices tested was perfect and none was useless. We felt that the RAI was the most useful for our purposes and it will get extensive use as we try to correlate the recovery of bent stems to their root system architecture. The RAI could also serve as a useful index in many of the genetic studies that the literature (Adam and Howe, 1985; Barber, 1961;Cooper and Ferguson, 1981; Goddard and Strickland, 1964) indicates are the primary use of such indices.

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Table 1—Measurements,as described in figure 1, used to calculate the indices for the 12 longleaf pine saplings shown in figure 2 beginning their sixth growing season in central Louisiana: (a) shortest line length (SLL); (b) shortest line area(SLA); (c) rectangular area (RA); (d) height (H); (e) deflection area (DA); (f) maximum deflection distance (MDD); (g) maximum deflection height (MDH); (h) first deflection height (FDH); (i) stem length (SL); (j) angle to maximum deflection; (k) number of separate SLA (NS); and (l) number of DA (NV).

ID	DBH	(a) SLL	(b) SLA	(c) RA	(d) H	(e) DA	(f) MDD	(g) MDH	(h) FDH	(i) SL	(j) A	(k) NS	(l) NV
	ft	ft	ft^2	ft^2	ft	ft^2	ft	ft	ft	ft	degrees		
5	0.17	11.52	0.63	5.61	11.49	1.93	0.22	3.92	0.00	11.50	3.20	2	1
1	0.13	9.94	0.69	6.09	9.92	1.37	0.25	7.58	1.07	9.97	1.91	4	3
11	0.13	8.45	0.89	4.58	8.60	2.73	0.44	4.49	0.00	8.65	5.55	1	1
6	0.17	12.55	5.93	25.46	12.49	5.47	1.71	12.49	0.00	12.77	7.78	1	2
12	0.15	13.85	5.99	35.75	13.62	9.38	2.29	13.62	0.73	13.93	9.53	1	1
8	0.10	8.20	2.71	8.30	8.17	4.16	0.81	4.95	0.00	8.32	9.30	1	1
7	0.14	9.90	5.01	16.73	9.83	3.11	1.16	9.83	0.97	10.22	6.70	2	2
9	0.07	5.98	2.31	6.67	5.94	2.06	0.85	3.88	0.00	6.40	12.35	1	2
10	0.13	9.35	6.99	15.57	9.32	8.18	1.44	6.19	0.00	9.91	13.11	1	1
2	0.12	6.69	2.89	7.63	6.58	1.72	0.64	4.59	0.92	7.03	7.96	2	3
3	0.11	8.70	9.56	36.82	4.79	7.58	7.16	4.79	0.00	9.54	56.26	2	1
4	0.07	5.26	7.06	15.43	3.57	1.21	4.09	3.25	1.20	7.02	51.56	1	2

Table 2—Evaluated indices calculated for the 12 subjectively ranked longleaf pine saplings shown in figure 2 beginning their sixth growing season in central Louisiana. Subjective ranking (SR) was on a scale of 1 to 5 with 1 being a straight stem. For conciseness the following abbreviations are used: A=angle to maximum deflection; DA=deflection area; H=height; MDD=maximum deflection distance; NS= number of areas defined by the shortest line from base to tip; NV= number of areas defined by a vertical line centered at the stem base; R=stem radius at 4.5 feet; RA=rectangular area; SL=stem length; SLA=shortest line area; SLL=shortest line length. No. 1= SL/SLL; No. 2=SL/H; No. 3= Goddard and Strickland=NV*MDD; No. 4= Temel and Adams=(NV*MDD)/R; No. 5= modified Temel and Adams= NV*MDD)/(R*H); No. 6= A; No. 7= DA/H; No. 8 = RA/(H*R*2); No.9=SLA/NS; No. 10= SLA/H; No. 11=A/NS; No. 12=A/NV.

ID	SR	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11	No.12
				ft		ft^{-1}	degrees	ft		ft^2	ft	degrees	degrees
5	1.2	1.00	1.00	0.22	2.53	0.22	3.20	0.17	2.82	1.26	0.05	6.40	3.20
1	2.0	1.00	1.01	0.76	11.57	1.17	1.91	0.14	4.68	2.75	0.07	7.64	5.73
11	2.3	1.02	1.01	0.44	6.94	0.81	5.55	0.32	4.23	0.89	0.10	5.55	5.55
6	2.5	1.02	1.02	3.42	41.03	3.28	7.78	0.44	12.24	5.93	0.47	7.78	15.57
12	2.6	1.01	1.02	2.29	30.64	2.25	9.53	0.69	17.57	5.99	0.44	9.53	9.53
8	3.3	1.01	1.02	0.81	15.92	1.95	9.30	0.51	9.98	2.71	0.33	9.30	9.30
7	3.5	1.03	1.04	2.31	32.43	3.30	6.70	0.32	11.95	10.02	0.51	13.41	13.41
9	3.8	1.07	1.08	1.70	45.53	7.66	12.35	0.35	15.06	2.31	0.39	12.35	24.69
10	3.8	1.06	1.06	1.44	21.42	2.30	13.11	0.88	12.41	6.99	0.75	13.11	13.11
2	3.8	1.05	1.07	1.93	32.20	4.90	7.96	0.26	9.71	5.78	0.44	15.93	23.89
3	4.8	1.10	1.99	7.16	132.72	27.73	56.26	1.58	71.26	19.12	2.00	112.51	56.26
4	4.8	1.33	1.96	8.18	225.34	63.03	51.56	0.34	59.47	7.06	1.97	51.56	103.11

Table 3—Stem displacement indices through time for a longleaf pine sapling tree shown in figure 3 planted in November, 2004 in central Louisiana. For conciseness the following abbreviations are used: A=angle to maximum deflection; DA=deflection area; H=height; MDD=maximum deflection distance; NS= number of areas defined by the shortest line from base to tip; NV= number of areas defined by a vertical line centered at the stem base; R=stem radius at 4.5 feet; RA=rectangular area; SL=stem length; SLA=shortest line area; SLL=shortest line length. No. 1= SL/SLL; No. 2=SL/H; No. 3= Goddard and Strickland=ND*MDD; No. 4= Temel and Adams=(NV*MDD)/R; No. 5= modified Temel and Adams= NV*MDD)/(R*H); No. 6= A; No. 7= DA/H; No. 8 = RA/(H*R*2); No.9=SLA/NS; No. 10= SLA/H; No. 11=A/NS; No. 12=A/NV.

Date	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11	No.12
			ft		ft^{-1}	degrees	ft		ft^2	ft	degrees	degrees
08/18/09	1.33	1.96	8.18	225.34	63.03	51.56	0.34	59.47	7.06	1.97	51.56	103.11
01/14/10	1.05	1.07	1.93	32.20	4.90	7.96	0.26	9.71	5.78	0.44	15.93	23.89
07/23/10	1.00	1.01	0.60	10.70	1.13	3.59	0.22	5.81	1.71	0.09	7.18	3.59
08/16/10	1.01	1.01	0.32	4.94	0.49	4.31	0.17	4.24	1.68	0.06	12.94	4.31
10/25/10	1.00	1.00	0.27	3.98	0.38	1.48	0.16	4.14	1.26	0.04	4.45	1.48
01/27/11	1.01	1.00	0.25	3.10	0.30	3.31	0.15	3.23	0.59	0.06	3.31	3.31

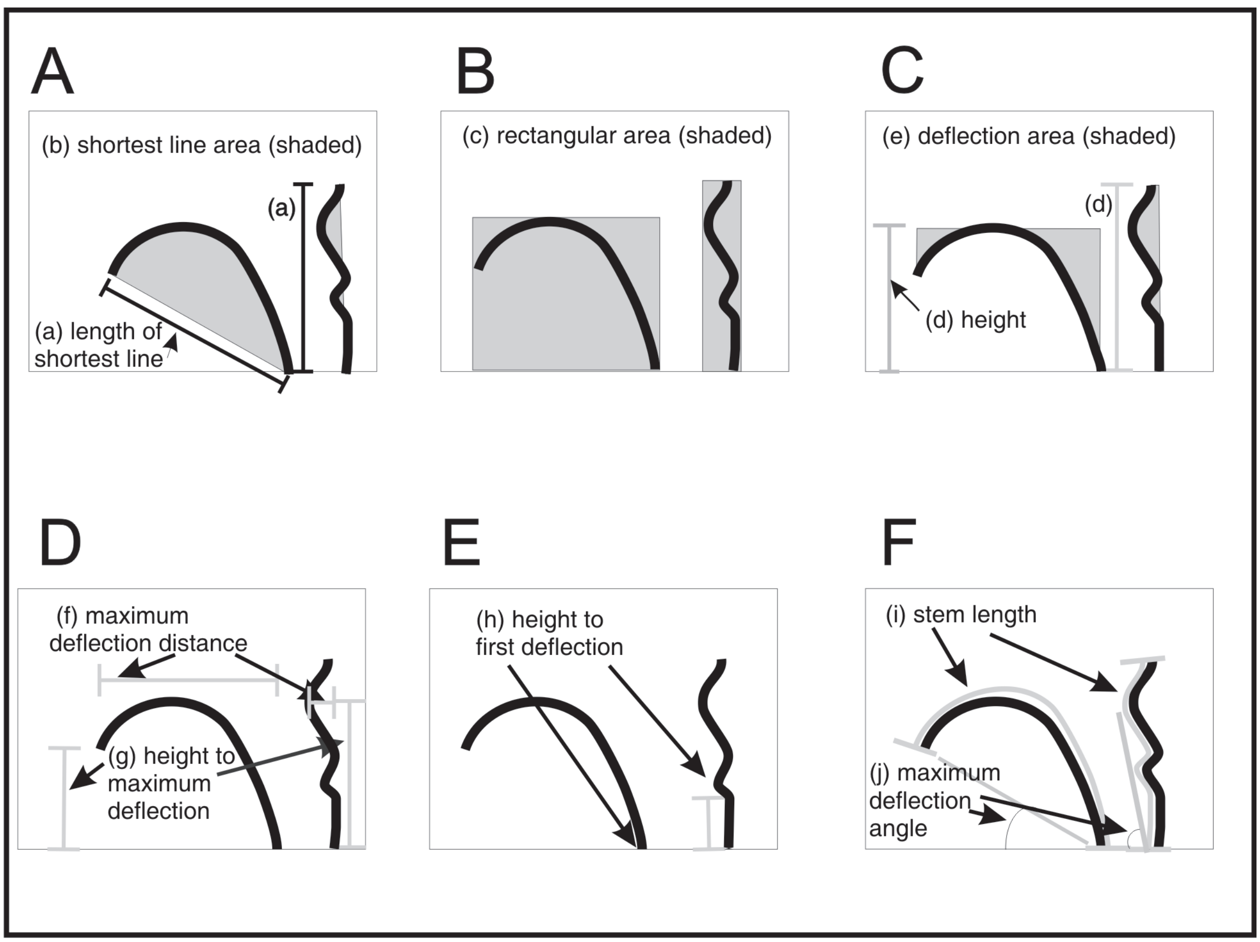

Figure 1—Diagram of the measurements taken on sample trees. Each of the six panels (A-F) contained two trees. The actual measurements are identified by lowercase letters (a-j). Measurements l and k are numbers of separated areas in A and C, respectively.

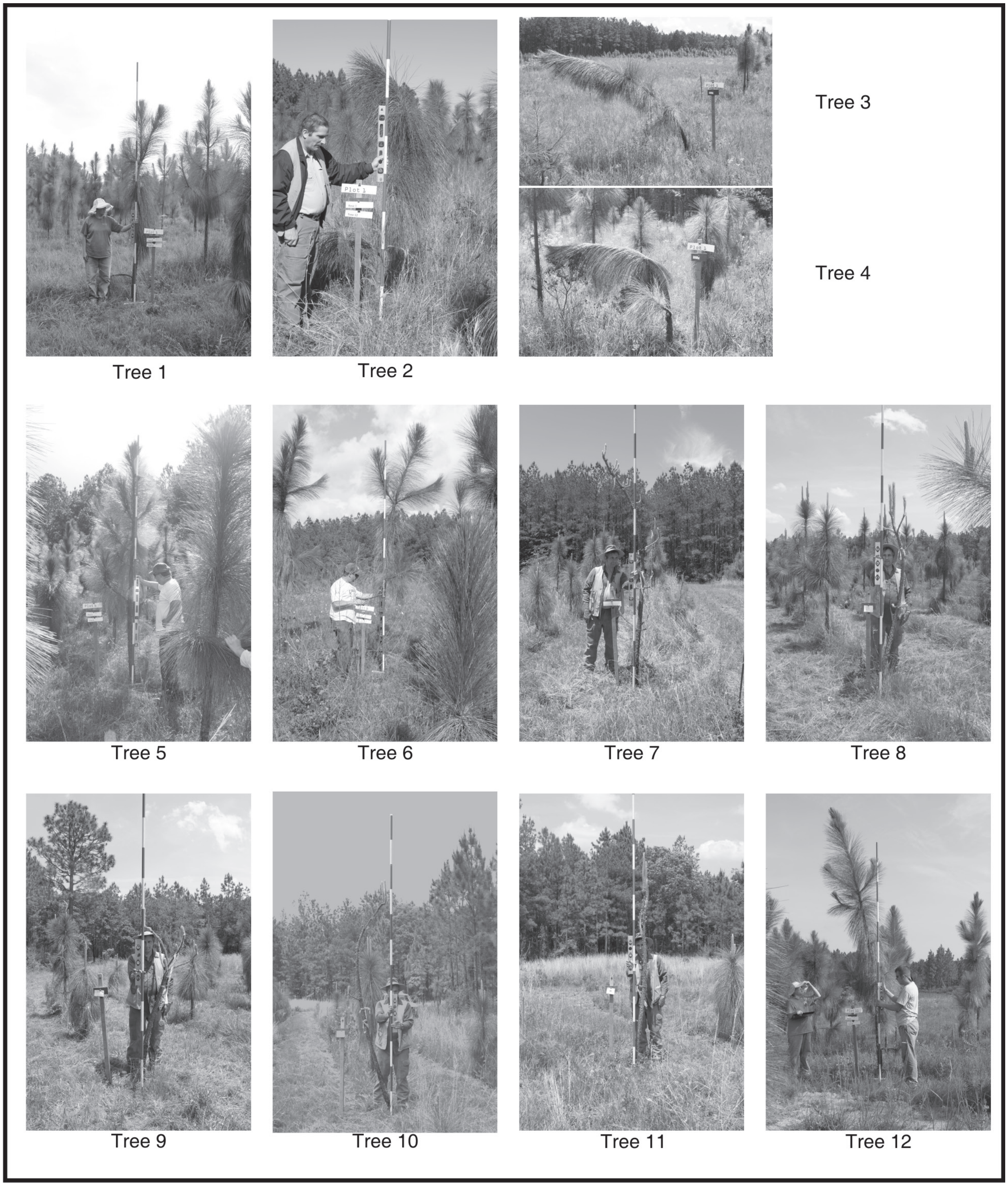

Figure 2—Photographs of the twelve longleaf pine saplings in the beginning of the sixth growing season. Stem deformity of these saplings were ranked subjectively and objectively. Note that trees 7 through 11 were stripped of needles for further analysis.

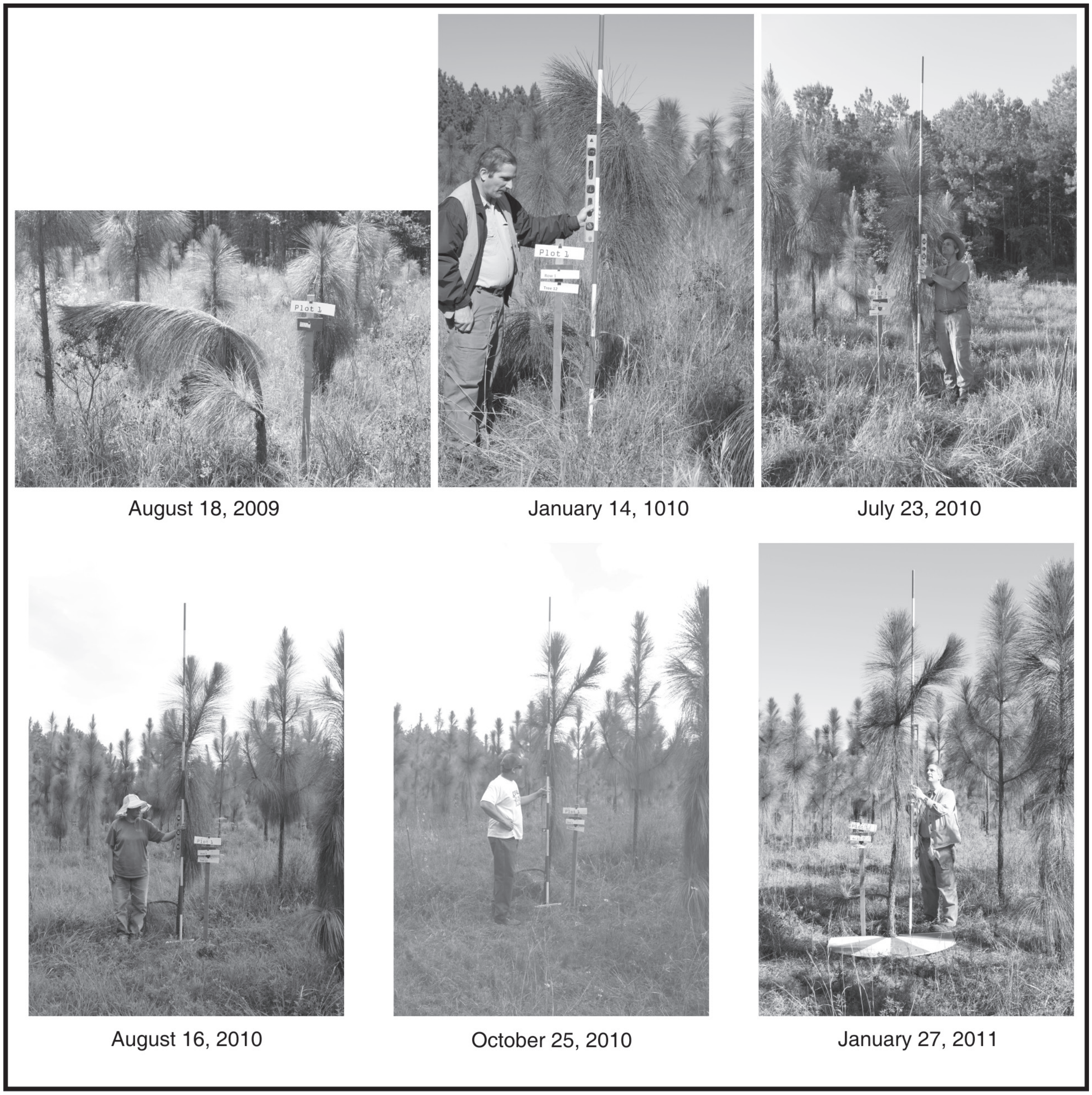

Figure 3—Photographs of the same longleaf pine sapling taken through time to show the recovery from stem displacement.

CHANGES IN NON-PINE WOODY SPECIES DENSITY, COMPOSITION, AND DIVERSITY FOLLOWING HERBICIDE AND FERTILIZATION APPLICATION TO MID-ROTATION LOBLOLLY PINE STANDS

Hal O. Liechty and Conner Fristoe

ABSTRACT

We monitored woody vegetation (dbh>1.0 in) response for up to six years following a herbicide (16 ounces imazapyr /acre), a fertilizer (365 pounds urea and 175 pounds diammonium phosphate/acre) and a combined fertilizer and herbicide application in four mid-rotation loblolly pine stands located within the Upper Gulf Coastal Plain in Arkansas. Approximately 60-80% of the original non-pine woody vegetation died within three years following herbicide application. Non-pine mortality was greater on plots that received both an herbicide and a fertilizer application than only the herbicide application. Significant recruitment of additional woody vegetation occurred following all treatment applications, but herbicide reduced this recruitment for up to six years. Woody vegetation species richness and diversity was reduced by the herbicide application but was not altered by fertilization.

INTRODUCTION

Fertilization and herbicide application are common practices used to increase productivity of loblolly pine (Pinus taeda L.) mid-rotation stands growing in the Gulf Coastal Plain. Growth responses of crop trees to fertilizer and herbicide applied individually or in a combined cultural treatment have frequently been reported for mid-rotation stands in this region (Bataineh and others 2006, Haywood and Tiarks 1990, Sword Sayer and others 2003, Williams and Farrish 2000). However, impacts of these treatments on non-crop trees or other woody species are rarely documented in the Gulf Coastal Plain. Studies in other regions have indicated that successful control of hardwood root stocks at younger ages (three to five years following loblolly pine establishment) reduces hardwood basal area and tree species richness into latter stand ages (Miller and others 2003). However, single release applications of herbicide may have only short-term impacts on woody vegetation and only minimal long-term impacts on woody species richness and diversity (Boyd and others 1995, Zutter and Zedaker 1989).

A better understanding of the impacts of herbicide and fertilization applications on non-pine woody vegetation in the Gulf Coastal Plain will not only help to explain pine crop tree response to these treatments but also the effect of these treatments on woody vegetation biodiversity. Maintenance of biodiversity can be an important forest management concern (Burton and others 1992) and can be an important consideration or component of forest management activities by landowners. We established a study in the Upper Gulf Coastal Plain of Arkansas and Louisiana to compare the effects of herbicide, fertilizer, and a combined herbicide+fertilizer application on non-pine woody (hardwood) vegetation in mid-rotation loblolly pine stands. We monitored density, composition, and diversity of these stands for up to six years following application of these treatments.

METHODS

DESIGN

Twelve plots (between 0.09 and 0.26 acres) were established at each of four mid-rotation loblolly pine stands (W. Crossett, S. Crossett, Crossroads, and S. Monticello) during 2001, 2002, and 2003. The sites were located in Union Parrish, LA and the counties of Ashely and Drew in AR. The W. Crossett, S. Crossett, and S. Monticello stands were established by planting 681 or 726 seedlings/acre during the early winter of 1986, while the S. Crossett stand was established using a seed tree regeneration harvest in 1981. All stands had been thinned the year prior to the study initiation. At each site herbicide (16 ounces imazapyr and 0.23 ounces surfactant/acre in 15 gallons/acre of water) was aerially applied to six of the twelve plots, as well as a 50 foot buffer around each plot, during the fall following plot establishment. During January or February following the first growing season after the herbicide application, 365 pounds/acre of urea and 175 pounds/acre of diammonium phosphate was applied by hand to three plots and associated buffers that received the herbicide treatment and three that did not receive the herbicide treatment. These herbicide and fertilizer applications provided four individual treatments

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(control, herbicide, fertilizer, and herbicide+fertilizer) with each treatment replicated three times in each stand.

MEASUREMENTS AND STATISTICAL ANALYSIS

Dbh (dbh ≥1.0 inches) and species were recorded prior to or just after herbicide application for all trees in each measurement plot. Dbh of each tree (dbh ≥1.0 inches) was measured annually through the end of the sixth growing season after plot establishment. The W. Crossett stand was inadvertently fertilized prior to the sixth growing season, so measurements following the fifth growing season for the W. Crossett and the sixth growing season for the remaining three sites were used for this study. Mortality of the trees was assessed annually and the number and species of ingrowth trees (dbh ≥ 1.0 inches) were recorded. The experimental design of the study was a split plot with the herbicide treatment being the whole plot treatment. Analysis of variance was used to determine differences between herbicide and fertilizer treatments. If there was a significant interaction, Tukey's mean separation test was used to determine differences between herbicide and treatment combinations. To evaluate differences in the proportion of hardwood mortality between herbicide and herbicide+fertilizer treatment combinations, a Kolmogorov-Smirov nonparametric test was used. All statistical tests were perform using a=0.05.

RESULTS

Non-pine woody vegetation (here after referred to hardwood) basal area at the end of the fifth or sixth growing season was lower with herbicide applications than without (Table 1). Fertilization did not have any impact on hardwood basal area. At the end of the study the hardwood basal area represented 10.1-10.6 percent of the total tree basal area in the plots that did not receive herbicide but only 3.0-3.2 percent in plots that received an herbicide application. Although herbicide application significantly increased net pine basal area growth, differences in total pine basal area among treatments at the end of the study were not significant (Table 1).

Within the control and fertilizer treatments between 8.2 and 8.5 percent of the hardwood basal area initially measured within the plots died during the 5 to 6 year study period. In plots that received an herbicide application 60.0-73.6 percent of the initial hardwood basal area died. The majority of the mortality within the herbicide and herbicide+fertilizer treatments occurred within the first three years following herbicide application. Mortality with the herbicide application was consistently greater when fertilizer was applied in addition to the herbicide (73.6 percent) compared to that of the herbicide only treatment (60.0 percent). Fertilization without herbicide application did not appear to alter hardwood mortality.

At the end of the study the amount of hardwood ingrowth was much lower in treatments that involved herbicide application than in treatments without herbicide application (Figure 1). However, ingrowth represented a similar proportion of the total hardwood basal area (24-36%) within each of the four treatments. Growth of the hardwood trees that survived the herbicide applications grew much slower than trees that were in treatments that did not receive the herbicide application. Annual basal area growth of the surviving hardwoods in the herbicide and herbicide+fertilizer treatments was approximately 3 percent, but annual growth in the other two treatments was 9-11 percent. Many of the hardwood trees that survived the herbicide application had reduced crown areas and low vigor. In addition the composition of the surviving hardwood trees in the plots which received the herbicide application was much different than in the control and fertilizer treatments. Fast growing hardwood trees such as sweetgum (Liquidambar styraciflua L.) and blackgum (Nyssa sylvatica Marsh.) were a major component of the hardwood mid-story within the control and fertilizer treatments but only a minor component in the other treatments due to their sensitivity to the imazapyr herbicide.

Species richness was the highest (36) in the control and the lowest (32) in the combined herbicide+fertilizer treatment (Table 2) at the end of the fifth or sixth growing season following study initiation. Although the combined herbicide+fertilizer treatment had the lowest species diversity (highest Simpson's diversity index and the lowest Shannon's diversity index), diversity was only significantly impacted by the herbicide application (Table 2). Diversity was significantly lower with herbicide application than without. Diversity was not significantly impacted by the fertilizer application.

DISCUSSION

The reduction in hardwood density with the herbicide application indicates that the imazapyr successfully reduced competition to the pine. Herbicide application had a much greater impact on the hardwood component of these stands than did the application of fertilizer. Herbicide significantly reduced hardwood and other non-pine woody vegetation for up to 6 years following application. The hardwoods in these stands did not recover to pre-treatment levels by the end of the six-year study period. Mid-rotation application of the herbicide also decreased diversity and species richness. Results from this study appear to be similar to those reported by Miller and others (2003) involving control of hardwoods at earlier stand ages. Miller and others (2003) indicated that long-term changes in hardwood species richness and basal area can occur with successful hardwood control or pine release activities. Reductions in growth of the surviving hardwoods and the amounts of ingrowth associated with herbicide application in our study suggests that these changes may persist to later stand ages beyond our six year period of observation. Although fertilization combined with the herbicide application increased hardwood mortality, differences in the amount of living hardwood basal area within the herbicide and the herbicide+fertilizer area at the end of the study were not significant. Increased mortality of the hardwood with the combined treatment may have been related to an increase in pine growth in response to fertilization.

CONCLUSIONS

An application of imazypyr herbicide can have a significant long-term impact on the non-pine woody vegetation within mid-rotation stands. Application of herbicide reduces the amount of this vegetation in these stands and thus reduces the species richness and diversity of mid-rotation loblolly pine stands. Application of fertilizer had little impact on the non-pine woody vegetation regardless of whether an herbicide application occurred or not.

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Table 1—Mean (standard deviation) hardwood and pine basal area prior to and at the end of the fifth or sixth growing season following the initial herbicide application for each treatment combination

	Control	Herbicide	Fertilizer	Herbicide +Fertilizer
	--------------------BA Prior to Treatment (ft^2/ac)-------------------			
Hardwood	7.8(5.4) a[1]	6.8(5.1) a	7.1(5.0) a	6.9(5.1) a
Pine	89.0(24.2) a	85.6(19.3) a	88.9(20.2) a	87.0(20.5) a
	---------------BA 5th or 6th Growing Season (ft^2/ac)----------------			
Hardwood	13.8(5.8) a	4.0(2.3) b	13.0(4.7) a	2.9(1.1) b
Pine	129.5(24.4) a	126.7(18.9) a	128.6(20.3) a	131.3(21.9) a

[1]Means with the same letter in a row are not significantly different at p=0.05.

Table 2—Species richness, mean Simpson's diversity index, and Shannon's (basal area) diversity index at the end of the fifth or sixth growing season following the initial herbicide application for each treatment combination

	Control	Herbicide	Fertilizer	Herbicide +Fertilizer
Species Richness	36	34	33	32
Simpson's Diversity	0.25 a[1]	0.35 b	0.27 a	0.36 b
Shannon (Basal Area)	0.43 b	0.40 a	0.47 b	0.32 a

[1]Means with the same letter in a row are not significantly different at p=0.05.

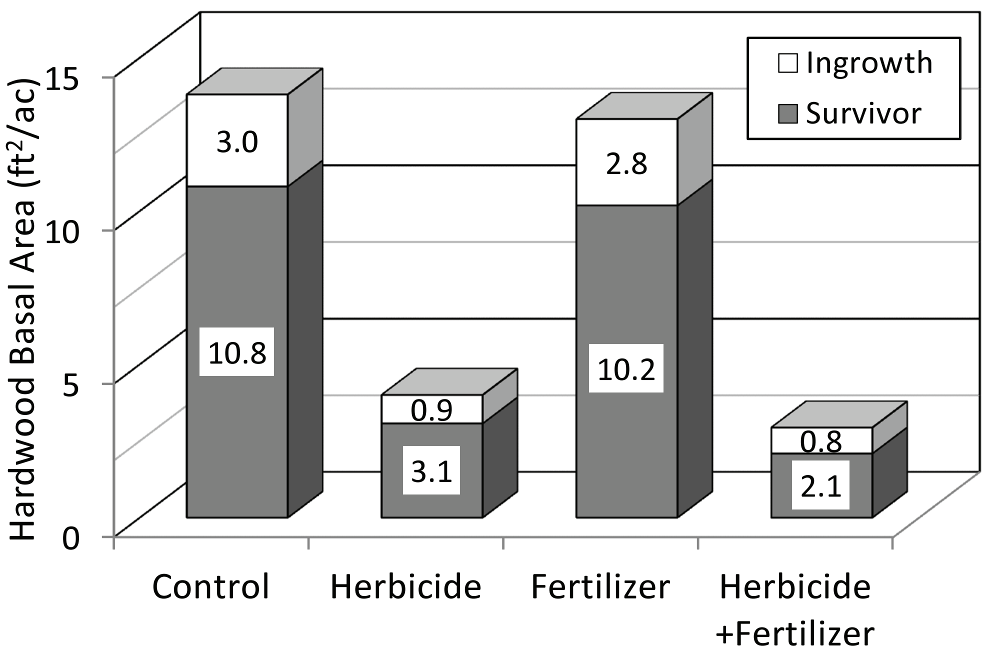

Figure 1—Living ingrowth and survivor hardwood basal area for each treatment at the end of the fifth or sixth growing following study initiation.

TWENTY-NINE YEARS OF DEVELOPMENT IN PLANTED CHERRYBARK OAK-SWEETGUM MIXTURES: IMPLICATIONS FOR FUTURE MIXED-SPECIES HARDWOOD PLANTATIONS

Brian Roy Lockhart, Andrew W. Ezell, John D. Hodges, and Wayne K. Clatterbuck

ABSTRACT

Results from a long-term planted mixture of cherrybark oak (*Quercus pagoda* Raf.) and sweetgum (*Liquidambar styraciflua* L.) showed sweetgum taller in height and larger in diameter than cherrybark oak early in plantation development. By age 17, cherrybark oak was similar in height and diameter with sweetgum and by age 21 was taller in height and larger in diameter than sweetgum depending on spacing arrangement. By age 29, cherrybark oak was competing with other cherrybark oak in the overstory canopy. The ascendance of cherrybark oak above sweetgum in intimate plantation mixtures confirms results from bottomland hardwood stand development in natural stands. Future bottomland hardwood mixed-species plantation research must include stand-level replication. Further, pure plantings of each species in the mixture are necessary to compare development to the planted mixture.

INTRODUCTION

Planting tree species mixtures is gaining in popularity as we begin to understand their benefits to the functions and values of forests. Benefits, compared to single-species plantations, include greater species and structural diversity (Twedt and Wilson 2002), development of a higher quality timber tree due to the influence of interspecific competition early in stand development, and greater timber yield (Binkley 1984, Kelty 1986). Greater timber yield in mixed-species plantations may occur due to more efficient use of growing space as species stratify into different canopy layers (Kelty 1986).

Few long-term examples exist of mixed-species plantation development in southern bottomland hardwoods. Instead, we have had to rely on field observations of developmental dynamics in natural stands (Bowling and Kellison 1983, Clatterbuck and Hodges 1988, Johnson and Krinard 1988) to develop mixed-species planting strategies. The primary objective of this study was to determine the long-term height and diameter growth patterns in artificial mixtures of cherrybark oak (*Quercus pagoda* Raf.) and sweetgum (*Liquidambar styraciflua* L.) planted at different spacings. Twenty-nine year results are presented.

METHODS

SITE

The study is located on the Noxubee National Wildlife Refuge in Oktibbeha County, MS (33° 18' N, 88° 44' W). The site is a low terrace adjacent to the active floodplain of the Noxubee River. Soil is a Stough fine sandy loam (coarse-loamy, siliceous, semiactive, thermic Fragiaquic Paleudults) which is considered marginal for cherrybark oak and sweetgum (SI50 = 80 to 85 feet using the Baker and Broadfoot System; Baker and Broadfoot 1979) because of the presence of a fragipan. The climate is described as warm and humid (Brent 1973). Average annual rainfall is 50.8 inches, ranging from 6.1 inches in March to 2.5 inches in October. Average annual temperature is 64° F, ranging from 81° F in July to 46° F in January. Prior to planting, the site was used for grazing and hay production.

PLANTING DESIGN AND ESTABLISHMENT

Three spacing arrangements were used in the study. The first spacing involved planting mixtures of cherrybark oak and sweetgum on an 8 by 8 foot spacing (8x8). This spacing was the acceptable plantation spacing for trees in the southern United States in the early 1980s. The first row in this spacing arrangement was planted in sweetgum (see Lockhart and others 2006 for a diagram of the spacing arrangement), with cherrybark oak and sweetgum seedlings alternated on the second row; the third row was also planted in sweetgum. This arrangement resulted in each cherrybark oak seedling being surrounded by eight sweetgum seedlings. A total of 35 cherrybark oak seedlings and 188 sweetgum seedlings were planted in seven rows (three rows were alternating cherrybark oak and sweetgum seedlings), excluding buffer trees. This spacing arrangement is equivalent to

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108 cherrybark oak seedlings per acre and 572 sweetgum seedlings per acre.

The second spacing arrangement involved planting mixtures of cherrybark oak and sweetgum on a 5 by 5 foot spacing (5x5) using the same row design as the 8x8 described above. The closer spacing was chosen based on previous work in natural stands of cherrybark oak and sweetgum (Clatterbuck 1985). A total of 45 cherrybark oak seedlings and 168 sweetgum seedlings were planted in 11 rows (five rows alternating cherrybark oak and sweetgum seedlings). This spacing arrangement is equivalent to 367 cherrybark oak seedlings per acre and 1,372 sweetgum seedlings per acre.

The third spacing arrangement involved planting mixtures of cherrybark oak and sweetgum on a 5 by 5 foot similar to the 5x5 except two rows of sweetgum were planted on each side of the alternating cherrybark oak and sweetgum row (5x5D) for a total of 14 sweetgum seedlings surrounding each cherrybark oak seedling. This arrangement was used to provide greater interspecific competition in case the first row of sweetgum was quickly overtopped. A total of 27 cherrybark oak and 182 sweetgum seedlings were planted in 11 rows (three rows alternating cherrybark oak and sweetgum seedlings). This spacing arrangement is equivalent to 225 cherrybark oak seedlings per acre and 1,517 sweetgum per acre.

The site was disced prior to planting. Seedlings were then planted in March 1982. Cherrybark oak seedlings were 2-0 stock produced in a nursery at the Blackjack Research Facility on the Mississippi State University campus (about 15 miles from the study site). Sweetgum seedlings were 1-0 stock purchased from a private nursery. Thirty-six cherrybark oak seedlings (34 percent of the total number of cherrybark oak planting spots) were replanted with 1-0 stock following first-year mortality with the 2-0 stock. Periodic mowing was conducted within and between rows during the first two growing seasons following planting.

MEASUREMENTS

Height and diameter measurements were conducted following the 1989, 1991, 1998, 2002, and 2010 growing seasons (stand ages 8, 10, 17, 21 and 29, respectively). Tree height was measured with a height pole in 1989 and 1991, a laser height instrument in 1998 and 2002, and a clinometer in 2010. Diameter (d.b.h., 4.5 feet above ground) was measured with a standard diameter tape. In 2002 and 2010, crown classes (dominant, codominant, intermediate, and overtopped) were assigned for each tree based on the tree crown's position and condition (Meadows and others 2001).

ANALYSES

Statistical analyses were conducted using PC-SAS. Each cherrybark oak and surrounding sweetgum was considered an experimental unit. Survival was calculated as the number of trees alive at each measurement time, including replanted cherrybark oak seedlings. Sweetgum height and diameter within each cherrybark oak plot were averaged and compared with cherrybark oak using repeated-measures analysis. The Wilks' Lambda test was used to test the effect of time and time by species interactions. Only those plots with a live cherrybark oak following the 2010 measurements were included in all analyses. An alpha level of 0.05 was used to determine statistical significance.

RESULTS

SURVIVAL

Survival across all spacings was 73 and 97 percent for cherrybark oak and sweetgum, respectively. Cherrybark oak survival following the 2010 growing season ranged from 86 percent in the 8x8 to 62 percent in the 5x5, while sweetgum survival was nearly 100 percent across all spacings (table 1). Much of the cherrybark oak mortality occurred prior to the 1989 measurements.

HEIGHT

Height differences of 11 to 18 feet, depending on spacing, existed between cherrybark oak and sweetgum by 2002 (fig. 1). Time and time by species interactions were different across all spacings ($p \leq 0.01$ within each spacing) indicating that while both species grew in height over time, their patterns of height growth differed. During 1989 and 1991 sweetgum was taller than cherrybark oak within each of the 3 spacings ($p \leq 0.05$). Seventeen years after planting (1998), no height differences existed among the 3 spacings ($p \geq 0.08$). By 2002, cherrybark oak was taller than sweetgum in the 8x8 ($p = 0.02$) and 5x5D ($p=0.02$), but similar in height in the 5x5 ($p = 0.14$). Following the 2010 growing season, cherrybark oak was much taller than sweetgum within each spacing ($p < 0.01$).

DIAMETER

Cherrybark oak and sweetgum diameter development patterns were similar to their respective height development patterns (table 2). At the time of the 1989 and 1991 measurements, sweetgum was larger in diameter than cherrybark oak in the 8x8 and 5x5, while the two species had similar diameters in the 5x5D. Cherrybark oak and sweetgum had similar diameters within each spacing by age 17 (1998). Afterwards, cherrybark oak diameters were considerably larger than sweetgum.

CROWN CLASSES

A majority of the cherrybark oak crowns were in the dominant or codominant position at the time of the 2010 measurements (table 3). No sweetgum crowns were classed as dominant and only one percent were considered codominant. A majority of the sweetgum crowns were overtopped in the 5x5 and 5x5D while 99 percent of the sweetgum crowns in the 8x8 were intermediate or overtopped.

DISCUSSION

STAND DEVELOPMENT

Lockhart and others (2006) previously reported the ascendance of cherrybark oak above sweetgum by age 21 followed natural stand development patterns of cherrybark oak-sweetgum stratification. Planted sweetgum dominated cherrybark oak during the early years of stand development in each of the three spacings. But sweetgum height and diameter development slowed during the stem exclusion stage of stand development, with cherrybark oak eventually overtopping sweetgum. By age 17, cherrybark oak had either caught or passed sweetgum in height and diameter, depending on spacing, and was significantly taller in height and larger in diameter by age 21. Differences in height and diameter were further accentuated by age 29. By 2010, the codominant cherrybark oaks were competing with other cherrybark oaks in the overstory canopy, while sweetgum either slowed in height growth (8x8) or had no increases in height (5x5 and 5x5D). A similar pattern of oak stratification has been documented in cherrybark oak-sweetgum mixtures in natural stands (Clatterbuck and Hodges 1988), bottomland red oak [cherrybark oak, water oak (Q. nigra L.), and willow oak (Q. phellos L.)]-sweetgum-American hornbeam (Carpinus carolinana Walt.) mixtures in Arkansas and Mississippi (Bowling and Kellison 1983, Johnson and Krinard 1988), and northern red oak (Q. rubrum L.)-red maple (Acer rubra L.)-black birch (Betula lenta L.) mixtures in the northeastern United States (Oliver 1978).

Results from this study indicate that cherrybark oak, planted in intimate mixtures with sweetgum, develops similarly to bottomland red oak-sweetgum mixtures in natural stands (Bowling and Kellison 1983, Clatterbuck and Hodges 1988, Johnson and Krinard 1988). Best individual cherrybark oak development occurred at the 8x8. These trees were taller in height and larger in diameter compared to cherrybark oaks in the 5x5 and 5x5D. Sweetgum in the 8x8 did reach a pulpwood merchantability standard (4 inches d.b.h.) before being overtopped by cherrybark oak. Therefore, we recommend that planting intimate mixtures of cherrybark oak and sweetgum be conducted on 8 by 8 foot spacings. A 10 by 10 foot spacing would probably be acceptable.

FUTURE RESEARCH

The present study represented a case study of cherrybark oak and sweetgum stand development in intimate mixtures. A scientifically rigorous study is needed to fully explore the cause and effect of different species mixtures in bottomland hardwood plantation development, especially when the objective is long-term quality sawtimber production and wildlife habitat. Several weaknesses in the present study include the lack of stand-level replication within and among the different plantation spacings. Further, replicated pure plantings of each species are necessary to serve as a baseline to compare stem and stand level growth. An example mixed-species plantation design is shown in fig. 2. An 8-acre treatment plot, using one designated tree spacing arrangement, is split into four 2-acre subplots. Two of the subplots would contain a pure planting of each species, assuming a two-species mixture is used. The third subplot would contain pure rows of each species such that Row 1 would contain species a, Row 2 would contain species b, row 3 would contain species a and so forth. Our experience is that planters would rather plant pure rows of a species to simplify the planting operation. While efficient, this design does not eliminate early intraspecific competition as trees within a row will be competing with others of the same species. The fourth subplot would contain a planting design based on known or observed stand development patterns, similar to those used in the present study. Possible bottomland hardwood species mixtures can be developed from Lockhart and others (2008). Ideally, four or five replicates of this treatment plot would be needed to adequately test bottomland hardwood mixed-species plantation development.

ACKNOWLEDGMENTS

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Table 1—Survival of cherrybark oak and sweetgum planted in mixture at three spacing arrangements in Oktibbeha County, MS

Spacing	Species	n	1989	1991	1998	2002	2010
feet			percent				
8 x 8	cherrybark oak	35	89	89	89	89	86
	sweetgum	138	100	100	100	100	100
5 x 5	cherrybark oak	45	82	82	82	80	62
	sweetgum	168	100	100	100	99	92
5 x 5D	cherrybark oak	27	78	78	78	78	70
	sweetgum	182	99	99	99	99	98

Table 2—Diameter (dbh, 4.5 feet) of cherrybark oak and sweetgum planted in mixture at three spacing arrangements in Oktibbeha County, MS. Values in parentheses represent one standard error

Spacing	Species	1989	1991	1998	2002	2010
feet		inches				
8 x 8	cherrybark oak	1.8 (0.1)	2.8 (0.2)	5.5 (0.3)	7.0 (0.4)	9.3 (0.6)
	sweetgum	2.4 (<0.1)	3.4 (0.1)	5.1 (0.1)	5.6 (0.1)	6.3 (0.1)
p-value		< 0.01	< 0.01	0.33	< 0.01	<0.01
5 x 5	cherrybark oak	1.0 (0.1)	1.6 (0.1)	3.4 (0.4)	4.5 (0.5)	7.3 (0.9)
	sweetgum	1.2 (0.1)	2.0 (0.1)	3.1 (<0.1)	3.3 (<0.1)	3.6 (0.1)
p-value		0.01	0.02	0.45	0.04	< 0.01
5 x 5D	cherrybark oak	1.1 (0.1)	1.7 (0.1)	3.7 (0.4)	5.0 (0.6)	7.3 (0.9)
	sweetgum	1.2 (0.1)	1.9 (0.1)	3.1 (0.1)	3.3 (<0.1)	3.5 (0.1)
p-value		0.085	0.14	0.11	0.01	< 0.01

Table 3—Percent of trees by crown class following the 2012 growing season for cherrybark oak and sweetgum planted in mixture at three spacing arrangements in Oktibbeha County, MS

Spacing	Species	Dominant	Co-dominant	Intermediate	Overtopped
feet		----------------------------------percent----------------------------------			
8 x 8	cherrybark oak	4	78	7	11
	sweetgum	0	1	46	53
5 x 5	cherrybark oak	17	46	10	27
	sweetgum	0	0	3	97
5 x 5D	cherrybark oak	28	38	17	17
	sweetgum	0	0	22	78

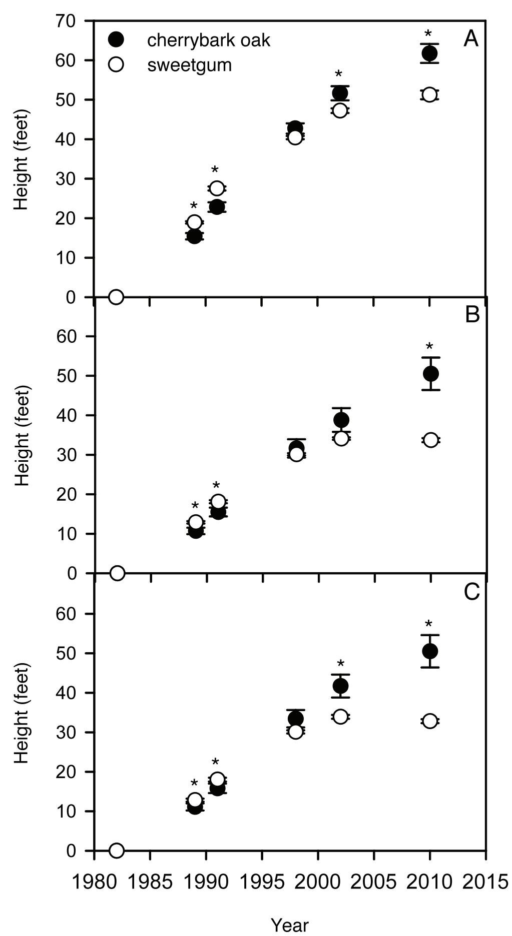

Figure 1—Height development of cherrybark oak and sweetgum planted in mixtures at three spacing arrangements in Oktibbeha County, MS. (A) 8 by 8 foot spacing; (B) 5 by 5 foot spacing; (C) 5 by 5 foot spacing with two rows of sweetgum. Asterisks indicate difference at p≤0.05. Bars represent one standard error.

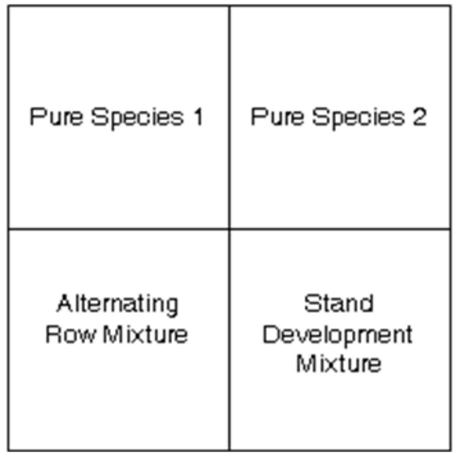

Figure 2—Example bottomland hardwood mix-species research design.

RELATIVE MAXIMA OF DIAMETER AND BASAL AREA

Thomas B. Lynch and Difei Zhang

It has often been observed that maximum dbh growth occurs at an earlier age than maximum individual tree basal area growth. This can be deduced from the geometry of the tree stem, by observing that a dbh increment at a given radius will be associated with a larger basal area increment than an equal dbh increment occurring at a shorter radius from the stem center. Thus basal area increment continues to increase after dbh increment has culminated. Nevertheless it is of interest to prove mathematically that the age of maximum basal area growth occurs later than the age of maximum dbh increment for a broad range of continuous functions that could be used to model diameter and basal area growth. This can be done using differential calculus for continuous functions representing diameter and basal area increment.

Tree cross-sectional growth at breast height can be characterized by diameter growth or by basal area growth functions. West (1980) compared individual tree diameter growth functions to individual tree basal area growth functions for use in forest growth simulators. West (1980) found either function to be equally effective. Borowski (1972) used finite differences to argue that when cross-sectional area is decreasing, the change in the diameter growth rate is always negative, indicating that the age of maximum diameter growth rate has passed.

Here we use differential calculus to show that the age of maximum basal area growth always occurs later than the age of diameter growth. Differentiating basal area growth, we obtain a function of diameter growth and acceleration. Using this function it is easily shown that at the age of maximum basal area growth, acceleration in diameter is negative. Assuming that diameter and basal area follow classic sigmoid curve forms, diameter growth will attain a maximum and then decline. Thus a negative acceleration for diameter indicates that maximum diameter growth has already occurred.

Finally we wish to consider the age of maximum individual volume increment in relation to the ages of maximum basal area increment and diameter increment. It is demonstrated that if the second partial derivative of individual tree volume with respect to basal area is strictly positive, then the age of maximum individual tree volume growth will be higher than the age of maximum individual tree basal area growth.

These results could be of interest to those who use continuous, differentiable functions to model basal area and diameter growth. An advantage of modeling basal area growth might be that it has a longer period of monotonically increasing with age. On the other hand, it might be desired to model diameter growth including a maximum at a younger age.

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ESTIMATING FUEL CONSUMPTION DURING PRESCRIBED FIRES IN ARKANSAS

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ABSTRACT

While prescribed fire is essential to maintaining numerous plant communities, fine particles produced in smoke can impair human health and reduce visibility in scenic areas. The Arkansas Smoke Management Program was established to mitigate the impacts of smoke from prescribed fires. This program uses fuel loading and consumption estimates from standard fire-behavior fuel models developed elsewhere in the United States. The accuracy of these models for determining fuel loading and consumption in Arkansas, however, is unknown. We established 120 Brown's transects in fifteen burn units and three community types on the Ouachita National Forest in Arkansas to determine fuel loads before and after prescribed fires. The three community types were shortleaf pine-oak (Pinus echinata-Quercus sp.) forest, oak forest, and shortleaf-pine woodland. We also compared fuel-consumption estimates of fine woody fuels derived from Brown's transects with estimates derived from sampling plots, where we physically collected fuels, before and after the prescribed fires. We used Feat Firemon Integrated (FFI) software with localized bulk density values to quantify fuel consumption on six of the fifteen prescribed fires. Preliminary analyses showed that fuel consumption occurring in the Ouachita Mountains is consistent with expected values based on standard fire-behavior fuel models and that fuel consumption in restored woodlands is significantly less than that in closed-canopy forests.

INTRODUCTION

Fire is an important ecosystem process that has influenced the structure and composition of forest, woodland, and grassland communities for millennia (Frost 1998, Pyne 1982). Fire suppression over the last 100 years has changed many fire-dependent communities (Harmon 1982, Harrod and others 1998, Foti 2004). In some forest communities, fuel build up has led to an increase in fire intensity, resulting in stand replacement crown fires where frequent low intensity surface fires once occurred (Agee and Skinner 2005). In many eastern forests, shade-tolerant, fire-sensitive species have invaded fire-dependent communities, making them less susceptible to fire (Nowacki and Abrams 2008). As a result, fire-dependent communities are in decline and some associated species are imperiled or endangered (Ligon and others 1986, Kelly and others 2004). Prescribed fire plays an important role in restoring historic community structure and composition. It also helps prevent catastrophic crown replacement fires (Agee and Skinner 2005) and restores fire-dependent communities and their suite of pyrophilic species (Covington and others 1997, Sparks and others 1998, Sparks and others 1999, Andre and others 2007, Jenkins and others [in press]).

Despite the benefits prescribed fires provide, they also produces smoke containing particulate matter, carbon monoxide, sulfur dioxide, nitrogen oxides, and volatile organic compounds (Liu 2004). These particles and compounds degrade air quality by reducing visibility and impairing healthy respiration (Brunekreef and Holgate 2002). Recently, the Environmental Protection Agency (EPA) reported that fine particles (particles ≤ 2.5 µm or $PM_{2.5}$) were particularly detrimental to human respiratory health and 70% of particulate matter produced during prescribed and wildland fires consists of these fine particles (EPA 1998). This report encouraged many states to establish Smoke Management Programs to address air quality concerns associated with prescribed fire.

The Arkansas Forestry Commission established a Smoke Management Program (SMP) in 2006 to address air quality issues resulting from prescribed fire (Arkansas Forestry Commission 2006). This program addresses many smoke-related issues including: notification requirements, identifying how close a prescribed fire can be to a smoke sensitive area, defining appropriate atmospheric conditions to conduct a prescribed fire, and providing available fuel loading estimates for each community type (Arkansas Forestry Commission 2006). Available fuel-loading values for different Arkansas community types were taken from standard fire-behavior fuel models (Scott and Burgan 2005). These models were derived from a planar intersect method called Brown's transects (Brown 1974) and collection of fuels in 10.76 square foot sample plots in community types around the U.S. (Ottmar and Vihnanek 1998, 1999, 2000, and 2002, Ottmar and others 2003). However, no data existed specifically for community types in Arkansas. Some land managers felt that these models should be validated with local fuel loading data collected in Arkansas community types. Emissions from prescribed fires are a function of both area burned and amount of fuel consumed (EPA 1995). Thus, accurate fuel loading and consumption values are important for determining emissions produced and the number of acres that can be burned at a given time to remain in compliance with Arkansas' SMP.

The Ouachita National Forest (ONF) of Arkansas and Oklahoma houses many fire-dependent communities including shortleaf pine-oak (*Pinus echinata*-*Quercus* spp.)

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forest, oak forest, and shortleaf-pine woodland. Managers use prescribed fire to improve wildlife habitat, prepare sites for tree planting, restore woodland stand structure and diversity, and reduce hazardous fuels. Between 2005 and 2010 the ONF burned an average of 115,700 acres annually (Forest Service 2010).

In this study, we determined fuel consumption in three community types (shortleaf pine-oak forest, oak forest, and shortleaf-pine woodland) during prescribed fires on the ONF. For the purpose of this study, forest communities are defined as closed-canopy forest (>70 percent canopy cover) with little herbaceous cover (<25 percent). Pine-oak forest are pine dominant with an oak component and oak forest are oak dominated. The pine woodland community is defined as an open forest (<70 percent canopy cover) with dense herbaceous cover (>25 percent). We used Brown's transects (Brown 1974) to capture dead and down fuel and 9 square foot sampling plots, where fuel was physically removed (henceforth referred to as collection plots), to capture live fuels (grasses, forbs, and small shrubs attached to the ground). In an analysis of Brown's transect data from the ONF between 2001 and 2009 the variability of fine woody fuels suggested the need for different methods for quantifying these fine fuels (McDaniel and others 2009). Plot-collection methods seemed reasonable; therefore we collected fine fuels in 1 square foot collection plots. Both methods were similar to those used to develop standard fire-behavior fuel models (Ottmar and Vihnanek 1998, 1999, 2000, and 2002, Ottmar and others 2003) and those used in fuels management programs across the U.S. (USDI National Park Service 2003).

We address three questions:
1. Are standard fire-behavior fuel models accurate for assessing fuel consumption during prescribed fires in the dominant community types on the Ouachita National Forest?
2. Is there a difference in fuel consumption of 1- and10-hour fuels between sampling methods?
3. Is there a difference between fuel consumption in forest and woodland communities?

METHODS

STUDY SITE

The ONF is located in the Ouachita Mountain Ecoregion (The Nature Conservancy 2003) of western Arkansas and eastern Oklahoma (Figure 1). Ridges are underlain by Pennsylvania and Mississippi sandstone and shale valleys with clayey colluviums and covered with pine-oak and oak woodlands and forests (U.S. Department of Agriculture, 1999). We conducted our study in the central part of the Ouachita Mountain Ecoregion on the Mena, Oden, and Poteau Ranger Districts of the ONF. The burn units ranged in size from 310 to 1940 acres (average = 851). Elevation on the burn units ranged from 800 to 1400 feet.

DATA COLLECTION

The main community types on the ONF are Ozark-Ouachita shortleaf pine-oak forest, Ozark-Ouachita dry-mesic oak forest, and Ozark-Ouachita shortleaf pine-bluestem woodland (LANDFIRE 2010), henceforth referred to as pine-oak forest, oak forest, and pine woodland, respectively. We used LANDFIRE's Existing Vegetation Type (EVT) layer for the Continental US (LANDFIRE 2010) to select transect locations within planned burn units in 2010 and 2011. We established 40 Brown's transects within each community type for a total of 120 transects. Each Brown's transect was 50 feet long, permanently marked with rebar at each end, and followed Brown's protocol (Brown 1974). We used a 10 factor prism to obtain basal area and species composition of trees at the origin of each Brown's transect. Half of the Brown's transects had collection plots associated (Figure 2).

Due to time and weather constraints, only 54 transects were burned in 2010; thus most data represent only 54 of the 120 Brown's transects (32 pine-oak forest transects with 70 collection plots, 13 oak forest transects with 40 collection plots, and 9 pine woodland transects with 25 collection plots). We installed 10 Brown's transects in an established pattern around a random point in each burn unit (Figure 3). Percent of each community type in burn units varied. Three transects were located 660 feet up-slope and 660 feet down-slope from the random point, and four transects were located at the same elevation as the random point (Figure 3). Transects in each of the three lines ran parallel to the slope and were separated by 330 feet (Figure 3). One burn unit had only four transects because the prescribed fire occurred before all ten transects could be installed.

Along each Brown's transect, before and after prescribed burns, we tallied dead and down woody fuel that bisected the transect. In the first six feet of the Brown's transect we tallied 1- and 10-hour woody fuels (<0.25 inch and 0.25-1.0 inch, respectively). In the first 12 feet of the Brown's transect we tallied 100-hour fuels (>1.0-3.0 inches). We measured the diameter of each 1000-hour fuel (> 3.0 inches) to the nearest tenth inch along the entire 50-foot Brown's transect. We sampled depth (to the nearest 0.1 inch) of litter and duff using a ruler at 10 points along each Brown's transect pre- and post-burn.

Half of the Brown's transects used enhanced methodology where five collection plots were located along two parallel transects 10 feet on either side of the main transect (Figure 2). We collected pre-burn data on the right side transect and post-burn data on the left side transect. We clipped 1-hour combustible live fuels (grasses, forbs, and small shrubs attached to the ground) in five 9 square foot plots located at 10-foot intervals along transects parallel to the initial Brown's transect (Figure 2). We collected samples and placed them in paper bags. Fuel samples were oven-dried at 80 °C for at least 3 days (72 hours) to obtain dry mass. Dead and down 1- and 10-hour fuels were sampled in five 1 square foot plots nested within the live fuel plots (Figure 2). We collected all 1- and 10-hours fuels located within these plots and placed them in paper bags. When woody fuels were only partially within plots, we collected only the portions that were located within plots. We dried samples and obtained a dry weight in the same manner as live fuels.

ANALYSES

We used localized bulk density values to convert inches of litter and duff into tons per acre (2.04 and 6.41 tons/acre/inch for pine-oak forest and pine woodland; 1.38 and 4.84 tons/acre/in for oak forest; Ottmar and Andreu 2007). We used Fire Ecology Assessment Tool-Firemon Integrated (FFI) software to quantify fuel consumption on six prescribed fires. We determined fuel loading differences in community types and data collection methods using a *t*-test and calculated standard error using basic statistics (SigmaStat 3.0 and SigmaPlot 8.0 2002).

RESULTS

Fuel consumption during prescribed fires on the ONF was within the range of the standard fire-behavior fuel models (Table 1). Fuel consumption was 4.2 (2[SE] ± 1.2), 3.1 (± 1.1), 0.9 (± 1.0) tons/acre in the pine-oak forest, oak forest, and pine woodland, respectively. The models generally underestimated fuel consumption in forest communities and overestimated fuel consumption in woodland communities.

Litter was one of the primary fuels consumed in all three communities (Table 2). Substantial duff was consumed in pine-oak and oak forests, but not woodlands. Fine and coarse woody fuel consumption was higher in the forest communities, but variability was high in all community types. Two to three times as much fine woody fuel as coarse woody fuel was consumed in the forest communities. A relatively small amount of fine or course woody fuel was consumed in the woodland community. Lower basal area appears to be associated with lower fuel consumption of all types (Table 2).

There was a significant difference in 1-hour fuel consumption between the plot collection and Brown's transect methods (Table 3). Given the aggregated distribution of fine woody fuel across the landscape and the inherent error associated with Brown's transects, a difference of 0.2 tons/acre is considered negligible (Brown 1974). There was no significant difference in 10-hour fuel consumption between the plot collection and Brown's transect methods (Table 3).

Overall fuel consumption in forest communities was significantly greater ($P < 0.05$) than in woodland communities (Figure 4). Live fuel consumption in forest communities contributed little to overall fuel consumption (<0.1 ton/acre; Table 2). Live fuel consumption in woodland communities was significantly higher than forest communities ($P < 0.05$), but was not more than 0.26 (±0.19) tons/acre in any community (Table 2).

DISCUSSION

Fuel consumption during prescribed fires in Arkansas seems to be accurately represented by the standard fire-behavior fuel models. Nonetheless, fuel consumption in forests is on the higher end of what the models predict, especially for oak forests. This may be a result of small sample size as only 13 of 40 transects have been completed. Slightly lower fuel consumption in pine woodlands was likely a result of small sample size and the burn history of the unit. The low fuel consumption of fine and coarse woody fuel, litter, and duff in the pine woodland was a result of low pre-burn fuel loading (7.3 tons/acre) compared with pine-oak and oak forests (12.1 and 9.4 tons/acre, respectively). This is likely due to the frequent burning of this unit. More data is needed in all communities, but especially the oak forest and pine woodland.

We found little difference in fuel consumption estimates derived from collection plots and Brown's transects. However, the effort required by the two methods differed considerably. We estimated a 50-fold increase in the time needed for collection plots compared to Brown's transects. Additionally, the same piece of ground is measured pre- and post-burn with Brown's transects, whereas collection plots must be in different locations because fuels are removed. We recommend Brown's transects over fuel-collection plots for assessing consumption of fine woody fuels. Although Brown's transects do not capture live fuel consumption, we found the contribution of live fuel to total fuel loading small in all communities. Further, the time required to physically collect live fuels in the communities of the ONF is not justified by the information gained.

Eastern forests were historically more open than they are today (Foti 2004). Early explorers noted the open condition of the forest in their journals and notes (Nuttall 1999). It is also well documented that fire, mostly Native American fire, was a main driving force behind these forest conditions (Guyette and Spetich 2002, Delcourt and Delcourt 1997). In the Ouachita Mountain ecoregion, a lack of fire has lead to a widespread succession of woodlands to closed-canopy forest communities. Of the 8 million acres in the Ouachita Mountain ecoregion that were once woodland, only 6% remain (LANDFIRE 2010).

In 1994, the ONF initiated a large-scale restoration effort for pine-woodland communities located on National Forest System lands (Hedrick and others 2007). The original restoration target of 50,000 acres in 1994 grew to 254,000 acres with the 2005 Forest Plan (Hedrick and others 2007). When compared with untreated controls, studies showed that restoration of pine woodland benefited song birds (Wilson and others 1995), red-cockaded woodpecker (*Picoides borealis*) numbers (Hedrick and others 2007), some herpetofauna (Perry and others 2009), and herbaceous plants (Sparks and others 1998), and was not detrimental to tree growth (Guldin and other 2005). Our study shows that woodland communities consume less fuel per acre than forest communities and thus produce less smoke. While woodlands are burned more often than forests and overall may produce the same amount of smoke, the concentration per unit time is less. The EPA Air Quality Standards are concerned with the hourly average of emissions (EPA 1998) and therefore, restoring forests to the woodland condition may reduce human exposure to highly concentrated smoke and prevent violations in air quality standards. We are continuing this fuels research and hope to have all units burned in the spring of 2012.

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Table 1—Comparison of fuel consumption values predicted by standard fire behavior fuel models and Brown's transect data collected on dormant season prescribed fires on the Ouachita National Forest in Arkansas, 2010

Community Type	Standard Fuel Model	Actual Brown's transect data*
Pine-oak forest	3.0 – 4.4 tons/acre	3.0 – 5.4 tons/acre
Oak forest	0.8 – 2.5 tons/acre	2.0 – 4.2 tons/acre
Pine woodland	1.5 – 5.9 tons/acre	0 – 1.9 tons/acre

* Includes Brown's transect data only (N = 32, 13, and 9 for pine-oak forest, oak forest, and pine woodland)

Table 2—Fuel consumption (tons/acre) derived from Brown's transects and collection plots and basal area (ft^2/acre) by community type on the Ouachita National Forest of Arkansas, 2010

Community Type	FWF*	CWF*	Litter*	Duff*	Total*	Live Fuel[ƚ]	Basal Area [λ]
Pine-oak forest	1.23 ±0.92	0.38 ±0.36	1.28 ±0.22	1.30 ±0.44	4.22 ±1.20 [a]	0.07 ±0.07 [a]	105.0 ±11.4 [a]
Oak forest	1.01 ±1.00	0.38 ±0.17	1.25 ±0.30	0.50 ±0.18	3.12 ±1.08 [a]	0.04 ±0.03 [a]	93.5 ± 9.2 [a]
Pine woodland	0.19 ±0.36	0.21 ±0.38	0.46 ±0.3	0.05 ±0.40	0.91 ±0.98 [b]	0.26 ±0.19 [b]	70.5 ± 7.6 [b]

FWF = Fine woody fuel, CWF = Coarse woody fuel; Numbers represent ±2 standard error, within columns different letters indicate a significant difference (p≤0.05) * Data includes Brown's transect data only (N = 32, 13, and 9 for pine-oak forest, oak forest, and pine woodland)
ƚ Data includes plot collection data only (N = 14, 8, and 5 for pine-oak forest, oak forest, and pine woodland)
λ Data includes all 120 plots (N = 40 for all community types)

Table 3—Difference in fuel consumption (tons/acre) values of 1- and 10-hour fuels using Brown's transects and plot collection methods during prescribed fires on the Ouachita National Forest of Arkansas, 2010

	1-hour fuels	10-hour fuels
Brown's transect	0.06 ±0.02 [a]	0.23 ±0.15 [a]
Plot collection	0.19 ±0.04 [b]	0.30 ±0.12 [a]

Mean ±2 standard error, within columns different letters indicate a significant difference (P≤0.05).

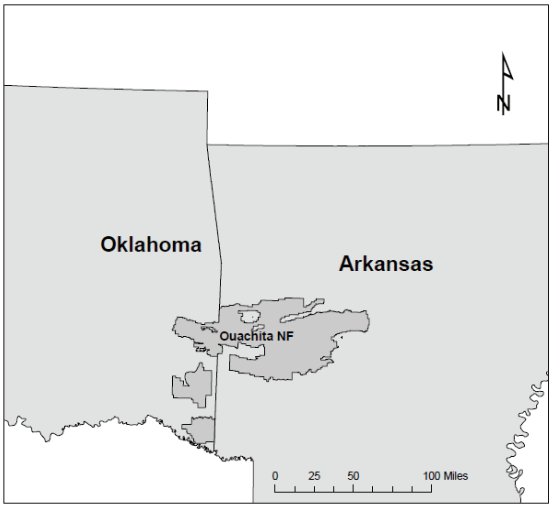

Figure 1—Location of the Ouachita National Forest of western Arkansas and eastern Oklahoma.

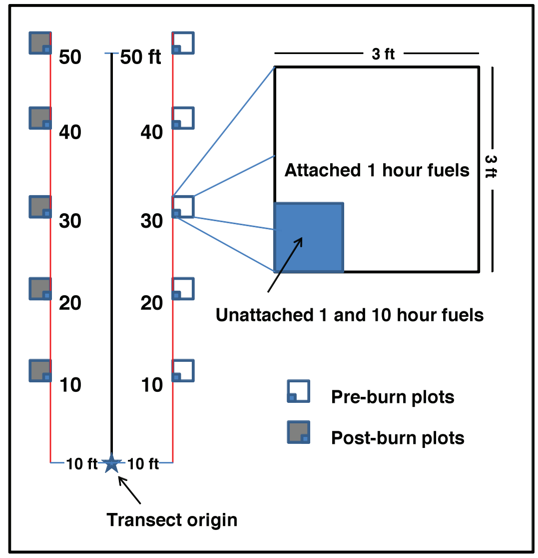

Figure 2—Enhanced Brown's transect plot design consisting of both the center Brown's transect and collection plots on each side transect. Plot design was used to measure fuel consumption on prescribed fires on the Ouachita National Forest of Arkansas, 2010.

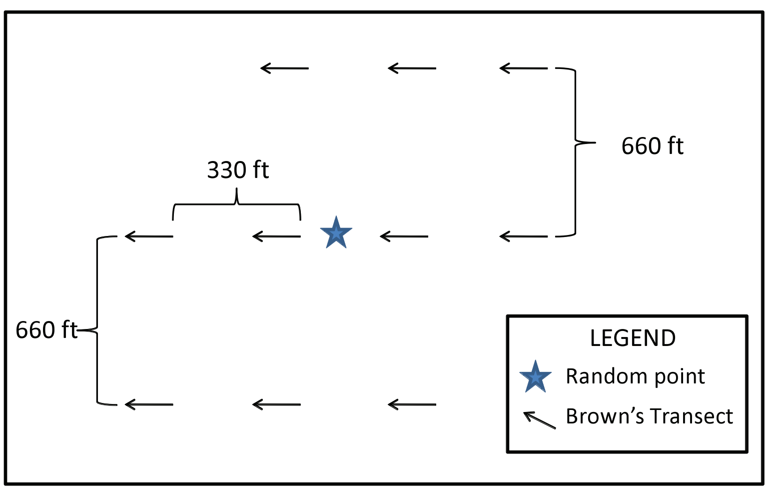

Figure 3—Plot layout for Brown's transects in each burn unit on the Ouachita National Forest of Arkansas, 2010.

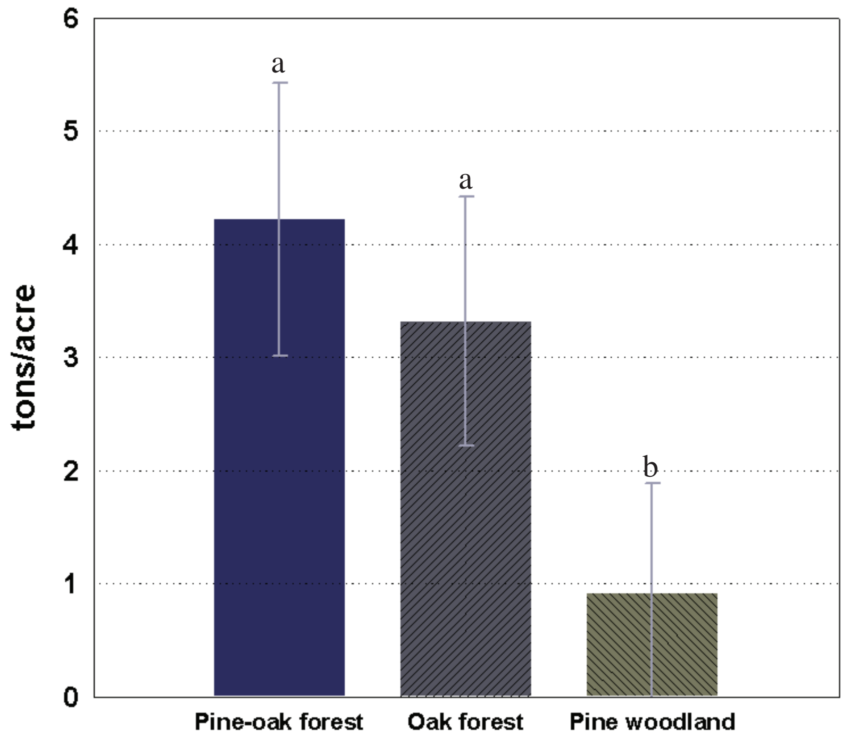

Figure 4—Overall fuel consumption in pine-oak forest, oak forest, and pine woodland using only Brown's transect data on the Ouachita National Forest in Arkansas, 2010. Different letters indicate a significant difference (P≤0.05, Mean ±2SE) among forest types.

LONG-TERM EFFECTS OF WETLAND HARVESTING PRACTICES ON PRODUCTIVITY AND CARBON POOLS

Scott McKee, Mike Aust, John Seiler, and Brian Strahm

Forested wetlands are valued for social and ecological benefits including filtering sediments, uptake of nutrients, carbon storage, reduction of flood depths, protection of shorelines and streambanks, and provision of terrestrial and aquatic wildlife habitat (Walbridge 1993, Kellison and Young 1997, Brady and Weil 2002). Although the importance of wetland functions are recognized, few studies examine long-term recovery rates of ecosystem functions such as forest productivity, sediment trapping, and carbon storage following disturbances in forested wetlands (Aust et al. 2006). Timber harvesting is an important commercial activity in forested wetlands and harvests have been common in US wetlands for centuries (Stine 2008). Harvest disturbances have in some instances been shown to have short-term negative consequences on site productivity, water quality, and carbon storage, but long-term patterns and relationships are uncertain.

Due to the paucity of long-term information, the primary goals of this study are to quantify the long-term effects of different harvest disturbances on two major wetland functions: productivity and carbon storage. This study evaluated the effects of three harvest related disturbances that were originally applied in 1986 to a tupelo (Nyssa aquatic)-cypress (Taxodium distichum) forested wetland in the Mobile-Tensaw River Delta of southwestern Alabama. The three original disturbances were 1. helicopter harvest (HELI), 2. skidder simulation where 50% of the site was rutted to a depth of 30 cm (SKID), and 3. helicopter harvest followed by glyphosate herbicide removal of all sprouts and seedbank regeneration for two years following harvest (GLYPH). A nearby mature area within the same original stand represented mature forest or reference conditions (REF). Above- and below-ground plant biomass, below-ground woody debris, soil carbon, soil deposition rates, and soil CO_2 efflux rates were measured in this study. Additional information regarding treatments and ecosystem recovery during the first 16 years was summarized by Aust et al. (2006).

Twenty four years after disturbances were applied, forest above-ground biomass and carbon levels were higher in areas disturbed by ground based SKID (77.1 Mg C ha^{-1}) as opposed to the HELI removals (55.7 Mg C ha^{-1}, Table 1). These results correspond with earlier trends following disturbance and are explained by the SKID trafficking effects on soil water, aeration and microtopography and species on the site. The original impact on soil conditions within the SKID treatments apparently reduced survival of competing species while favoring the tupelo coppice and the changed microtopography increased the heterogeneity of soil aeration. Below-ground biomass (to a depth of 60 cm) and carbon levels were also found to be greater in the SKID disturbance (12.8 Mg C ha^{-1}, Table 1). The below-ground carbon storage was primarily attributable to increased roots linked to the above-ground biomass. Non-root related soil carbon levels were not found to be significantly different for the disturbance treatments. Total soil CO_2 efflux measurements indicated that SKID treatments were releasing the least carbon (8.9 μM CO_2 m^{-2} s^{-1}) while GLYP treatments are releasing the most (12.8 μM CO_2 m^{-2} s^{-1}, Table 1). GLYPH disturbances originally created herbaceous dominated freshwater marsh, which has reverted to a low-density early succession forested wetland with a large herbaceous component (1021 stems ha^{-1} and 1.4 Mg C ha^{-1} of herbaceous vegetation, Table 1). This herbaceous vegetation and associated fine root turnover in GLYPH is contributing to annual root turnover and decay in the soil. Total forest carbon estimate SKID treatments are holding the most total carbon with 206.1 Mg C ha^{-1} while HELI and GLYPH treatments are holding 168.7 and 144.2 Mg C ha^{-1} respectively (Table 1). REF areas are currently holding 332.6 Mg C ha^{-1} (Table 1).

Overall, current long-term patterns of ecosystem above- and below-ground productivity and carbon storage indicate that harvest disturbances were relatively transitory in this ecosystem. Ecosystem biomass and carbon patterns of HELI

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and SKID are becoming more similar to the original site conditions represented by the REF areas. The resiliency of these highly disturbed treatments are explained by the frequent inputs of non-compacted, nutrient-rich sediments, presence of species that are well adapted to very poorly drained and aerated conditions, high rates of coppice regeneration, and the increase of microtopography within SKID treatments.

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Table 1—Total forest C measurements by harvesting treatment and pool (significance determined using alpha = 0.05). SKID = Skidder simulation treatment, HELI = helicopter logged treatment, GLYPH = glyphosate treatment, and REF = reference area

	Treatment			
Measurement	**SKID**	**HELI**	**GLYPH**	**REF**
Above-ground C Pools (Mg C ha^{-1})				
Overstory ($p < 0.001$)	73.9 b	52.8 c	26.4 d	209.4 a
Lower Story ($p < 0.001$)	3.0 a	2.6 a	0.5 b	0.1 b
Herbaceous ($p < 0.001$)	0.2 bc	0.3 b	1.4 a	0.2 c
Total	77.1 (33.0%)	55.7 (33.1%)	28.3 (19.6%)	209.7 (63.0%)
Below-ground C Pools to a depth of 60 cm (Mg C ha^{-1})				
Roots	12.9	6.9	7.0	10.8
Buried Debris	12.5	8.2	13.8	11.2
Soil C	103.6	97.9	95.1	100.9
Total	129.0 (62.6%)	113.0 (67.0%)	115.9 (80.4%)	122.9 (37.0%)

EFFECTS OF THINNING ON ABOVEGROUND CARBON SEQUESTRATION BY A 45-YEAR-OLD EASTERN WHITE PINE PLANTATION: A CASE STUDY

W. Henry McNab

ABSTRACT

Aboveground carbon sequestration by a 45-year-old plantation of eastern white pines was determined in response to thinning to three levels of residual basal area: (1) Control (no thinning), (2) light thinning to 120 feet^2/acre and (3) heavy thinning to 80 feet^2/acre. After 11 years carbon stocks were lowest on the heavily thinned plot, but there was little practical difference between carbon dynamics on the unthinned and lightly thinned plots. Carbon stocks of an adjacent 113-year-old unthinned reference hardwood stand of mixed oaks were about half that of the unthinned pine plantation. Results from this unreplicated pilot study are useful primarily for planning future investigations.

INTRODUCTION

Forests are an important long term, but temporary, sink for carbon (Johnsen and others 2001). Until other technology becomes available, however, forests provide an immediate means for storing atmospheric carbon dioxide, which is believed to be an important factor contributing to climate change (Birdsey 1992). Carbon storage pools and rates of sequestration by soil and vegetation may be altered by management decisions such as species selection, rotation lengths and basal area stocking (Foley and others 2009). Dense, plantings of conifers are particularly efficient for carbon sequestration as has been demonstrated for loblolly pine (Pinus taeda) in the favorable climate, terrain, and soils of the southern US (Richter and others 1999).

Eastern white pine (P. strobus) (hereafter white pine) has long been recognized as an important native conifer of the southern Appalachian Mountains (Pinchot and Ashe 1897, Holmes 1911) that has been widely managed for timber production in the Lake States and New England (Burns and Honkala 1990). It has many characteristics desirable for carbon sequestration such as extended longevity, accumulation of high levels of aboveground biomass, commercially valuable, favorable response to management, relatively few insect and disease problems, and ease of regeneration by planting (Sohngen and Brown 2008). White pine is recommended as a highly desirable timber species for small tracts of marginal site quality (Dierauf and Scrivani 1995, Clatterbuck and Ganus 2000). Small forest tracts are also receiving increased attention for their potential to sequester carbon (Hoover and others 2000). Carbon sequestration by white pine has been reported for extensive areas where it is a component in stands of mixed species (Birdsey 1996).

Carbon sequestration by mature white pine plantations has not been reported in the southern Appalachians. Carbon storage by white pine could compare favorably with other conifers because of the high levels of biomass attainable in densely stocked stands, even on sites of marginal quality (Huntington 1995). The primary purpose of this study was to quantify carbon stocks and the rate of carbon sequestration by a planting of white pine in response to levels of residual basal area stocking. A secondary objective was to compare carbon dynamics of the white pine planting with an adjacent unmanaged, natural stand of upland hardwoods. The scope of my study was limited to the aboveground carbon stocks of a single stand. Inadequate experimental material allowed installation only of a nonreplicated case study, the results of which are useful primarily as a source of information for planning further investigations.

MATERIAL AND METHODS

STUDY SITE

The study was conducted in the Bent Creek Experimental Forest, located about 10 miles southwest of Asheville, N.C., in the Pisgah National Forest. The experimental forest occupies most of a 6,300-acre watershed typical of the southern Appalachian Mountains that ranges in elevation from about 2,100 to 4,000 feet and includes two landscape-scale ecoregions: broad basins and low mountains. Soils are

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derived from metamorphic rocks, primarily gneisses and schists. Winters are short and mild, with a January mean temperature of 36°F. Summers are long and warm, with an August mean temperature of 75°F. Annual precipitation averages 45 inches in the basin ecoregion and is uniformly distributed among the seasons.

The study was installed in the basin ecoregion of the experimental forest on a 9-acre tract with uniform soil and history of recent land use, beginning with settlement by European immigrants in the early 1800s. Soils are classified as Typic Hapludults and are mapped as a complex of Evard-Cowee series that are deep (>40 inches), highly acidic (pH<5.5), well drained and characterized by an accumulation of clay in the B horizon. For almost 100 years the tract was part of a farm where land was utilized for subsistence agriculture, which likely included a repeated succession of uses including woodlot, cultivated field, and unimproved pasture (Nesbitt 1941).

Disturbance associated with agriculture ended with purchase of the tract (and extensive surrounding lands) by the USDA Forest Service from the Biltmore Estate in 1914. Balch (1928), in the first designed ecological study installed in the newly established experimental forest, reported vegetation on old field sites in the basin ecoregion consisted of a shade intolerant overstory mixture of pines (shortleaf (Pinus echinata), Virginia (P. virginiana), and pitch (P. rigida)) and oaks (black (Quercus velutina), scarlet (Q. coccinea), and white (Q.alba)), a midstory of tolerant hardwoods (sourwood (Oxydendrum arboreum), blackgum (Nyssa sylvatica), dogwood (Cornus florida), and red maple (Acer rubrum), and an understory of tree seedlings and saplings, and ericaceous shrubs. There is no record or evidence of fire occurrence during the past 50 years. Site index for upland oaks averages 70 feet at 50 years of age.

Use of about half of the tract changed in early 1952, from old field succession to planted pine plantation, which resulted in two forest types suitable for installation of the study described herein. On a 5-acre parcel of the tract, vegetation was clearcut and planted with white pine seedlings as a demonstration of rehabilitating low value hardwood stands. Vegetation on the adjacent hardwood parcel remained largely undisturbed until 1974, when the pine overstory was harvested to salvage mortality resulting from an extensive outbreak of southern pine beetle (Dendroctonus frontalis) throughout the experimental forest (Ward and others 1974). Additional salvage logging occurred on the hardwood parcel in 1987, to utilize an average of five large (>18 inches dbh), old (mean 103 years) scarlet and black oaks per acre that had died likely from stress associated with several years of severe drought. More recently, in late 1995, the remnants of Hurricane Opal caused windthrow of scattered large scarlet oaks in the hardwood stand. The adjacent pine plantation had been thinned by an unknown amount in 1968, but unlike the hardwood stand showed no apparent effects of disturbance from insects, droughts, or hurricanes. The white pine plantation was used to evaluate carbon dynamics resulting from thinning treatments and the hardwood stand was used as a reference or base line for comparison with a mature natural stand of unmanaged, endemic arborescent vegetation. When this study was installed in early 1997, the pine plantation was 45 years old and the hardwood stand was about 113 years.

THINNING TREATMENTS

The central part of the plantation was subdivided into three plots, each about 0.9 acre. Each plot was assigned one of three thinning treatments. Treatments consisted of thinning from below to three levels of residual basal area: (1) control (no thinning), (2) BA120 – residual basal area of approximately 120 feet^2/acre of basal area, and (3) BA80 -- residual basal area of approximately 80 feet^2/acre. After thinning, the population of all live stems ≥2 inches diameter breast height (dbh) on each plot was inventoried from individually identified trees and recorded by species and diameter. The treatments were made as part of a commercial timber sale and probably had been selected originally as appropriate for a conventional silvicultural study of stand response to thinning. Careful records were not maintained for trees harvested from each plot for use in calculation of carbon sequestered as timber products; the preharvest stand was reconstructed for both of the thinned plots.

In the hardwood reference stand, five small (0.05 acre) permanent plots had been systematically established in 1996 to quantify disturbance from Hurricane Opal. Those plots were relocated in 2008, each was expanded in area to 0.1 acre and vegetation was inventoried as for the pine plantation. The hardwood stand was considered as fully stocked even though basal area reductions similar to thinning had occurred in 1974, 1987, and 1995, which likely caused differential growth response of residual trees. No large scale disturbance has occurred in the hardwood stand since 1995, although senescence and death of individual large trees has continued, particularly among the scarlet oaks.

CARBON STOCKS ESTIMATION

Carbon stocks for both the pine plantation and hardwood stand were estimated for dry wood and bark of the main stem following standard methods that utilize either biomass or volume and specific gravity (Hoover and others 2000). White pine biomass was estimated for each tree using an allometric prediction equation based on dbh that was applicable over a wide range of tree sizes in Maine (Young and others 1980); a suitable model was not found for the southern Appalachians. For hardwoods, volume was estimated by species using models based on dbh developed in the southern Appalachian Mountains by Clark and Schroeder (1986). A generalized prediction equation for mixed hardwoods was used for species not represented in their study (e.g. sourwood). Biomass was estimated from volume using specific gravity for each species or group of species (Clark and Schroeder 1986). Carbon content of the biomass was estimated using a standard conversion factor (i.e. 50 percent of dry biomass) reported by Pearson and others (2007).

The effects of the residual basal area thinning treatments on carbon dynamics were determined after 11 years, in early 2008. Two response variables were evaluated for the three white pine plots and the hardwood reference stand: (1) carbon stored in both the harvested timber products and total aboveground carbon stored in the residual trees and (2) mean annual rate of carbon sequestration. Lack of replication precluded statistical assessment of differences among the three thinning treatments. For similar reasons, comparison of carbon storage and rate of sequestration by the white pine plantation with the reference hardwood stand could not be statistically tested.

RESULTS

After 11 years of response to thinning, white pine basal areas of the control, BA120, and BA80 treatment plots had increased 16.1, 31.1, and 39.3 percent respectively (Table 1). For the hardwood reference stand, basal area at the beginning of the study was about 31 percent that of the unthinned white pine plot and at the end of the study had increased slightly to 36 percent. The large increase in tree density in the hardwood stand, from 244 to 386 stems per acre, resulted mostly from ingrowth of white pine saplings that had originated from seeds windblown from the adjacent plantation.

Pretreatment white pine carbon stocks were estimated to be slightly lower on the BA80 residual basal area treatment compared to the Control and BA120 treatments (Table 2). In early 1997, immediately after thinning, 44 percent of the standing carbon stocks had been harvested from the BA120 residual basal area plot and 65 percent from the BA80 plot. At the end of the study period, the net increment of carbon storage in standing trees ranged from 11.7 tons on the BA120 treatment to 8.5 tons on the BA80 treatment. The rate of carbon sequestration by white pines on the Control and BA120 treatment plots was similar at about 1 ton/acre/year.

Hardwood carbon stocks averaged 21 tons/acre initially and increased to 25 tons/acre after 11 years (Table 2). The rate of sequestration averaged almost 0.4 ton/acre/year. In comparison with the unthinned white pine treatment, the hardwood reference stand stored only about half the carbon at the beginning and end of the study, but the rate of sequestration was only a third, due largely to unutilized mortality.

DISCUSSION

Results of this pilot study suggest that aboveground carbon storage by white pine was not increased by thinning from below to reduce residual basal area. Carbon sequestration on the BA120 treatment was about the same as that of the unthinned Control when initial basal area was reduced by 44 percent. The BA80 basal area treatment, however, reduced the rate of carbon sequestration by 0.24 ton/acre annually compared to the Control. McNab and Ritter (2000) reported similar findings based on volume rather than biomass, suggesting that although thinning captures probable mortality it does not appear to increase productivity of mature white pine plantations in the southern Appalachians. A potentially useful finding of this study was that the 45-year old white pine planting receiving the BA80 treatment stored about twice the amount of carbon compared to the older hardwood stand with about the same level of basal area stocking.

The rates of aboveground carbon accumulation by the Control treatment of white pine in this study were about midway in the range reported for other highly disturbed sites elsewhere in the East (Table 3). Carbon sequestration by the reference hardwood stand in this study (0.4 ton/acre/year) was similar to that reported for an oak stand in Minnesota (0.5 ton/acre/year). Carbon storage by the unthinned white pine plot in this study, however, was only about half that for a younger stand of loblolly pine in the piedmont of South Carolina. Although plantations of white pine can equal the biomass of loblolly pine (Kinerson and others 1977), carbon storage will generally always be less because of differences in wood specific gravity (0.34 vs 0.47). Longer rotations, however, may be a feasible method for increasing carbon stocks of managed white pine forests (Huang and Konrad 2006, Foley et al 2009).

Results of this pilot study are not suitable for making forest management decisions related to carbon sequestration by white pine plantations. My results do, however, suggest the importance of considering possible unintended effects that certain tree species selected for carbon management might have on other land resources. For example, annual water yields are less from large watersheds planted with white pine compared to a cover of natural hardwoods (Swank and Miner 1968). However, most of the reduction of water results from interception of precipitation by the evergreen foliage of white pines during the winter months, when soils are usually at field capacity during years of normal rainfall

(Beck 1985). Other issues to consider when evaluating white pine for carbon management are presented by Bennett and Desmarais (2003).

In summary, results from this unreplicated case study suggest that short-term aboveground carbon storage by white pine plantations is not increased by thinning and also that nearly mature white pine plantings may store more carbon than older natural hardwood stands. More specifically, basal area may be reduced by almost 50 percent in older, fully stocked white pine plantations on low quality sites in the southern Appalachians with little reduction in the rate of carbon sequestration. However, results from this preliminary investigation are not intended for management decisions and are presented primarily for demonstration and as a source of information to guide future studies.

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Dr. Erik C. Berg designed and established this study as demonstration of a conventional intermediate stand treatment (thinning) in an eastern white pine plantation when he was assigned to the Upland Hardwood Silviculture Research Work Unit as Forester, in 1995. The thinning treatments were made as a commercial timber harvest managed by Ted M. Oprean, District Silviculturist on the Pisgah Ranger District of the Pisgah National Forest, who reported the sale of 57 ccf of sawtimber for $2,485.77 and 59 ccf of pulpwood for $59.00 from the 5-acre plantation in March 1997.

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Table 1—Average (standard deviation) dimensions of the tree stand in the white pine plantation and hardwood reference stand at the beginning (1997) and end (2008) of the study in the Bent Creek Experimental Forest

Year	Thinning treatment[a]	Basal area[b]	Tree density	Quadratic mean dbh
		feet^2/acre	number/acre	inches
Eastern white pine plantation				
1997	Control	244.3[d]	230.5[d]	13.9
1997[c]	BA120	132.5	98.9	15.7
1997[c]	BA80	76.3	48.1	17.1
2008	Control	283.6	207.1	15.8
2008	BA120	173.7	96.6	18.1
2008	BA80	106.3	45.4	20.7
Hardwood reference stand				
1997	None	75.3 (15.7)	244.0 (38.5)	7.5
2008	None	103.5 (17.3)	386.0 (80.2)	7.0

[a]Treatments: White pine plantation – Control, no thinning; BA120, thin to residual basal area of 120 ft^2/acre; BA80, thin to residual basal area of 80 ft^2/ac. Rationale for the selected levels of thinning is unknown, but the BA120 level was likely in consideration of the B-line of residual basal area as the minimum stocking for maximum growth of white pine stands in New England (Leak 1982). Hardwood reference stand – Treatments were not made in this stand, which provided a comparison with the adjacent pine plantation.
[b]Basal area (<2 ft^2/ac) of scattered suppressed hardwoods in the white pine plantation was excluded. White pine site index (mean total height of dominants and codominants at 50 years of age) for each treatment was: Control=99, BA120=98, BA80=95.
[c]Stand characteristics after thinning. Prethinning basal area of the BA120 treatment was 234.8 feet^2/acre and 227.6 feet^2/acre on the BA80 treatment.
[d]Standard deviations are not presented for values of the white pine plantation because the population of trees was inventoried on each treatment plot, unlike in the hardwood stand that was sampled.

Table 2—Aboveground carbon stocks before (1997) and after (2008) installation of three thinning treatments in an eastern white pine plantation and an unthinned hardwood reference stand in Bent Creek Experimental Forest

Thinning treatment	1997 carbon stocks Initial	Harvested	Residual	2008 carbon stocks Standing	Total[a]	Net change of carbon stocks[b]	Rate of carbon sequestration[c]
	tons per acre						tons/ac/yr
White pine plantation							
Control	46.7	0.0	46.7	58.1	58.1	11.4	1.04
BA120	50.1	21.9	28.2	39.9	61.8	11.7	1.06
BA80	45.4	29.5	15.9	24.7	54.2	8.8	0.80
Hardwood reference stand							
None	21.1	0.0	21.1	25.3	25.3	4.2	0.38

[a]Sum of carbon harvested in 1997 and standing in 2008.
[b]Difference between standing carbon stocks in 2008 and residual stocks in 1997.
[c]Average annual carbon storage in harvested wood and standing biomass during the 11-year study.

Table 3—Comparison of rates of aboveground carbon sequestration by forests on disturbed sites in the eastern US

Forest type (state)	Stand age	Rate of carbon sequestration	Source
	years	tons/ac/yr	
Oak hardwoods (NC)	113	0.4	This study
Oak hardoods (MN)	39	0.5	Johnston et al (1996)
Pine-hardwoods (GA)	70	0.7	Huntington (1995)
White pine (RI)	115	0.7	Hooker (2003)
White pine (NC)	45	1.0	This study
Loblolly pine (VA)	47	1.4	Schiffman and Johnson (1989)
Loblolly pine (SC)	35	1.9	Richter et al. (1999)

GROWTH AND BOLE QUALITY RESPONSES TO THINNING IN A RED OAK-SWEETGUM STAND IN SOUTHEASTERN ARKANSAS: NINE-YEAR RESULTS

James S. Meadows

ABSTRACT

Science-based guidelines for thinning in southern bottomland hardwood stands are inadequate. To address this need, we established a series of thinning studies based on stand density management in hardwood stands on minor streambottom sites across the South. In the third study in this series, four thinning treatments were applied to a poletimber-sized, red oak-sweetgum (Quercus spp.-Liquidambar styraciflua) stand in southeastern Arkansas in September 1999: (1) unthinned control; (2) light thinning to 70 to75 percent residual stocking; (3) heavy thinning to 50 to 55 percent residual stocking; and (4) B-line thinning to the recommended residual stocking for bottomland hardwoods. By the end of the ninth year after treatment, thinning had improved stand-level basal area growth but with no differences among the three levels of thinning in the rate of growth. Thinning also had increased diameter growth of residual trees, especially red oaks, but the magnitude of diameter growth response by red oaks did not differ among the three levels of thinning. The increased diameter growth of residual trees accelerated the rate of stand development through rapid increases in the number of red oak sawtimber trees per acre and rapid increases in quadratic mean diameter. The number of epicormic branches on the butt log was high and did not differ statistically among treatments.

INTRODUCTION

Management of hardwood stands for the production of high-quality sawtimber requires the capability to develop and sustain satisfactory growth rates and high-grade logs in trees of commercially valuable species. To achieve this goal, thinning often is used in mixed-species hardwood stands to increase growth of residual trees, to maintain and possibly enhance bole quality of residual trees, and to improve species composition of the residual stand (Meadows 1996).

Thinning regulates stand density and increases diameter growth of residual trees. In general, diameter growth increases as thinning intensity increases. Goelz (1995) proposed that desirable residual stocking after thinning in even-aged, sawtimber stands of southern hardwoods ranges from 65 to 80 percent. However, very heavy thinning may reduce stand density to such an extent that stand growth is diminished even though growth of individual trees may be enhanced. Goelz (1997) estimated that the minimum stocking level necessary to maintain acceptable stand-level growth in southern hardwood stands ranges from 40 to 60 percent.

Even though thinnings are designed to maintain and possibly enhance bole quality of residual trees, they sometimes have adverse effects on bole quality. New epicormic branches may develop along the boles of residual hardwood trees during the first few years after thinning. Epicormic branches are adventitious twigs that develop from dormant buds along the bole. Standard grading rules for hardwood factory logs stipulate that epicormic branches greater than 3/8 inches in diameter at the bark surface are defects on logs of all sizes, grades, and species (Rast and others 1973). Consequently, the presence of a sufficient number of well-distributed epicormic branches may reduce log grade and both lumber grade and value (Meadows and Burkhardt 2001).

Meadows (1995) hypothesized that species and tree health control the release of those dormant buds that develop into epicormic branches, such that healthy, upper-crown-class trees are much less likely to produce epicormic branches after thinning than are unhealthy, lower-crown-class trees. Because well-designed hardwood thinnings retain healthy, high-quality trees of desirable species and remove unhealthy, low-quality trees, production of epicormic branches across the residual stand actually may decrease after thinning (Sonderman and Rast 1988). Conversely, thinnings that fail to retain healthy, high-quality trees often result in the development of numerous epicormic branches along the boles of residual trees.

Thinning also improves both species composition and stand quality in mixed-species hardwood stands (Meadows 1996). Thinning prescriptions that emphasize quality and value of individual trees tend to decrease the proportion of low-quality, low-value trees and to increase the proportion of high-quality, high-value trees in the residual stand. Trees that are damaged or diseased, that have low-quality boles, or that are undesirable species should be removed from the stand; trees that are healthy, that have high-quality boles, and that are desirable species should be retained.

Science-based information on thinning in southern bottomland hardwood stands is inadequate. Published guidelines, such as those proposed by McKnight (1958),

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Johnson (1981), Meadows (1996), and Goelz and Meadows (1997), are too general and are based more on experience than on actual research results. To address this need, we established a series of thinning studies based on the concept of stand density management in red oak-sweetgum (Quercus spp.-Liquidambar styraciflua) stands on minor streambottom sites across the South. The underlying presumption of stand density management is that hardwood stands are managed best through regulation of stand density. The stand to be thinned is marked to some pre-determined level of residual density spread uniformly across the stand.

All studies in this series use the same design, treatments, and methods. Each study will determine the effects of several levels of thinning on: stand growth and development; and growth and bole quality of individual trees. Results from the entire series of studies will be combined to develop practical thinning guidelines for managing existing stands of southern bottomland hardwoods. The study reported here is the third in the series. Early results from other studies in the series were reported by Meadows and Goelz (1998, 1999, and 2002) and by Meadows and Skojac (2006).

METHODS

STUDY AREA

The study area is located within the floodplain of the Saline River in Cleveland County, north of the city of Warren, in southeastern Arkansas. The site is nearly flat and is subject to periodic flooding in winter and spring. Ochlockonee silt loam (coarse-loamy, siliceous, active, acid, thermic Typic Udifluvent) is the predominant soil series, with average site indices of 90 feet at 50 years for willow oak (*Q. phellos*) and 112 feet at 50 years for sweetgum (Broadfoot 1976).

The study area lies in a 138-acre, even-aged stand composed primarily of red oak and sweetgum. Principal red oak species are willow oak and water oak (*Q. nigra*), with scattered cherrybark oak (*Q. pagoda*) and Nuttall oak (*Q. texana*). In addition to sweetgum, other common species in the overstory include overcup oak (*Q. lyrata*), green ash (*Fraxinus pennsylvanica*), and baldcypress (*Taxodium distichum*). The primary understory species is American hornbeam (*Carpinus caroliniana*). The stand was about 35 years old at the time of study installation. We classified the stand as a poletimber stand on a medium-quality site, with high initial stocking.

PLOT DESIGN

Plot design followed a standard format for silvicultural research plots.[1] Each treatment was applied uniformly across a 2.0-acre rectangular treatment plot that measured 4 by 5 chains (264 by 330 feet). One 0.6-acre rectangular measurement plot was established in the center of each treatment plot. Each measurement plot was 2 by 3 chains (132 by 198 feet), which provided a buffer strip 1 chain (66 feet) wide around each measurement plot. The entire study covered an area of 24 acres.

TREATMENTS

Treatments were defined as different levels of residual stocking, based on the stocking guide developed by Goelz (1995) for southern bottomland hardwoods: (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 the desirable residual stocking recommended by Putnam and others (1960).

All thinning treatments removed most of the smaller poletimber trees as well as sawtimber trees that were damaged or diseased, had poor bole quality, or were undesirable species. Hardwood tree classes, as originally defined by Putnam and others (1960) and modified by Meadows (1996), formed the cutting priority for each treatment. Cutting stock and cull stock trees were removed first, followed by reserve growing stock trees, when necessary, until the target residual stocking for each treatment was met. Three replications of the four treatments were applied in a randomized complete block design to the 12 treatment plots (experimental units) in September 1999.

STATISTICAL ANALYSIS

Data were subjected to a one-way analysis of variance for a randomized complete block design with three replications of four treatments, for a total of 12 experimental units. Treatment effects were considered fixed, while block effects were considered random. Alpha was set at 0.05 for all statistical tests. Plot-level variables represented the mean for all residual trees on each measurement plot. Treatment means were separated through the use of Duncan's New Multiple Range Test.

RESULTS AND DISCUSSION

STAND CONDITIONS PRIOR TO THINNING

Prior to thinning, the study area averaged 343 trees and 123 square feet of basal area per acre, with a quadratic mean diameter of 8.2 inches, among trees ≥ 3.5 inches d.b.h. Average stocking across the study area was 117 percent, which greatly exceeded maximum full stocking (100 percent), the point at which thinning is recommended in even-aged stands of southern bottomland hardwoods (Goelz 1995). There were no significant differences among treatments in any preharvest characteristics (table 1). Many codominant trees exhibited symptoms of poor health, such as crown deterioration, loss of apical dominance, and the

[1]Marquis, D.; Smith, C.; Lamson, N. [and others]. 1990. Standard plot layout and data collection procedures for the Stand Establishment and Stand Culture Working Groups, Northeastern Forest Experiment Station. 55 p. Unpublished report. On file with: James S. Meadows, Southern Research Station, P.O. Box 227, Stoneville, MS 38776

presence of numerous epicormic branches along the boles. Most of these trees were removed during the thinning operation. Thinning the stand a few years earlier, however, would have prevented overstocking and would have minimized the proportion of trees in poor health.

Red oak and sweetgum clearly dominated this poletimber stand. Prior to thinning, these species together accounted for 83 percent of stand basal area. Red oak comprised 56 percent of stand basal area and dominated the upper canopy of the stand, whereas sweetgum accounted for 27 percent of the basal area and was found in both the upper and middle canopies. Other species, such as overcup oak, green ash, and baldcypress, made up 13 percent of stand basal area and occurred as scattered individuals throughout the upper canopy. American hornbeam in the lower canopy accounted for the remaining 4 percent of stand basal area.

STAND DEVELOPMENT AFTER THINNING

Stand conditions immediately after thinning—Light thinning reduced stand density to 125 trees and 80 square feet of basal area per acre, increased quadratic mean diameter to 10.9 inches, and reduced stocking to 70 percent (table 2). Compared to the overall stand averages prior to thinning, it removed 64 percent of the trees and 35 percent of the basal area. Heavy thinning reduced stand density to 106 trees and 58 square feet of basal area per acre, increased quadratic mean diameter to 10.0 inches, and reduced stocking to 52 percent. It removed 69 percent of the trees and 53 percent of the basal area. B-line thinning reduced stand density to 118 trees and 70 square feet of basal area per acre, increased quadratic mean diameter to 10.4 inches, and reduced stocking to 62 percent. It removed 66 percent of the trees and 43 percent of the basal area. All thinning treatments produced stand characteristics significantly different from the unthinned control, with one exception: quadratic mean diameter of the residual stand after heavy thinning was not significantly different from quadratic mean diameter of the unthinned control.

Stand conditions 9 years after thinning—Stand-level growth in the unthinned control plots over the past 9 years has been slow (table 3). Basal area increased 11 square feet per acre (from 132 to 143 square feet per acre), an average of only 1.2 square feet per acre per year. Cumulative mortality was 25 percent, an average rate of 2.8 percent per year. Most of the trees that died were small, overtopped trees that were in poor health at the time of study establishment. Quadratic mean diameter of the unthinned control plots increased 1.7 inches, from 8.9 to 10.6 inches. However, much of the increase in quadratic mean diameter is the result of the deaths of many small trees rather than the result of actual diameter growth by surviving trees. With a current quadratic mean diameter of 10.6 inches, the unthinned stand remains in the poletimber size class. Stocking 9 years after study establishment averaged 126 percent, a level that well exceeds maximum full stocking (100 percent). The unthinned control plots are greatly overstocked and stagnant, a condition that has led to slow stand-level growth and moderately high mortality.

By the end of the ninth year after treatment, all three levels of thinning exhibited stand-level characteristics that were significantly different from the unthinned control, but no significant differences in cumulative basal area growth and quadratic mean diameter were found among the three levels of thinning (table 3). Cumulative basal area growth rates ranged from 2.7 to 3.1 square feet per acre per year across the three levels of thinning, as compared to only 1.2 square feet per acre per year in the unthinned control. Because the rates of basal area growth were so similar among the three levels of thinning, significant differences in stand basal area that were created immediately after thinning (table 2) still persist 9 years later (table 3). Similarly, increases in quadratic mean diameter among the three levels of thinning ranged from 4.7 to 5.1 inches, as compared to only 1.7 inches in the unthinned control. The current quadratic mean diameters of the thinned plots indicate that all three levels of thinning accelerated the rate of stand development to the extent that all thinned plots presently are classified as small-sawtimber stands. The unthinned control, with a current quadratic mean diameter of 10.6 inches, remains classified as a poletimber stand. Because hardwood sawtimber is much more valuable than hardwood poletimber, all three levels of thinning increased stand value dramatically in just 9 years.

Clearly, thinning greatly improved stand basal area growth and development, with no differences found among the three levels of thinning in the rate of stand growth. Relative to the unthinned control plots, the thinned plots are growing more rapidly, are developing at a more accelerated pace, are healthier, and contain more valuable timber. These desirable responses to thinning will help achieve the management goal of high-quality, hardwood sawtimber production.

DIAMETER GROWTH

Relative to the unthinned control, all three levels of thinning significantly increased cumulative diameter growth of residual trees, averaged across all trees of all species, throughout the 9 years since thinning (table 4). Significant differences among treatments observed after the first year continued to widen over time. In fact, by the end of the third year after thinning, cumulative diameter growth of residual trees after both heavy thinning and B-line thinning was significantly greater than cumulative diameter growth of residual trees after light thinning. This pattern continued through the end of the ninth year after thinning. By that time, both heavy thinning and B-line thinning had nearly tripled individual-tree diameter growth relative to the unthinned control.

Diameter growth response data were separated into two species groups: red oak and sweetgum. Relative to the unthinned control, all three levels of thinning significantly increased diameter growth of residual red oaks, through the ninth year after thinning (fig. 1). Cumulative diameter growth in the thinned plots ranged from 2.2 inches after light thinning to 2.7 inches after heavy thinning, as compared to 1.7 inches in the unthinned control plots. All three levels of thinning also significantly improved cumulative diameter growth of sweetgum, but response was less than that observed among red oaks. In contrast to the red oaks, diameter growth response of sweetgum was significantly greater after both heavy thinning and B-line thinning than after light thinning.

Even though all three levels of thinning significantly increased cumulative diameter growth of residual red oaks relative to the unthinned control, there were no significant differences among those three levels of thinning (fig. 1). In other words, diameter growth response of residual red oaks 9 years after thinning was statistically the same for light thinning, heavy thinning, and B-line thinning. Diameter growth response of residual red oaks to thinning was independent of residual stand density, at least within the range of residual densities evaluated in this study: 58 square feet of basal area per acre after heavy thinning to 80 square feet of basal area per acre after light thinning. The same result was observed in other studies within our series of thinning studies based on stand density management (Meadows and Goelz 2002, Meadows and Skojac 2006).

Clearly, all three levels of thinning successfully increased diameter growth of residual trees during the first 9 years after treatment. The largest increases were observed among red oaks. In fact, when the three levels of thinning are averaged together, thinning increased diameter growth of residual red oaks by 47 percent relative to the unthinned control. Because the magnitude of the diameter growth response by red oaks did not differ within the fairly broad range of residual densities evaluated in this study, thinning prescriptions that strictly adhere to stand density management may not be appropriate in bottomland hardwood stands with a large component of red oak. Rather, thinning prescriptions that focus on development and maintenance of high-quality, high-value trees may be more suitable for those stands.

PRODUCTION OF EPICORMIC BRANCHES

When averaged across all trees of all species, thinning had no significant effect on the number of epicormic branches on the butt logs of residual trees throughout the 9 years since thinning (table 5). Means after all three levels of thinning increased steadily for the first 3 years after thinning, remained relatively stable through the sixth year, then appeared to decline somewhat over the last 3 years. This same pattern was observed in other studies within this series of thinning studies based on stand density management (Meadows and Goelz 2002, Meadows and Skojac 2006). In contrast, the number of epicormic branches on the butt logs of trees in the unthinned control remained relatively constant through the first 9 years of the study.

The number of epicormic branches on the butt log varied widely among individual trees. Most trees that appeared to be healthy, with large, well-shaped crowns and dense foliage, had either no epicormic branches or only a few. Conversely, most trees that appeared to be unhealthy, with small crowns and sparse foliage, generally had many epicormic branches. These general observations tend to support the hypothesis advanced by Meadows (1995) that tree health is the primary factor that controls the production of new epicormic branches in response to disturbance.

Because hardwood species vary widely in their susceptibility to the production of epicormic branches (Meadows 1995), data were partitioned by the species groups red oak and sweetgum (fig. 2). None of the three levels of thinning had a significant effect on the number of epicormic branches on the butt logs of residual red oak or sweetgum, 9 years after thinning. However, wide variation in the data may have prevented detection of significant differences among treatments within each species group. The number of epicormic branches on the butt logs of residual red oaks ranged from 8.7 after B-line thinning to 11.4 after heavy thinning, as compared to 8.3 branches on the butt logs of red oaks in the unthinned control. Much broader variation was found among sweetgum trees, where means ranged from 5.3 branches after B-line thinning to 11.8 branches after heavy thinning, as compared to 6.4 branches in the unthinned control. All of these means are sufficiently high to likely cause reductions in log grade and value.

The presence of numerous epicormic branches on trees in the unthinned control plots likely was due to two factors: (1) overall poor stand health throughout the study, and (2) a large proportion of red oak and sweetgum in the stand. The original stand was overstocked and stagnant at the time of study establishment and remained so in the unthinned control plots throughout the study. Many trees in the stand exhibited symptoms of poor health. Meadows (1995) hypothesized that trees in poor health are more susceptible to the production of epicormic branches than are trees in good health. Meadows (1995) further observed that hardwood species vary greatly in the likelihood that they will produce epicormic branches and classified willow oak, water oak, and sweetgum as highly susceptible to the production of epicormic branches. Therefore, it is likely that the large proportions of these species in the stand contributed to the large number of epicormic branches found on trees throughout the study.

These two factors, combined with the use of thinning prescriptions based on stand density management, led to the presence of large numbers of epicormic branches on the butt logs of residual trees after all three levels of thinning. When the stand was marked, there were insufficient numbers of trees in good health to meet the target residual densities specified by the three thinning prescriptions. To maintain the target residual densities uniformly across the treatment plots, it was necessary to retain relatively large numbers of trees in poor to moderate health in all thinned plots. These trees usually already have several epicormic branches and are very susceptible to the production of additional epicormic branches. Consequently, strict adherence to stand density management forced the retention of many less-than-desirable trees, which resulted in a large number of epicormic branches on residual red oak and sweetgum trees across all three levels of thinning.

ACCELERATED DEVELOPMENT OF RED OAK SAWTIMBER

Because red oak is more valuable than sweetgum and because sawtimber is more valuable than poletimber, the most valuable component of the stand is red oak sawtimber. If the basic goal of thinning is to increase the value of the stand, one way to evaluate the success of the thinning treatments is to monitor the number of red oak sawtimber (d.b.h. ≥ 12.0 inches) trees per acre over time. Because means for this variable were similar across the three levels of thinning during each year of the study, the data for the thinned plots were combined into a single mean for each year, which then was compared to the unthinned control (fig. 3).

The number of red oak sawtimber trees per acre in the unthinned control increased slowly during the past 9 years (fig. 3). There were 17 red oak sawtimber trees per acre in the unthinned control at the time of study establishment. Red oak sawtimber accounted for 14 percent of all living red oaks and 5 percent of all living trees at that time. By the end of the ninth year after study establishment, there were 28 red oak sawtimber trees per acre, which represented 33 percent of all living red oaks and only 12 percent of all living trees.

Similarly, there were 17 red oak sawtimber trees per acre, averaged across the three levels of thinning, just prior to thinning (fig. 3). Red oak sawtimber comprised 9 percent of all living red oaks and 5 percent of all living trees at that time. The average rate of increase in the number of red oak sawtimber trees per acre in the thinned plots was similar to the rate of increase in the unthinned control plots through the first 2 years after thinning. However, during the third year after thinning, the rate of increase accelerated substantially in the thinned plots. The gap between the thinned plots and the unthinned control plots in the number of red oak sawtimber trees per acre continued to widen from the third through the ninth years after thinning. By the end of the ninth year, there were 46 red oak sawtimber trees per acre in the thinned plots, which accounted for 57 percent of all living red oaks and 44 percent of all living trees.

Currently, in the unthinned control plots, red oak sawtimber accounts for one out of every three red oak trees and only one out of every eight trees of all species and sizes. With a current quadratic mean diameter of 10.6 inches and such a small component of red oak sawtimber, the unthinned control is classified as a poletimber stand. At the current stage of stand development, the primary timber product available for harvest in the unthinned control is pulpwood. Conversely, red oak sawtimber in the thinned plots accounts for over half of all red oak trees and nearly half of all trees. With quadratic mean diameters ranging from 12.8 to 13.0 inches and relatively large components of red oak sawtimber, the thinned plots for all three levels of thinning are classified as small-sawtimber stands. At this accelerated stage of stand development, both sawtimber and pulpwood are available for harvest in the thinned plots.

All three levels of thinning accelerated the rate of stand development, relative to the unthinned control. Because they contain both sawtimber and pulpwood rather than just pulpwood, the thinned plots are now more valuable than the unthinned control plots and likely will remain so for many years. Furthermore, this accelerated rate of stand development likely will reduce the length of the rotation in the thinned plots, as residual trees reach the desired size classes more rapidly. All in all, the three thinning prescriptions evaluated in this study provide acceptable pathways to achieve the management goal of high-quality sawtimber production in red oak-sweetgum stands.

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Table 1—Treatment means (± SE) for stand conditions prior to application of four thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p = 0.22 for number of trees, p = 0.27 for basal area, p = 0.06 for quadratic mean diameter, p = 0.51 for stocking)

Treatment	Trees	Basal area	Quadratic mean diameter	Stocking
	no./ac	ft^2/ac	inches	%
Unthinned	310 ± 16 a	132 ± 3 a	8.9 ± 0.3 a	122 ± 1 a
Light Thinning	323 ± 10 a	122 ± 7 a	8.3 ± 0.2 a	115 ± 6 a
Heavy Thinning	365 ± 38 a	116 ± 8 a	7.7 ± 0.1 a	112 ± 8 a
B-Line Thinning	373 ± 20 a	123 ± 3 a	7.8 ± 0.3 a	118 ± 1 a

Table 2—Treatment means (± SE) for stand conditions immediately after application of four thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p < 0.01 for number of trees, p < 0.01 for basal area, p = 0.04 for quadratic mean diameter, p < 0.01 for stocking)

Treatment	Trees	Basal area	Quadratic mean diameter	Stocking
	no./ac	ft^2/ac	inches	%
Unthinned	310 ± 16 a	132 ± 3 a	8.9 ± 0.3 b	122 ± 1 a
Light Thinning	125 ± 10 b	80 ± 1 b	10.9 ± 0.4 a	70 ± 1 b
Heavy Thinning	106 ± 3 b	58 ± 1 d	10.0 ± 0.2 ab	52 ± 1 d
B-Line Thinning	118 ± 7 b	70 ± 2 c	10.4 ± 0.5 a	62 ± 1 c

Table 3—Treatment means (± SE) for stand conditions 9 years after application of four thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p < 0.01 for number of trees, p < 0.01 for cumulative mortality, p < 0.01 for basal area, p < 0.01 for cumulative basal area growth, p = 0.01 for quadratic mean diameter, p < 0.01 for stocking)

Treatment	Trees	Cumulative mortality	Basal area	Cumulative basal area growth	Quadratic mean diameter	Stocking
	no./ac	%	ft^2/ac	ft^2/ac	inches	%
Unthinned	232 ± 8 a	25 ± 2 a	143 ± 6 a	11 ± 2 b	10.6 ± 0.4 b	126 ± 4 a
Light Thinning	116 ± 8 b	7 ± 1 c	107 ± 5 b	27 ± 3 a	13.0 ± 0.5 a	90 ± 4 b
Heavy Thinning	92 ± 1 c	13 ± 1 b	82 ± 1 c	24 ± 1 a	12.8 ± 0.1 a	70 ± 1 c
B-Line Thinning	109 ± 5 bc	8 ± 1 c	98 ± 3 b	28 ± 2 a	12.9 ± 0.5 a	83 ± 2 b

Table 4—Cumulative diameter growth (± SE) of residual trees 1, 2, 3, 4, 6, and 9 years after application of four thinning treatments. Means within each year followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p < 0.01 for all years)

	Years after thinning					
Treatment	1	2	3	4	6	9
	inches					
Unthinned	0.11 ± 0.02 b	0.18 ± 0.02 c	0.28 ± 0.03 c	0.37 ± 0.04 c	0.56 ± 0.04 c	0.84 ± 0.07 c
Light Thinning	0.26 ± 0.05 a	0.42 ± 0.05 b	0.70 ± 0.09 b	0.94 ± 0.12 b	1.36 ± 0.15 b	1.91 ± 0.20 b
Heavy Thinning	0.28 ± 0.02 a	0.51 ± 0.03 a	0.91 ± 0.06 a	1.29 ± 0.08 a	1.84 ± 0.09 a	2.51 ± 0.12 a
B-Line Thinning	0.29 ± 0.03 a	0.49 ± 0.02 ab	0.83 ± 0.04 a	1.15 ± 0.04 a	1.66 ± 0.08 a	2.32 ± 0.09 a

Table 5—Number (± SE) of epicormic branches found on the butt logs of residual trees immediately after thinning (year 0) and 1, 2, 3, 4, 6, and 9 years after application of four thinning treatments. Means within each year followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p = 0.09 for year 0, p = 0.52 for year 1, p = 0.22 for year 2, p = 0.18 for year 3, p = 0.20 for year 4, p = 0.13 for year 6, p = 0.28 for year 9)

	Years after thinning						
Treatment	0	1	2	3	4	6	9
Unthinned	8.6 ± 2.0 a	7.9 ± 1.9 a	8.8 ± 1.8 a	9.4 ± 1.9 a	9.7 ± 1.9 a	9.3 ± 1.5 a	8.5 ± 1.6 a
Light Thinning	5.0 ± 1.7 a	6.8 ± 2.2 a	9.1 ± 2.4 a	10.0 ± 2.2 a	10.3 ± 2.4 a	10.4 ± 2.1 a	9.6 ± 2.0 a
Heavy Thinning	4.7 ± 1.0 a	7.8 ± 1.6 a	12.4 ± 1.7 a	13.5 ± 1.6 a	13.7 ± 1.6 a	13.4 ± 1.5 a	11.4 ± 1.9 a
B-Line Thinning	3.4 ± 0.4 a	5.2 ± 1.4 a	7.9 ± 1.1 a	8.8 ± 0.9 a	8.8 ± 0.8 a	8.7 ± 1.0 a	7.6 ± 1.1 a

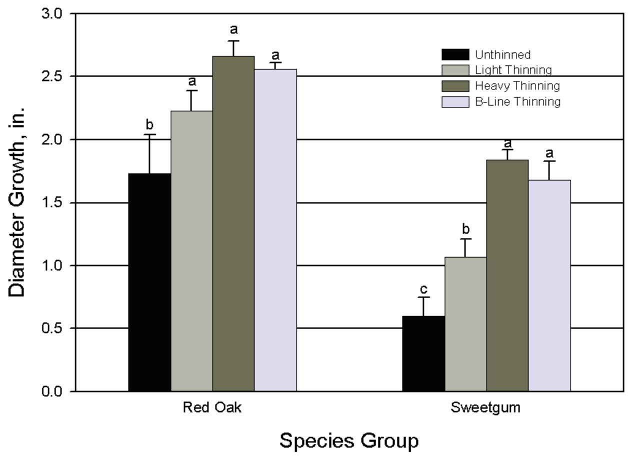

Figure 1—Cumulative diameter growth (± SE) of residual trees, by species group, 9 years after application of four thinning treatments. Means within each species group followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p = 0.01 for red oak, p < 0.01 for sweetgum).

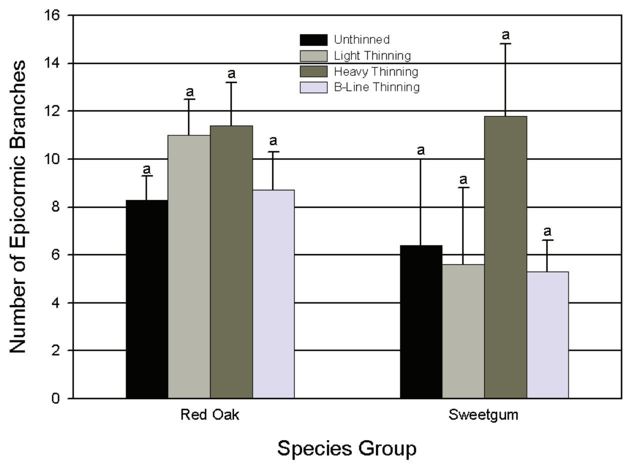

Figure 2—Number (± SE) of epicormic branches found on the butt logs of residual trees, by species group, 9 years after application of four thinning treatments. Means within each species group followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p = 0.09 for red oak, p = 0.35 for sweetgum).

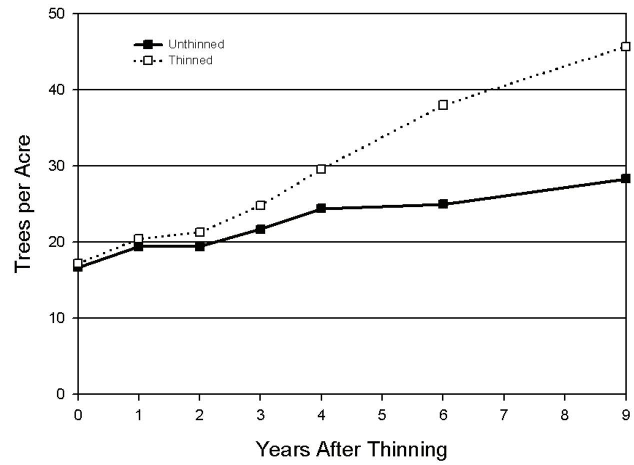

Figure 3—Number of red oak sawtimber trees per acre, through the 9 years since treatment application, in the unthinned control and averaged across the three levels of thinning.

STAND QUALITY MANAGEMENT IN A LATE-ROTATION, RED OAK-SWEETGUM STAND IN EAST MISSISSIPPI: PRELIMINARY RESULTS FOLLOWING THINNING

James S. Meadows and Daniel A. Skojac, Jr.

ABSTRACT

Stand quality management is a new management strategy in which thinning prescriptions are based solely on tree quality rather than a quantitative level of residual stand density. As long as residual density falls within fairly broad limits, prescriptions are based on tree quality alone. We applied four thinning prescriptions based on stand quality management, along with an unthinned control, to a late-rotation, red oak-sweetgum (*Quercus* spp.-*Liquidambar styraciflua*) stand in east Mississippi during the fall of 2007. Prior to thinning, stand density averaged 105 trees and 117 square feet of basal area per acre. Quadratic mean diameter of the stand was 14.4 inches. Red oaks comprised 51 percent of stand basal area and had a quadratic mean diameter of 18.0 inches. Residual stand density immediately after application of the four thinning prescriptions ranged from 48 to 69 square feet of basal area per acre. Through the first 3 years after treatment, diameter growth of residual trees increased significantly following all four thinning prescriptions. Thinning had little or no effect on the production of new epicormic branches on the butt logs of residual trees, even among red oaks.

INTRODUCTION

When the primary goal of management in mixed-species hardwood stands is to produce high-quality sawtimber, thinnings often are used to increase growth and enhance bole quality of residual trees and to improve species composition of the residual stand (Meadows 1996). Traditionally, thinning prescriptions in most southern hardwood stands are based on the concept of stand density management. The underlying assumption is that hardwood stands are managed best through regulation of stand density. The strategy of stand density management dictates that stands to be thinned are marked to a pre-determined level of residual density spread uniformly across the stand and that residual trees are spaced more or less evenly throughout the stand.

Stand density management works well and is used frequently in single-species stands. However, most hardwood stands contain a wide range of species that differ greatly in value and desirability. The spatial distribution of trees across a hardwood stand generally is much less than uniform. Trees may be clumped together in small, dense groups or may be so dispersed that small gaps devoid of merchantable trees occur.

Consequently, thinning prescriptions based on stand density management in highly diverse, irregularly distributed hardwood stands are flawed. In these stands, the timber marker often is forced to either leave low-quality trees or cut high-quality trees in order to maintain the target residual density uniformly across the stand. Residual stand quality and value may be compromised. Because the economic value of a hardwood stand is determined primarily by the species and bole quality of the trees in the stand, thinning prescriptions based on stand density management may produce residual stands of less-than-optimum economic value.

Results from a series of thinning studies based on stand density management in red oak-sweetgum (*Quercus* spp.-*Liquidambar styraciflua*) stands revealed that diameter growth rates of dominant and codominant red oaks did not differ statistically across thinning prescriptions with different target residual stand densities (Meadows and Goelz 2002, Meadows and Skojac 2006). Diameter growth responses of upper-crown-class red oaks were very similar throughout the range of residual stand densities evaluated in this series of studies: 58 to 88 square feet of basal area per acre. As long as residual stand density immediately after thinning falls within these broad limits, diameter growth response by dominant and codominant red oaks appears to be independent of residual stand density. Therefore, thinning prescriptions based on stand density management may not be appropriate in southern bottomland hardwood stands, especially those with a large component of red oak.

Stand quality management is a new management strategy designed to replace stand density management as the basis for thinning southern hardwood stands. The goal of stand quality management is to develop and maintain a high level of stand quality, with stand density relegated

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to a role of secondary importance. Thinning prescriptions based on stand quality management follow one simple rule: leave "good" trees and cut "poor" trees. Stand quality management dictates that, as long as residual stand density falls within fairly broad limits, thinning prescriptions and marking rules are based on tree quality alone.

The hardwood tree classification system developed by Meadows and Skojac (2008) provides a way to identify and separate "good" trees and "poor" trees. The classification system consists of five classes used only for sawtimber-sized trees and two classes used only for poletimber-sized trees. In descending order of desirability and value, the five sawtimber tree classes are (1) preferred growing stock, (2) desirable growing stock, (3) acceptable growing stock, (4) cutting stock, and (5) cull stock. Also in descending order of desirability and potential value, the two poletimber tree classes are (1) superior poletimber stock, and (2) inferior poletimber stock. Preferred growing stock, desirable growing stock, acceptable growing stock, and superior poletimber stock represent different degrees of "good" trees. Cutting stock, cull stock, and inferior poletimber stock represent "poor" trees. Each tree class represents a different level of tree quality and therefore categorizes the suitability of each tree in the stand to achieve the goals of management.

Under stand quality management, thinning prescriptions and marking rules are based solely on tree class, such that the various tree classes define the residual component for four different thinning prescriptions. Each prescription is designed to leave all trees of certain tree classes and to cut all trees of the other tree classes. Tree classes that are specified to be retained and tree classes that are specified to be removed differ from one prescription to the next.

To evaluate stand quality management as a new management strategy, we established a series of thinning studies in red oak-sweetgum stands on bottomland sites across the South. The thinning prescriptions evaluated in this series of studies are based on stand quality management. The study reported here is the second in the series. Early results from the first study in the series were reported by Meadows and Skojac (2010).

All studies in the series use the same design, treatments, and methods. Each study will determine the effects of four thinning prescriptions based on stand quality management on both stand-level and tree-level growth, quality, and value. Results from the entire series will be combined to develop a research-based model that will provide guidance to forest managers in the selection of the most appropriate thinning prescription to use in any given southern hardwood stand.

METHODS

STUDY AREA

The study area is located within the floodplain of the Noxubee River on the Noxubee National Wildlife Refuge in Noxubee County, south of the city of Starkville, in east-central Mississippi. The site is nearly flat and is subject to periodic flooding in winter and spring. Urbo silty clay loam (fine, mixed, active, acid, thermic Vertic Epiaquept) is the predominant soil series, with average site indices (base age of 50 years) of 100 feet for cherrybark oak (*Quercus pagoda*), 96 feet for water oak (*Q. nigra*), and 90 feet for sweetgum (Broadfoot 1976).

The study area supports a 65-year-old, red oak-sweetgum stand, in which the primary red oak species are cherrybark oak and water oak, with some scattered willow oak (*Q. phellos*). In addition to sweetgum, other common species in the overstory include hickory (*Carya* spp.), green ash (*Fraxinus pennsylvanica*), swamp chestnut oak (*Q. michauxii*), overcup oak (*Q. lyrata*), and American elm (*Ulmus americana*).

PLOT DESIGN

Plot design followed a standard format for silvicultural research plots.[1] Each treatment was applied across a 2.0-acre rectangular treatment plot that measured 4 by 5 chains (264 by 330 feet). One 0.6-acre rectangular measurement plot was established in the center of each treatment plot. Each measurement plot was 2 by 3 chains (132 by 198 feet), which provided a buffer strip 1 chain (66 feet) wide around each measurement plot within the treatment plot. The entire study covered an area of 30 acres.

TREATMENTS

Thinning treatments represented the four thinning prescriptions based on stand quality management. Marking rules for each thinning treatment consisted of a list of tree classes to be retained after thinning and a list of tree classes to be removed. Rules were applied to all trees within any given tree class, with no regard for residual stand density or uniform spacing of residual trees. The five treatments are listed below:

1) Unthinned Control (Control) – leave all trees

2) Acceptable with Superior Poletimber Thinning (AccSupP) – leave all Preferred, Desirable, and Acceptable growing stock trees, as well as all Superior Poletimber stock trees; cut all trees in the remaining tree classes

3) Acceptable with No Poletimber Thinning

[1] Marquis, D.; Smith, C.; Lamson, N. [and others]. 1990. Standard plot layout and data collection procedures for the Stand Establishment and Stand Culture Working Groups, Northeastern Forest Experiment Station. 55 p. Unpublished report. On file with: James S. Meadows, Southern Research Station, P.O. Box 227, Stoneville, MS 38776

(AccNoPole) – leave all Preferred, Desirable, and Acceptable growing stock trees; cut all trees in the remaining tree classes, including all Poletimber stock trees

4) Desirable with Superior Poletimber Thinning (DesSupP) – leave all Preferred and Desirable growing stock trees, as well as all Superior Poletimber stock trees; cut all trees in the remaining tree classes, including all Acceptable growing stock trees

5) Desirable with No Poletimber Thinning (DesNoPole) – leave all Preferred and Desirable growing stock trees; cut all trees in the remaining tree classes, including all Acceptable growing stock trees and all Poletimber stock trees

MEASUREMENTS AND STATISTICAL ANALYSIS

Prior to assignment of treatments, we recorded species, diameter at breast height (d.b.h.), crown class, and tree class, as defined by Meadows and Skojac (2008), on all trees of merchantable size (≥ 5.5 inches d.b.h.). We randomly assigned treatments to the plots and marked each 2.0-acre treatment plot for thinning according to the marking rules prescribed for the assigned treatment. We then tallied the number of large epicormic branches, as well as the total number of epicormic branches, on the 16-foot-long butt log of all residual trees. Large epicormic branches are greater than 3/8 inches in basal diameter and are counted as defects in logs of all sizes and species (Rast and others 1973). Three replications of the five treatments were applied in a randomized complete block design to the 15 treatment plots (experimental units) in October 2007. Crown class, d.b.h., and both total number and number of large epicormic branches on the 16-foot-long butt log were measured at the end of each of the first 3 years after thinning.

Data were subjected to a one-way analysis of variance for a randomized complete block design with three replications of five treatments, for a total of 15 experimental units. Treatment effects were considered fixed, while block effects were considered random. Alpha was set at 0.05 for all statistical tests. Plot-level variables represented the mean for all residual trees on each measurement plot. Treatment means were separated through the use of Duncan's New Multiple Range Test.

RESULTS AND DISCUSSION

STAND CONDITIONS PRIOR TO THINNING

Prior to thinning, the study area averaged 105 trees and 117 square feet of basal area per acre, with a quadratic mean diameter of 14.4 inches, among trees ≥ 5.5 inches d.b.h. Average stocking across the study area was 97 percent, just slightly below maximum full stocking (100 percent), the point at which thinning is recommended in even-aged stands of southern bottomland hardwoods (Goelz 1995). There were no significant differences among treatments in any preharvest characteristics (n = 3 per treatment; p = 0.78 for number of trees, p = 0.06 for basal area, p = 0.49 for quadratic mean diameter, p = 0.08 for stocking). Symptoms of severe competition among trees were not evident. Most dominant and codominant trees appeared to be healthy.

Red oaks and sweetgum dominated this 65-year-old sawtimber stand. Prior to thinning, these species together accounted for 74 percent of stand basal area. Primary red oak species were cherrybark oak and water oak, with some willow oak scattered throughout the stand. Collectively, these red oak species comprised 51 percent of stand basal area, with a quadratic mean diameter of 18.0 inches, and dominated the overstory. Sweetgum accounted for 23 percent of stand basal area, with a quadratic mean diameter of 11.6 inches, and was found in the overstory, midstory, and understory. Other species, such as swamp chestnut oak, overcup oak, hickory, green ash, and American elm, made up the remaining 26 percent of stand basal area and occurred as scattered individuals throughout the stand.

Prior to thinning, about 65 percent of stand basal area consisted of trees in the preferred growing stock, desirable growing stock, acceptable growing stock, and superior poletimber stock tree classes (fig. 1). These classes represent "good" trees that are capable of meeting the goals of management. The remaining 35 percent of stand basal area was comprised of trees in the cutting stock, cull stock, and inferior poletimber stock tree classes. These classes represent "poor" trees that are incapable of meeting the goals of management. This roughly 2:1 ratio of "good" trees to "poor" trees is typical of most previously unmanaged stands of southern bottomland hardwoods.

STAND DEVELOPMENT AFTER THINNING

The Acceptable with Superior Poletimber Thinning (AccSupP) reduced stand density to 29 trees and 69 square feet of basal area per acre, increased quadratic mean diameter to 20.6 inches, and reduced stocking to 54 percent (table 1). Relative to overall stand averages prior to thinning, it removed 72 percent of the trees and 41 percent of the basal area. The Acceptable with No Poletimber Thinning (AccNoPole) reduced stand density to 28 trees and 61 square feet of basal area per acre, increased quadratic mean diameter to 20.2 inches, and reduced stocking to 48 percent. It removed 73 percent of the trees and 48 percent of the basal area. In contrast, the Desirable with Superior Poletimber Thinning (DesSupP) reduced stand density to 26 trees and 57 square feet of basal area per acre, increased quadratic mean diameter to 19.9 inches, and reduced stocking to 45 percent. It removed 75 percent of the trees and 51 percent of the basal area. The Desirable with No Poletimber Thinning (DesNoPole) reduced stand density to 18 trees and 48 square feet of basal area per acre, increased quadratic mean diameter to 22.0 inches, and reduced stocking to 37 percent. It removed 83 percent of the trees and 59 percent of the basal area. Because this older stand contained few superior poletimber stock trees, the two levels of Acceptable thinning (AccSupP and AccNoPole) produced very similar residual stands. Likewise, the residual stands produced after the two levels of Desirable thinning (DesSupP and DesNoPole) were very similar to each other.

All thinning treatments produced stand characteristics significantly different from the unthinned control (table 1). No significant differences in trees per acre, basal area per acre, or stocking were detected among the four thinning treatments immediately after thinning, but minor statistical differences were found in quadratic mean diameter.

Stand conditions 3 years after thinning—Stand-level responses to the four thinning treatments were negligible during the first 3 years after thinning (table 2). For example, cumulative stand basal area growth averaged 3 square feet per acre or less in response to all thinning treatments, whereas cumulative stand basal area growth in the unthinned control averaged 4 square feet per acre. Average increases in quadratic mean diameter ranged from 0.3 to 0.7 inches among the four thinning treatments, while the increase in quadratic mean diameter averaged 0.4 inches in the unthinned control. Minor statistical differences in quadratic mean diameter among the four thinning treatments that existed immediately after thinning disappeared by the end of the third year after thinning.

DIAMETER GROWTH

By the end of the second year after thinning and continuing through the end of the third year, cumulative diameter growth of residual trees increased significantly following all four thinning treatments, when averaged across all trees of all species (table 3). In fact, the rate of diameter growth of residual trees after all thinning treatments was nearly double that of trees in the unthinned control. However, we detected no significant differences in diameter growth among the four thinning treatments during any of the first 3 years after thinning.

To focus the analysis on the more valuable trees in the stand, we separated the diameter growth response data into two species groups: red oak and sweetgum. Through the end of the third year after thinning, we were unable to detect significant differences in cumulative diameter growth among treatments within either the red oak group or sweetgum (fig. 2).

Because most red oaks typically respond quickly to thinning, it was surprising to find no significant differences in cumulative diameter growth among treatments within the red oak group through the first 3 years after thinning (fig. 2). Wide variation in diameter growth response of red oaks within some treatments may have prevented the detection of significant differences. However, cumulative diameter growth of residual red oaks following AccSupP thinning (0.67 inches) was nearly identical to that of residual red oaks following DesSupP thinning (0.68 inches). Both thinning treatments retained superior poletimber stock trees in addition to sawtimber trees specific to each treatment. The same trend was found for cumulative diameter growth of residual red oaks in the AccNoPole and DesNoPole thinning treatments (0.91 inches for both treatments). Both thinning treatments retained only those sawtimber trees specific to each treatment; all poletimber trees were removed during thinning. Although thinning treatments did not significantly increase diameter growth of residual red oaks, relative to red oaks in the unthinned control, diameter growth responses to the AccNoPole and DesNoPole thinning treatments were strong and may produce significant increases in the near future.

Clearly, residual sweetgum trees did not benefit from any of the thinning treatments (fig. 2). Increased diameter growth by sweetgum, in response to thinning, often is delayed while the tree expands its crown to take advantage of the additional growing space and other resources generated by the thinning operation. This response is particularly common among sweetgum trees that are weak codominants, as was the situation in this study prior to thinning. We anticipate that the diameter growth response of residual sweetgum trees will improve in the near future.

PRODUCTION OF EPICORMIC BRANCHES

Thinning operations in hardwood stands sometimes have adverse effects on bole quality of residual trees. New epicormic branches may develop along the merchantable boles of residual trees during the first few years after thinning. Epicormic branches are adventitious twigs that develop from dormant buds along the bole (Brown and Kormanik 1970). Standard grading rules for hardwood factory logs stipulate that epicormic branches greater than 3/8 inches in diameter at the bark surface are defects on logs of all sizes, grades, and species (Rast and others 1973). Meadows and Burkhardt (2001) surmised that, in general, as few as five epicormic branches, somewhat evenly distributed along a 16-foot-long hardwood log, may reduce the grade of that log. Because epicormic branches greater than 3/8 inches in basal diameter produce defects in the underlying wood, their presence also may reduce both lumber grade and value. Consequently, production of epicormic branches along the merchantable boles of residual trees may become a serious problem associated with thinning in hardwood stands.

Meadows (1995) hypothesized that tree health controls the release of dormant buds that develop into epicormic branches, such that healthy, upper-crown-class trees are much less likely to produce epicormic branches than are unhealthy, lower-crown-class trees. Consequently, thinning prescriptions that retain healthy sawtimber trees and remove unhealthy sawtimber trees, as well as most poletimber trees, can minimize production of new epicormic branches in most hardwood stands. In contrast, thinning prescriptions that fail to retain healthy trees may result in the development of numerous epicormic branches along the boles of residual trees.

To assess the impact of thinning on epicormic branch production, we counted the number of large epicormic branches on the 16-foot-long butt log of all residual trees immediately after thinning and at the end of each of the first 3 years after thinning. We defined large epicormic branches as those branches greater than 3/8 inches in basal diameter.

When averaged across all trees of all species, the four thinning treatments had no significant effects on the number of large epicormic branches on the butt logs of residual trees at the end of each of the first 3 years after thinning (table 4). Immediately after thinning, however, residual trees in these four treatments actually had significantly fewer large epicormic branches than did trees in the unthinned control. Because the prescriptions evaluated in this study are based on tree quality and tree health, trees with numerous epicormic branches prior to thinning generally were removed from the stand during the thinning operation. Trees with no epicormic branches and trees with few epicormic branches generally were retained, thus effectively reducing the mean number of large epicormic branches on residual trees immediately after each of the four thinning treatments. During the first 3 years after thinning, the number of large epicormic branches on the butt logs of residual trees in thinned plots increased gradually, to the extent that there no longer are significant differences in the number of large epicormic branches between each of the four thinning treatments and the unthinned control. This same pattern was observed in thinning studies based on stand density management (Meadows and Goelz 2002, Meadows and Skojac 2006). In those studies, the number of epicormic branches on residual trees increased steadily for the first 3 years after thinning, remained stable for the next several years, and then declined slowly. Results in this study followed the same trend, at least through the first 3 years after thinning.

Because hardwood species vary widely in their susceptibility to the production of epicormic branches (Meadows 1995), data were partitioned by species groups: red oak and sweetgum (table 5). Meadows (1995) classified water oak, willow oak, and sweetgum as highly susceptible to the production of epicormic branches, but classified cherrybark oak as only moderately susceptible. However, none of the four thinning treatments had a significant effect on the number of large epicormic branches on the butt logs of residual red oaks or sweetgum by the end of the third year after thinning. Residual red oaks averaged fewer than two large epicormic branches on the butt log, while residual sweetgum trees averaged less than one large epicormic branch on the butt log, regardless of treatment.

Yet, there often is a proliferation of epicormic branches along the boles of hardwood trees in response to thinning (Stubbs 1986, Ward 1966). We believe the reason this proliferation of epicormic branches did not occur in this study is because our thinning prescriptions are based on stand quality management, which places strong emphasis on retention of healthy, high-quality trees. Our prescriptions did not force us to leave unhealthy, low-quality trees simply to maintain a target residual stand density, which would have been required if our prescriptions were based on stand density management. Because healthy trees are much less likely to produce epicormic branches than are unhealthy trees, retention of healthy, high-quality trees, even of susceptible species like red oak and sweetgum, minimized the production of epicormic branches in response to the four thinning treatments evaluated in this study.

Based on the general rule that as few as five epicormic branches on a 16-foot-long hardwood log may reduce the grade of that log (Meadows and Burkhardt 2001), we expect that the number of large epicormic branches observed on residual red oak and sweetgum trees in this study will not result in log grade reductions. We also anticipate that there will be no reductions in timber value or lumber value associated with epicormic branches. Previous research indicates that production of epicormic branches generally ceases by the end of the third year after thinning and the number of branches usually stabilizes after that (Meadows and Goelz 2002, Meadows and Skojac 2006). Thus, it is unlikely that significantly more epicormic branches will be produced on residual trees in the near future. Rather, it is likely that the number of epicormic branches on residual trees will remain relatively stable for the next several years. Consequently, it is clear that our stand quality management prescriptions minimized production of epicormic branches and had no adverse effects on bole quality of residual trees.

PRELIMINARY REMARKS

Generally, 3 years is not long enough to draw definitive conclusions about a thinning study. So, we offer the following preliminary remarks for consideration:

1. Diameter growth of residual trees increased significantly following all four thinning prescriptions, when averaged across all trees of all species. However, we were unable to detect significant differences among treatments in cumulative diameter growth of red oaks.

2. Thinning had little or no effect on the number of large epicormic branches on the butt logs of residual trees, even among red oak species that are moderately to highly susceptible to production of epicormic branches.

3. Statistically, it does not appear that thinning benefitted residual red oaks after 3 years. However, diameter growth of residual red oaks in the AccNoPole and DesNoPole prescriptions is vigorous, while epicormic branch production across all four thinning prescriptions has been negligible.

ACKNOWLEDGMENTS

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Table 1—Treatment means (± SE) for stand conditions immediately after application of five thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p < 0.01 for all variables)

Treatment	Trees	Basal area	Quadratic mean diameter	Stocking
	no./ac	ft^2/ac	inches	%
Unthinned Control	93 ± 14 a	108 ± 7 a	14.8 ± 0.7 c	89 ± 7 a
Acceptable/Superior	29 ± 2 b	69 ± 8 b	20.6 ± 0.5 ab	54 ± 6 b
Acceptable/No Pole	28 ± 2 b	61 ± 3 b	20.2 ± 1.0 ab	48 ± 2 b
Desirable/Superior	26 ± 3 b	57 ± 11 b	19.9 ± 1.0 b	45 ± 9 b
Desirable/No Pole	18 ± 2 b	48 ± 3 b	22.0 ± 0.3 a	37 ± 3 b

Table 2—Treatment means (± SE) for stand conditions 3 years after application of five thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p < 0.01 for all variables)

Treatment	Trees	Basal area	Quadratic mean diameter	Stocking
	no./ac	ft^2/ac	inches	%
Unthinned Control	91 ± 13 a	112 ± 6 a	15.2 ± 0.7 b	92 ± 6 a
Acceptable/Superior	28 ± 2 b	68 ± 6 b	20.9 ± 0.4 a	53 ± 5 b
Acceptable/No Pole	27 ± 2 b	64 ± 2 b	20.9 ± 1.1 a	50 ± 2 b
Desirable/Superior	25 ± 3 b	59 ± 11 b	20.5 ± 1.0 a	46 ± 8 b
Desirable/No Pole	18 ± 2 b	51 ± 4 b	22.7 ± 0.3 a	39 ± 3 b

Table 3—Cumulative diameter growth (± SE) of residual trees 1, 2, and 3 years after application of five thinning treatments. Means within each year followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p = 0.12 for year 1, p = 0.03 for year 2, p = 0.01 for year 3)

Treatment	Years after thinning 1	2	3
	---- inches ----		
Unthinned Control	0.12 ± 0.01 a	0.22 ± 0.02 b	0.33 ± 0.02 b
Acceptable/Superior	0.18 ± 0.03 a	0.43 ± 0.07 a	0.59 ± 0.07 a
Acceptable/No Pole	0.17 ± 0.02 a	0.43 ± 0.05 a	0.62 ± 0.07 a
Desirable/Superior	0.15 ± 0.01 a	0.38 ± 0.02 a	0.56 ± 0.02 a
Desirable/No Pole	0.19 ± 0.01 a	0.48 ± 0.04 a	0.69 ± 0.06 a

Table 4—Number (± SE) of large epicormic branches found on the butt logs of residual trees immediately after thinning (year 0) and 1, 2, and 3 years after application of five thinning treatments. Means within each year followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p < 0.01 for year 0, p = 0.17 for year 1, p = 0.30 for year 2, p = 0.46 for year 3)

	Years after thinning			
Treatment	0	1	2	3
Unthinned Control	1.3 ± 0.2 a	1.3 ± 0.2 a	1.3 ± 0.3 a	1.2 ± 0.2 a
Acceptable/Superior	0.4 ± 0.2 b	0.7 ± 0.4 a	0.7 ± 0.4 a	1.1 ± 0.6 a
Acceptable/No Pole	0.4 ± 0.1 b	0.9 ± 0.1 a	1.0 ± 0.1 a	1.3 ± 0.1 a
Desirable/Superior	0.2 ± 0.1 b	0.7 ± 0.3 a	0.8 ± 0.3 a	1.2 ± 0.3 a
Desirable/No Pole	0.1 ± 0.1 b	0.2 ± 0.2 a	0.3 ± 0.2 a	0.4 ± 0.3 a

Table 5—Number (± SE) of large epicormic branches found on the butt logs of residual trees, by species group, 3 years after application of five thinning treatments. Means within each species group followed by the same letter are not significantly different at the 0.05 level of probability (n = 3 per treatment; p = 0.09 for red oak, p = 0.54 for sweetgum)

	Species group	
Treatment	Red oak	Sweetgum
Unthinned Control	0.7 ± 0.1 a	0.7 ± 0.1 a
Acceptable/Superior	1.6 ± 0.6 a	0.9 ± 0.7 a
Acceptable/No Pole	1.2 ± 0.3 a	0.2 ± 0.2 a
Desirable/Superior	1.9 ± 0.6 a	0.3 ± 0.3 a
Desirable/No Pole	0.1 ± 0.1 a	0.6 ± 0.1 a

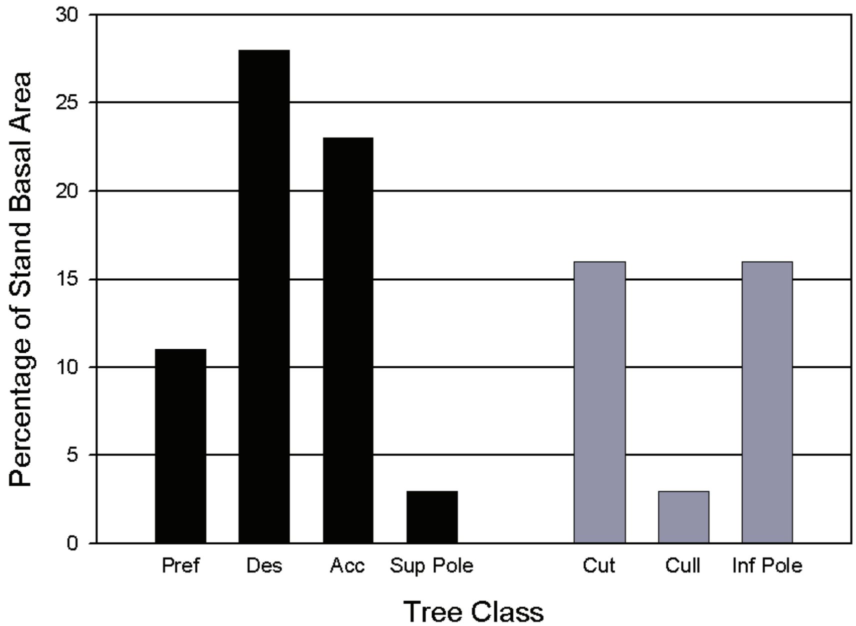

Figure 1—Tree class distribution, expressed as the percentage of stand basal area in each tree class, prior to application of five thinning treatments.

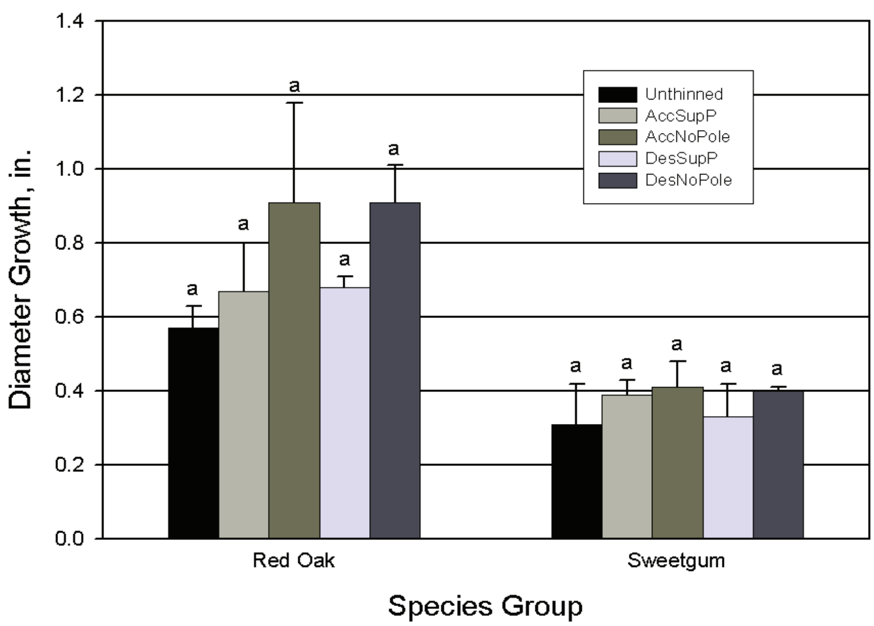

Figure 2—Cumulative diameter growth (± SE) of residual trees, by species group, 3 years after application of five thinning treatments. Means within each species group followed by the same letter are not significantly different at the 0.05 level of probability ($n = 3$ per treatment; $p = 0.45$ for red oak, $p = 0.89$ for sweetgum).

PRESCRIBED BURNING COST RECOVERY ANALYSIS ON NONINDUSTRIAL PRIVATE FORESTLAND IN NORTH CAROLINA

Ronald J. Myers, William Powell, and Mark Megalos

ABSTRACT

A statewide internal analysis of prescribed burning costs was conducted by the North Carolina Division of Forest Resources (NCDFR) in 2008 to examine the regional differences of site preparation and silvicultural burning costs, and to determine which components were most responsible for losses or gains. This study analyzed actual costs for 90 site preparation (2,559 acres) and 76 silvicultural burns (3,932 acres) conducted across North Carolina in 2008.

Summary statistics revealed that NCDFR incurred a net loss/acre statewide on both types of prescribed burning. Silvicultural prescribed burns resulted in a smaller loss (-$7/acre) than site preparation burning (-$11/acre). Losses resulting from construction and patrolling fire lines were higher for site preparation burns (-$425/mile) than for silvicultural burns (-$317/mile). Recommendations were sent to agency administrators to revise rates to recover expenses while continuing to provide prescribed burning services at the lowest-possible cost to nonindustrial private forest nonindustrial private forest (NIPF) landowners

Keywords: prescribed burning, site preparation, silvicultural burning, cost recovery analysis, NIPF landowners.

INTRODUCTION

Prescribed burning is a cost effective silvicultural treatment for NIPF landowners to improve forest health conditions, control non-native invasive (NNI) species, enhance wildlife habitat, and restore forest functions (Lotti 1960, Dubois 1995). In the recent past, government agencies and forest industry were responsible for most prescribed burning. Low cost prescribed burning was conducted for a variety of purposes. However, the low rates that were charged didn't always capture the actual prescribed burning costs. New requests and interest in prescribed burning have increased the demand for prescribed burning. Private burning contractors are often willing to meet this new demand provided they can profitably recover costs of burning- while remaining competitive to agency pricing.

In North Carolina, the State's Division of Forest Resources (NCDFR) internal policy allows for a burning charge sufficient to cover agency costs while encouraging participation by private contractors. With the exception of frequent regional costs data published in the Forest Farmer magazine and subsequent manuals; very few research papers document prescribed burning costs (Dubois et. al. 2001, Vasievich 1981, Cleaves 1997). The purpose of this study is to share prescribed burning cost information for use and consideration by practitioners, government agencies, and natural resource management organizations. Timely evaluation and identification of the key components influencing NCDFR's prescribed burning cost should allow for proper rate structures and profitable burning by independent contractors.

METHODS

Data for this study was collected from 166 NCDFR forestation job reports from 13 district headquarters located in 3 administrative units that correspond to the mountain, piedmont, and coastal plain physiographical regions. Cost data from 90 site preparation burns (2,559 acres) and 76 silvicultural burns (3,932 acres) were analyzed. Job report information included personnel labor costs, vehicle costs for transport and support, and fuel costs. Personnel hourly labor rates were calculated from a midpoint salary level by position and adding related indirect benefit costs. Equipment expenses included fire suppression rate schedule for trucks, hauling units, crawler tractors, and support vehicles. A tractor plow costs were calculated from tachometer hour rate specific to the tractor type/ size reported on the fire job report.

Prescribed burning costs were summarized in two ways: 1) the total cost, and 2) the fireline construction total cost (which included patrolling cost). Prescribed burning income was calculated from invoices, job reports, and signed contracts with current rates for prescribed burning by physiographical region, acre/size class, minimum acreage charge, type of prescribed burn, and equipment rate per mile used for fireline construction plus any surcharge or overhead fees. A $100 per burn surcharge was applied when equipment was used for line patrolling. The profit or loss per acre was derived by subtracting burn expenses from income generated. Further analysis was conducted across prescribed burning type and physiographical region. For this

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study, silvicultural burning includes any in-stand burning for the purpose of forest health, habitat improvement, and fuel mitigation.

RESULTS AND DISCUSSION

SITE PREPARATION BURNING

Average site preparation burning costs ($36.51) were nearly double those costs/acre of silvicultural burns ($19.87) statewide (Tables 1 and 3). The mean site preparation burning costs/acre were higher for the mountain region at $61.90 compared to $31.57 for the piedmont region and $16.07 for the coastal plain region (Table 1). Personnel labor costs were greatest in the mountain region averaging(12.99 hours/acre), whereas piedmont mean labor hours/acre were 1.28, and 0.58 for the mountain regions respectively (Table1). Higher personnel labor costs for the mountains were likely a result of topographical constraints on equipment, excessive number of personnel on smaller burn units, and training new personnel. Site preparation burning resulted in a (-$10.91) loss per acre statewide. Only the coastal plain region operated at a profit/acre of $5.48 while piedmont and the mountain regions had losses of (-$6.80) and (-$31.41) respectively (Table 1). The mountain region site preparation burning loss/acre was nearly triple the statewide average. Additional analysis for site preparation burns in the mountain region showed a mean loss/acre of (-$34.78) for tracts less than 40 acres, and (-$117.01) for tracts that were less than 20 acres. Unit size was shown to have a great influence on per acre cost.

SILVICULTURAL BURNING

Silvicultural burning resulted in lower mean costs/acre than site preparation burning, yet still resulted in a (-$7.25) loss/acre. The mean labor hours/acre was highest in the mountain region (8.13) and declined greatly for the, piedmont(1.06hours/acre) and coastal plain(0.62 hours/acre) regions (Table 3). The mean labor hours/acre for silvicultural burning statewide was 3.78 hours compared with 4.95 hours for site preparation burning. The mean silvicultural burning costs/acre was greatest in the mountain region, $35.98 compared to $16.01 for the piedmont and $7.63 for the coastal plain region (Table 3). Similarly, only the coastal plain region was profitable ($9.88/acre) while piedmont and the mountain regions had losses of (-$6.13) and (-$25.50), respectively (Table 3).

FIRELINE CONSTRUCTION AND PATROLLING

Analysis of total fireline costs/mile was conducted by examining line construction costs and patrolling costs, separately and in combination. Statewide, fireline construction and patrolling costs resulted in a loss/mile for all of the fireline components for site preparation and silvicultural burning. The total mean cost/mile of fireline installment was $746.60 for site preparation burning and $582.44 for silvicultural burning. The total cost of fireline construction resulted in a loss/mile (-$424.60) for site preparation and (-$317.48) for silvicultural burning when averaged across the state.

Total fireline construction costs/mile was similar for site preparation and silvicultural prescribed burning at $513.26/mile. Statewide patrolling costs were highest for site preparation burning, averaging $140.76 costs/mile while silvicultural patrolling costs were much less($36.51/mile). Line construction and patrolling costs were generally lower for the mountain region largely due to the reliance on personnel rather than more costly heavy equipment.

The total line construction and patrolling costs for site preparation burning were very similar for both the piedmont and coastal plain regions (Table 2). The piedmont region has the highest mean costs/mile of fireline for site preparation burning at $861.80/mile resulting in the highest loss/mile of fireline installation (-$526.70/mile) for all three regions. This loss/mile of fireline installment for site preparation was approximately twice the amount reported for the mountain region at (-$260.20). This is the result of a greater total miles of fireline installed during site preparation burning in the piedmont and a higher number of hours patrolling firelines with heavy equipment. Patrolling accounted for approximately 41% of the total equipment tachometer hours for both the coastal plain and piedmont regions for site preparation burning.

The piedmont region has the highest mean costs/mile for total fireline costs for silvicultural burning at $672.42/mile resulting in the highest loss/mile for total fireline installation (-$401.30/mile) for all three regions (Table 4). Mountain and coastal plain regions were able to conduct line patrolling during silvicultural burning without a loss per mile, while the piedmont region lost $64.51/mile. The total fireline costs for silvicultural burning in the piedmont region was approximately twice the costs for the other two regions.

CONCLUSIONS

The coastal plain region was the only geographical region able to conduct prescribed burning without a net loss/acre. Our analysis indicated that the current burning rate structure failed to recover operating costs statewide. Armed with this new information, NCDFR administrators were able to institute a simplified burning rate schedule that appropriately recovered costs. Regional equipment rates for fireline construction are currently based on actual equipment tachometer hours of operation and no longer billed by the mile. This allows for the recovery of the equipment operating costs for fireline construction and patrolling. Line patrolling by heavy equipment had a deleterious impact on fireline cost effectiveness even with a surcharge in place.

Fireline construction rates did not recover the actual operating costs of equipment used when billed by the mile.

Fireline construction and patrolling costs were significant component of site preparation and silvicultural burning. Heavy equipment patrolling led to higher losses/mile especially when not monitored to minimize costs. Other equipment alternatives should be considered for use when patrolling, especially on less intensive silvicultural burning. Diligent fire managers need to properly plan personnel staffing to conduct the prescribed burns safely and cost effectively, while training new personnel. Prescribed burning costs and charging rates should be periodically reviewed to assess real costs and recovery charges. This will facilitate private burning contractor competition without the specter of subsidized agency cost overruns.

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Table 1—Personnel labor summary for site preparation burning in NC by geographic region

	Coastal Plain	Piedmont	Mountains	Statewide
Total # burns	17	44	29	90
Total acres burned	879	1191.5	489	2559.5
Mean acres/burn	51.7	27.1	16.9	28.43
Mean labor hrs/ac	0.58	1.28	12.99	4.95
Mean income/ac	21.55	24.77	30.49	25.60
Mean costs/ac	16.07	31.57	61.90	36.51
Profit/loss per acre	5.48	-6.80	-31.41	-10.91

Table 2—Fireline summary statistics for site preparation burning in NC by geographic region

	Coastal Plain	Piedmont	Mountains	Statewide
		Line construction		
Mean cost/mile	609.78	656.08	556.03	513.26
Profit/loss per mile	-410	-416	-286	-372
		Line patrolling		
Hrs. patrolling	33.5	99.2	15.5	148
Mean costs/mile	168.11	196.98	44.20	140.76
Profit/loss per mile	-78.96	-99.32	26.67	-54.57
		Total Fireline		
Total miles fireline	17.5	43	30	90.5
Mean income/mile	290.90	335.10	340	321.90
Mean cost/mile	777.90	861.80	600.20	746.60
Profit/loss per mile	-487.00	-526.70	-260.20	-424.60

Table 3—Personnel labor summary for silvicultural burning in NC by geographic region

	Coastal Plain	Piedmont	Mountains	Statewide
Total # of burns	21	34	21	76
Total acres burned	1829	1493	610	3932
Mean acres/burn	87	44	29	51.7
Mean labor hrs/ac	0.62	1.06	8.13	3.78
Mean income/ac	8.75	9.87	10.48	12.62
Mean costs/ac	7.63	16.01	35.98	19.87
Profit/loss per acre	9.88	-6.13	-25.50	-7.25

Table 4—Fireline summary statistics for silvicultural burning in NC by geographic region

	Coastal Plain	Piedmont	Mountains	Statewide
		Line construction		
Mean cost/mile	504.85	532.94	487.23	513.26
Profit/loss per mile	-333	-331	-228	-304
		Line patrolling		
Hrs. patrolling	9	51	8	68
Mean costs/mile	38.32	139.46	38.28	87.18
Profit/loss per mile	28.35	-64.51	28.39	-13.10
		Total Fireline		
Total miles fireline	18	31.50	18	67.50
Mean income/mile	325.56	271.11	325.55	282.96
Mean cost/mile	525.55	672.42	525.55	600.44
Profit/loss per mile	-200	-401.3	-199.9	-317.48

WHOLE-CANOPY GAS EXCHANGE AMONG FOUR ELITE LOBLOLLY PINE SEED SOURCES PLANTED IN THE WESTERN GULF REGION

Bradley S. Osbon, Michael A. Blazier, Michael C. Tyree, and Mary Anne Sword-Sayer

Planting of artificially selected, improved seedlings has led to large increases in productivity of intensively managed loblolly pine (*Pinus taeda* L.) forests in the southeastern United States. However, more data are needed to give a deeper understanding of how physiology and crown architecture affect productivity of diverse genotypes. The objective of this study was to gain an understanding of whole-canopy gas exchange and crown architecture characteristics that govern productivity of four rapid-growing loblolly pine seed sources.

Four seed sources of loblolly pine were planted in 0.15-acre plots at the LSU AgCenter Hill Farm Research Station in northwest Louisiana in January 2005. Each seed source was replicated 12 times in a randomized complete block design. Soil type was used as the blocking factor. The soils are USDA NCRS Sacul series, which is a very fine sandy loam with shallow clay subsoil, and Wolfpen series, which is a loamy fine sand with deep clay subsoil. All seed sources were from the eastern portion of the loblolly pine range. Two of the seed sources were of open-pollinated half-sib families (7-56 and 8-103), and two seed sources were clones (93 and 9).

Light compensation point (LCP), light saturated photosynthesis (Asat), and daytime dark respiration (Rd) were calculated from photosynthesis light response curves with a LI-6400 portable photosynthesis system (LI-COR, Lincoln, NE) between August 4 and September 9, 2009. These variables were measured on two needles sampled from the first foliage flushes of 2008 and 2009 in the upper-mid crown section from one tree per plot.

A destructive harvest was conducted in mid-September 2009 to obtain the crown architecture characteristics of each seed source. Six trees for each seed source were harvested, and the aboveground tissue was separated into stem, branch and foliage. Foliage was also separated by year of production. The variables measured for each seed source included: the ratio of foliage weight to branch weight, the ratio of branch weight to stem weight, and the average branch diameter (Table 1). Specific leaf area (SLA) was also measured on 4 subsamples per foliage flush on each destructively harvested tree. Site-specific non-linear regression equations that predicted foliage, branch, and stem dry weights from tree total height and dbh were created from the destructively harvested trees. Tree height and diameter at breast height (dbh) measurements of the trees on which LCP, Asat, and Rd were measured were used as inputs in the regression equations to estimate the trees' foliage weight. Crown leaf area (CLA) was then estimated for each of the trees by multiplying average SLA obtained for each seed source from the destructively harvested trees by foliage dry weight estimated from the regression equations. Crown-level Asat and Rd were estimated from multiplying CLA by the leaf level measurements.

Significant differences were found among seed sources in LCP, Asat, Rd, and crown leaf area (Figure 1). Light compensation point was higher for 93 than 9 in 2008 foliage, whereas no differences in LCP among families was found in 2009 foliage (Figure 1A). Crown-level Asat in 2008 foliage was greatest in 93, and Asat of 7-56 exceeded that of 9 and 8-103. In 2009 foliage 93 and 7-56 had the greatest crown Asat, and Asat of 9 was greater than that of 8-103 (Figure 1B). Trends among seed sources in crown-level Rd in 2008 and 2009 foliage were similar to those of Asat (Figure 1C). Crown leaf area in 2008 foliage of 93 and 7-56 were greater than that of 9 and 8-103; trends in leaf area of 2009 foliage among seed sources were identical to that observed for Asat in 2009 foliage (Figure 1D).

Clone 93 and family 7-56 have a higher crown-level leaf area and photosynthetic capacity than clone 9 and family 8-103 (Figure 1), but 93 and 7-56 have different presentations of leaf area (Table 1). Family 7-56 has a

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higher proportion of branches to stem and larger branch diameter (Table 1). Meanwhile, clone 93 has a higher amount of foliage per branch, smaller branch diameter, and fewer branches per stem (Table 1). Thus, while 7-56 and 93 had the highest potential for biomass production as inferred by their relatively high Asat and CLA, the tendency of 93 to have a crown form with fewer branches and branches smaller in diameter would likely lead to greater yields of trees of top grade.

Table 1—Crown architecture characteristics of four loblolly pine seed sources at the LSU AgCenter Hill Farm Research Station in northwest Louisiana

Seed Source	Foliage Weight : Branch Weight	Branch Weight : Stem Weight	Average Branch Diameter (cm)
7-56	1.18 c	0.78 a	1.42 a
8-103	1.23 bc	0.55 bc	1.24 ab
9	1.56 ab	0.59 ab	1.22 ab
93	1.66 a	0.33 c	1.02 b

NOTE: Seed sources 7-56 and 8-103 are half-sib families, and 9 and 93 are clonal varieties. Means within columns differ at P < 0.05.

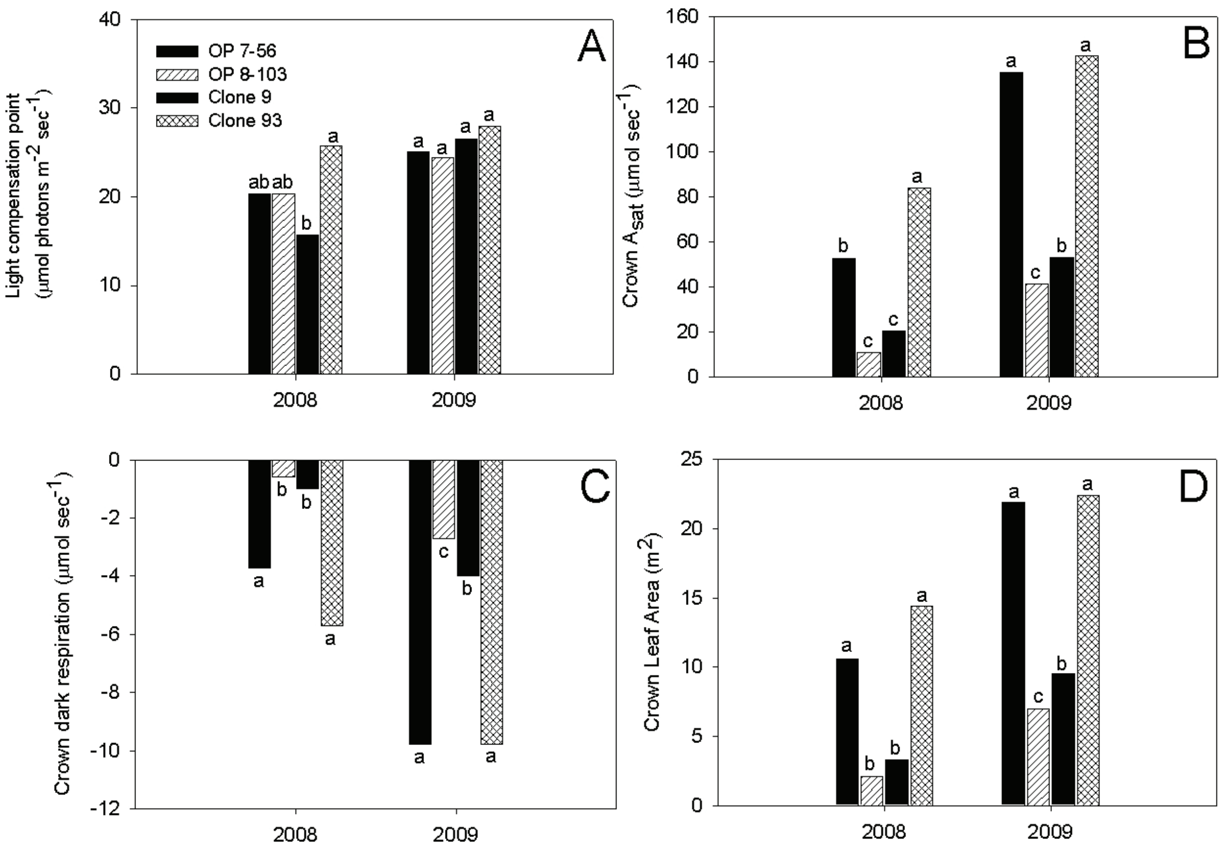

Figure 1—Leaf-level light compensation point (A) and crown-level Asat (B), daytime dark respiration (C), and leaf area (D) measured for first flushes of foliage produced in 2008 and 2009 of four loblolly pine seed sources at the LSU AgCenter Hill Farm Research Station in northwest Louisiana. Seed sources 7-56 and 8-103 are half-sib families, and 9 and 93 are clonal varieties. For each variable and foliage flush, bars headed by different letter differ at P < 0.05.

LONG AND SHORT TERM CHANGES IN THE FORESTS OF THE CUMBERLAND PLATEAU AND MOUNTAINS USING LARGE SCALE FOREST INVENTORY DATA

Christopher M. Oswalt and Andrew J. Hartsell

ABSTRACT

The Cumberland Plateau and Mountains (CPM) are a significant component of the eastern deciduous forest with biological and cultural resources strongly connected to and dependent upon the forest resources of the region. As a result, continuous inventory and monitoring is critical. The USDA Forest Service Forest Inventory and Analysis (FIA) program has been collecting data within the region since the 1950's, and provides a valuable resource for tracking the status of the CPM forests. Using two different datasets derived from large scale inventories within the region, both historical trends and short-term changes are analyzed. Across the CPM region, timberland has experienced less than a 1 percent decline from the early 1950's to present. Concomitantly, the CPM region has experienced a significant increase in standing growing stock volume. Volume estimates have increased between 100 and 200 percent across the region since the late 1960's and early 1970's. The CPM region currently contains an estimated 9.8 million acres of forest land and 18.2 billion cubic feet of volume. Both long-term and short-term changes indicate a stable forestland base within the region. While forests have shifted within the region from one forest type to another, the CPM continues to be dominated by natural hardwood forests.

INTRODUCTION

The Cumberland Plateau and Mountains (CPM) together, are a significant component of the Eastern Deciduous Forest. The CPM is rich with biological and cultural resources strongly connected to and dependent upon the forest resources of this region. As a result, continuous inventory and monitoring is critical to a forest land base being managed by and whose future condition is being influenced by multiple competing interests. The availability of systematically collected and unbiased forest information for forest land owners, managers and local, regional and state policymakers is essential to make sound scientifically based decisions regarding the forest resources of the region. The USDA Forest Service Forest Inventory and Analysis (FIA) program has been collecting data on CPM forests since the 1950s, and provides a valuable resource for tracking the status of these forests. The FIA program provides for the assessment of both long- and short-term changes to the CPM forests.

Of particular interest are recent inferences drawn from analyses conducted using fine-scale remotely-sensed data. McGrath and others (2004) concluded that the Cumberland Plateau forests "have been undergoing increasingly rapid rates of hardwood-to-pine conversions." Evans and others (2002) stated that the area has experienced "massive alteration of habitat at the landscape level." In addition to monitoring the forest resources of the CPM region, using broad-scale inventory data from the FIA program we are uniquely positioned to address these suppositions through the use of high-quality, robust data collected systematically across the entire area.

Specifically this paper addresses the following questions: 1) what are the general long-term trends in the forest resource across the Cumberland Plateau and Mountains area? 2) What are the general short-trends in the forest resource across the Cumberland Plateau and Mountains? 3) What, if any, changes have occurred in forest types on the Cumberland Plateau and Cumberland Mountains? 4) Has the overall footprint of planted forests (plantations) changed between 1990 and 2005?

METHODS

BROAD-SCALE INVENTORY

The FIA program is the primary source for information about the extent, condition, status and trends of forest resources across all ownerships in the United States (Smith and others 2002). FIA applies a nationally consistent sampling protocol using a quasi-systematic design covering all ownerships in the entire nation (Bechtold and Patterson 2005). FIA operates a multi-phase inventory based on an array of hexagons assigned to separate interpenetrating, non-overlapping annual sampling panels (Bechtold and Patterson 2005). In Phase 1, land area is stratified using aerial photography or classified satellite imagery to increase the precision of estimates using stratified estimation. In Phase 2, one permanent fixed-area plot is installed in each hexagon that contains accessible forest land and meets FIA specifications. Data are collected for more than 300 variables across multiple scales (e.g. plot, subplot, condition, and tree). Plot intensity for Phase 2 measurements is approximately one plot for every 6,000 acres of land (roughly 125,000 plots nationally).

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The plot design for FIA inventory plots consists of four 24.0 ft fixed-radius subplots spaced 120 ft apart in a triangular arrangement with one subplot in the center. All trees, with a diameter at breast height of at least 5 inches, are inventoried on forested subplots. Within each sub-plot, a 6.8 ft radius microplot offset 12 ft from sub-plot center is established. Within each microplot, all live tree seedlings are tallied according to species. Additionally, all trees with a d.b.h. between 1 and 5 inches are inventoried. Conifer seedlings must be at least 6 inches in height with a root collar diameter less than 1 inch. Hardwood seedlings must be at least 12 inches in height with a root collar diameter less than 1 inch.

DATA

All inventory data are made publicly accessible through the FIA database (FIADB). Data for this study were taken from the FIADB, version 3.0 (see Woudenberg and others 2010 for description of FIADB). The CPM was defined using Smalley's (1982) delineations. Two separate datasets were accumulated from data collected by the FIA program. The first dataset, hereafter referred to as historical data, was assembled based on all counties that contained the CPM region (Figure 1a) and was used for analyzing long-term trends of timberland area and growing stock volume. Historical data were available beginning in approximately the 1950s (Table 1). The second dataset, hereafter referred to as contemporary data, was assembled based on plots located within the CPM region (Figure 1b). Short-term, region-specific changes and the current status of the CPM forest resources were analyzed using data representing two points in time: 1990 and 2005 (Table 1). County-level data were necessary to examine long-term historical trends because most historical FIA data do not contain spatial information beyond the county of collection. Area of timberland and growing stock volume were used for long-term trend analysis because of the relative stability the variables offered.

ANALYSIS

Long-term trends were graphically assessed through comparison of both periodic and annual estimates across time. Statistical tests were not performed due to the variability in data collection and estimation procedures over such a long period of time. For short-term trends, we relied on comparisons of population estimates derived from the temporally indifferent estimators outlined by Bechtold and Patterson (2005). We compared two point-in-time estimates. We chose an end-point of 2005 because that represented the most current data when this analysis began. However, FIA has made great strides in making data available much faster recently and more recent data are now available for most states in the South. In addition to general trends in the forest resource, we were interested in shifts in forests types. To investigate temporal shifts in forest types across the CPM region, we calculated importance values (IVs) using frequency and dominance for each forest type and noted changes in rank from time 1 to time 2. We also identified significant changes in per acre basal area among forest types using simple analysis of variance (ANOVA) with Tukey mean seperation.

RESULTS

HISTORICAL DATA

Seventy counties (Alabama (19), Georgia (3), Kentucky (21), Tennessee (23) and Virginia (4)) contained significant portions of the CPM region based on visual observations. Across the 70-county region timberland (all forest land not withdrawn from timber production) declined an estimated 4 percent from the early 1960s to present (Figure 2).

The groups of counties within each of the 5 states that contain the CPM region have all experienced significant increases in standing growing stock volume. Volume estimates have increased approximately 93 percent across the region since the late 1960s and early 1970s (Figure 3). There have been greater increases in standing hardwood growing stock volume (125 percent increase) than softwood volume (15 percent increase). Significant declines in softwood growing stock volume occurred in the 1980s in Alabama, and in the late 1990s and early 2000s in Tennessee.

CONTEMPORARY DATA

In 1990 the CPM region was approximately 75 percent forested with an estimated 9.6 million acres of forest land (Table 2). According to the 2005 estimates, the region was 76 percent forested with an increase of approximately 260 thousand acres. In 2005 the Cumberland Mountains and Mid-, Northern, and Southern Cumberland Plateau regions, contained 1.5 million, 2.1 million, 3.1 million, and 3.2 million acres of forest land, respectively. The Cumberland Mountains and Mid-Cumberland Plateau experienced the largest gains in forest land area of over 100 thousand acres (9 and 6 percent, respectively). The Southern Cumberland Plateau gained approximately 80 thousand acres (3 percent) while the Northern Cumberland Plateau lost about 52 thousand acres (-2 percent).

While ownership patterns within the CPM region haven not significantly changed in the short-term between 1990 and 2005 (Table 2), changes in developmental stage (as approximated by FIA stand size class) have occurred. Across the CPM region the area of forest land represented by the large diameter stand size class has increased significantly (Figure 4). Area of large diameter stands increased approximately 22 percent while medium diameter declined 13 percent and small diameter stands declined 23 percent. The forests within the CPM region clearly are shifting to larger diameter stands.

Forest types across the CPM region, while having shifted slightly, largely remain dominated by hardwood species. Between 1990 and 2005, changes in forest type were primarily declines in area of softwood and mixed types with concomitant gains in many hardwood dominated types (Figure 5). Significant declines in per acre basal area were identified for the mixed upland hardwood, loblolly pine/hardwood, and mixed upland hardwood type in the Cumberland Mountains, Mid-Cumberland Plateau, and Northern Cumberland Plateau subregions, respectively (Table 3). Significant gains from 1990 to 2005 were identified for the white oak type in the Cumberland Mountains, the white oak/red oak/hickory and yellow-poplar/white oak/northern red oak types in the Mid-Cumberland Plateau subregion, the chestnut oak type in the Northern Cumberland Plateau subregion, and the loblolly pine and shortleaf pine/oak types in the Southern Cumberland Plateau subregion.

There were an estimated 610 thousand acres of planted forests in the CPM region in 1990. Approximately 69 percent of all planted forests in the region were found in the Southern Cumberland Plateau subregion. By 2005 there were an estimated 606 thousand acres of planted forests in the CPM region, an insignificant decline of 4 thousand acres. While an increase of 1 percent was observed in the Southern Cumberland Plateau subregion, over the entire CPM region, only 6 percent of forests were classified as having a planted stand origin in both 1990 and 2005 (Table 2).

DISCUSSION

The CPM is a region of the United States with considerable forest resource wealth and considered regionally and nationally important as an area with significant biodiversity (Clatterbuck and others 2006, Druckenbrod and others 2006, Dale and others 2009). Sustaining the forests of the CPM region with a high degree of ecological integrity is important to a wide array of stakeholders. Moreover, the forests of the CPM region are noted to provide support to unique species combinations and habitat (Buehler and others 2006). While changes are occurring, long- and short-term, within the forested systems of the CPM region, those changes have not resulted in any significant forest acreage loss to the region. While long-term trends, using historical FIA data, indicate that some losses in forest cover may have occurred between the 1950s and the mid- to late-2000s (4 percent decline in timberland), short-term trends indicate that the region may now be gaining forests. It is important to note that the historical data are based on place-in-time county-level estimates that included some areas not currently defined as the CPM region. In addition, historical FIA data did not include estimates of reserved forest area, only commercial forests or timberland. Direct comparison of current estimates of forest land area within the CPM with historical estimates is not possible.

The majority of forests in the region have been and are currently within private land holdings. Very little has changed with time with respect to broad scale ownership patterns. While the recent divestments of forest land by forest products companies has altered local ownership patterns in many cases, forests in the CPM region remain primarily in private hands. In fact, only ca. 13 percent of forest land within the CPM is owned by public institutions, similar to ownership patterns common in the eastern United States (Turner and others 2008, Hartsell and Johnson 2009, Oswalt and others 2009).

Some recent changes in the forests of the CPM region may present future challenges, particularly that many of the forests of the region are becoming older. Using stand size class as a proxy for developmental stage (Trani and others 2001, Franzreb and others 2011) the forests of the CPM region can be viewed as an aging resource. Over a 15-year period the region experienced significant declines in early successional habitat (small diameter stands) and habitat that could be classified as mid-successional (medium diameter stands). Concomitantly, the region has experienced significant gains in stands in the later stages of development that contain mostly large diameter trees. This shift with time illustrates an aging forest resource wherein younger stands are not being developed. This trend is not uncommon to forest of the eastern U.S. (Turner and others 2008, Hartsell and Johnson 2009, Oswalt and others 2009, Rose 2009) and can be viewed in temporal shifts of diameter class and age class distributions to older and larger age and size classes. An unbalanced distribution of developmental/successional stages across the CPM may point toward future challenges to sustaining the nature of the current forests matrix within the region.

Forests of the CPM region have been and continue to be dominated by hardwood forest types. Over the 15-year period between 1990 and 2005, forest types appeared to be relatively stable. Slight changes have occurred and largely reflect the impact of recent insect disturbances in the region. The outbreak of the southern pine beetle (*Dendroctonus frontalis* Zimmermann) between 1999 and 2002 has been well documented (see Oswalt and others 2009). That event resulted in a large degree of softwood mortality and subsequent shifts of the species composition of many forests in the region from softwood dominated or hardwood-softwood mixed stands to hardwood dominated stands. This trend is evident throughout the CPM with the exception of gains in importance and per acres basal area of the loblolly pine forest type in the Southern Cumberland Plateau.

While the loblolly pine forest type, native to the Southern Cumberland Plateau, has experienced some gains in the Southern Cumberland Plateau, such gains do not support the position that southern yellow pine plantations are replacing native hardwood forests of the CPM region at alarming rates. The FIA data collected across the region indicate a stable plantation population at nearly 6 percent of the forest land base. This information provides little support for the view that hardwood-to-pine conversion is a serious threat to the region at this time.

CONCLUSIONS

The forests of the CPM region have considerable ecologic and economic value. This forested resource, particularly with multiple competing interests, should continue to be monitored for changes that may warrant altered social behavior and/or management strategies. Currently, the forests of the region are highly productive and increasing in coverage. However, early successional forests are becoming more scarce. Presently, forests of the CPM region are thriving and hardwood dominated.

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Table 1—Inventory years with available data for each state in the Cumberland Plateau and Mountains (CPM) region

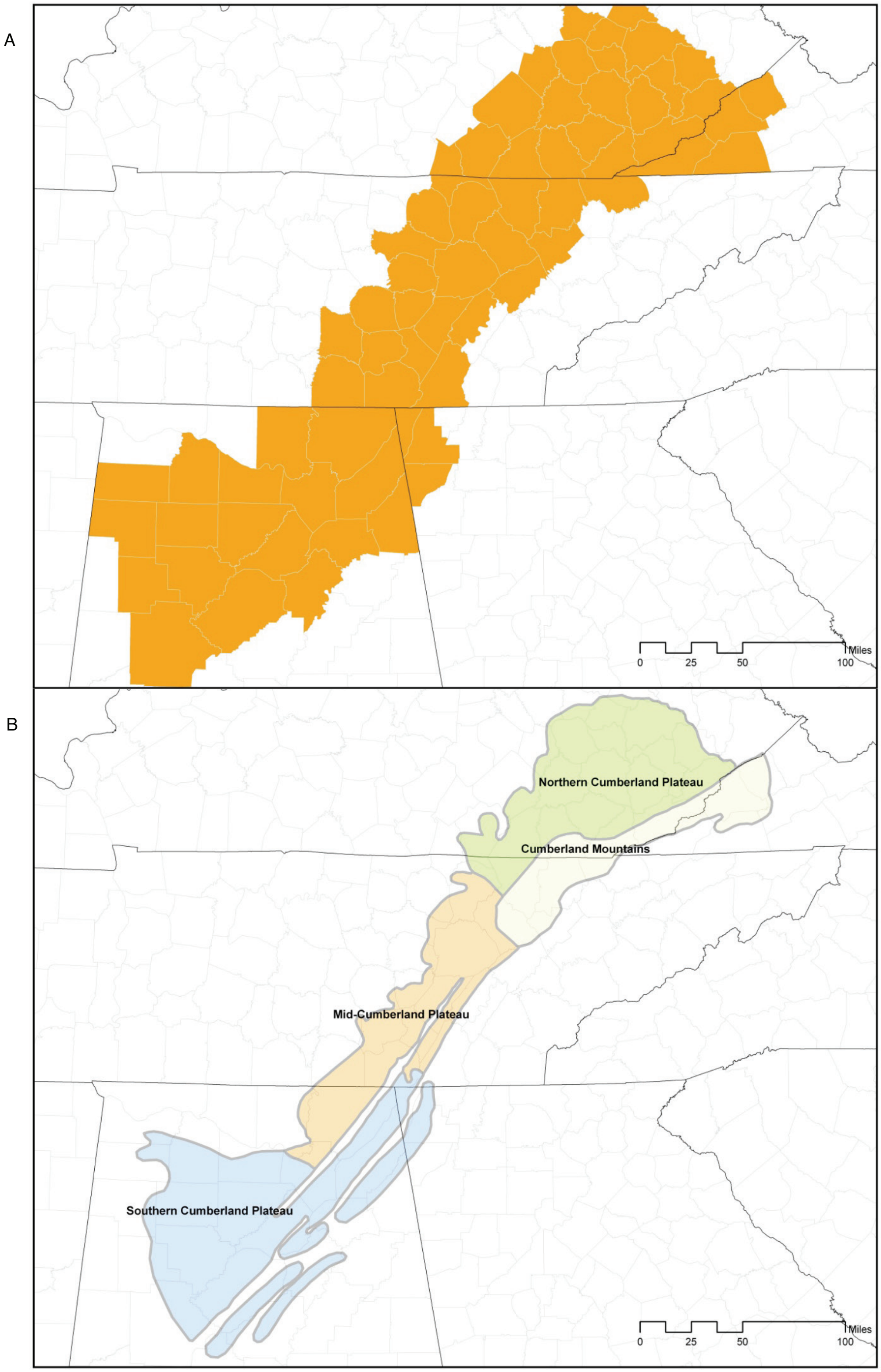
State	Historical Data	Contemporary Data	
		1990	2005
	Inventory year		
Alabama	1953, 1963, 1972, 1982, 1990, 2000, 2005	1990	2005
Georgia	1963, 1972, 1982, 1989, 1997, 2004	1989	2004
Kentucky	1949, 1963, 1975, 1988, 2004, 2005	1988	2005
Tennessee	1950, 1961, 1971, 1980, 1989, 1999, 2004, 2005	1989	2005
Virginia	1957, 1966, 1977, 1984, 1992, 2001, 2005	1992	2005

Table 2—Area of forest land by percent public or private ownership and percent planted origin for each subregion of the CPM region for 1990 and 2005

Year	Region	Forest land	Public	Private	Planted
		acres	*percent*		*percent*
1990	Cumberland Mountains	1,357,201	12	88	2
	Mid-Cumberland Plateau	2,011,473	10	90	5
	Northern Cumberland Plateau	3,121,808	21	79	2
	Southern Cumberland Plateau	3,108,798	5	95	14
	Total	9,599,281	13	87	6
2005	Cumberland Mountains	1,472,956	16	84	2
	Mid-Cumberland Plateau	2,128,964	11	89	4
	Northern Cumberland Plateau	3,069,523	22	78	1
	Southern Cumberland Plateau	3,188,282	10	90	15
	Total	9,859,725	15	85	6

Table 3—Mean basal area and associated standard error, calculated importance value and importance value rank for 1990 and 2005 along with change in basal area and associated p-value for statistical test of basal area change for each subregion of the CPM region

Region	Forest type	1990				2005				BA Change	P-value
		Basal area		IV	Rank	Basal area		IV	Rank		
		Mean	Stnd. Error			Mean	Stnd. Error				
Cumberland mountains	Eastern hemlock	131	-	0.06	7	181	28	0.07	6	50	
	Virginia pine	68	14	0.05	10	77	20	0.04	10	9	
	Eastern white pine/northern red oak/white ash	128	-	0.06	8	112	27	0.04	9	-16	
	Eastern red cedar/hardwood	34	9	0.02	13	3	-	0.00	14	-31	
	Shortleaf pine/oak	102	10	0.06	6	90	6	0.04	12	-12	
	Virginia pine/southern red oak	73	9	0.06	5	106	-	0.04	11	33	
	Chestnut oak	96	12	0.07	4	120	11	0.09	4	24	
	White oak/red oak/hickory	91	4	0.16	2	112	5	0.18	1	21	
	White oak	88	5	0.05	11	114	14	0.05	7	26	0.0028
	Northern red oak	96	38	0.04	12	95	18	0.05	8	-1	
	Yellow poplar/white oak/northern red oak	106	6	0.14	3	101	7	0.14	2	-5	
	Mixed Upland Hardwoods	94	5	0.19	1	75	7	0.13	3	-19	0.0254
	River birch/sycamore	-	-	0.00	14	76	-	0.03	13		
	Sugar maple/beech/yellow birch	85	7	0.05	9	117	11	0.09	5	32	
Mid-Cumberland Plateau	Eastern white pine/eastern hemlock	190	-	0.06	4	163	-	0.05	10	-27	
	Eastern hemlock	112	8	0.04	11	157	35	0.05	9	44	
	Loblolly pine	89	12	0.06	5	76	11	0.06	6	-13	
	Shortleaf pine	49	9	0.02	18	12	-	0.00	18	-37	
	Virginia pine	104	7	0.06	3	80	15	0.05	8	-24	
	Eastern white pine/northern red oak/white ash	87	6	0.03	15	145	59	0.05	11	57	
	Eastern red cedar/hardwood	87	20	0.03	14	96	2	0.04	13	9	
	Shortleaf pine/oak	104	6	0.05	7	94	20	0.03	14	-10	
	Virginia pine/southern red oak	91	9	0.06	2	94	10	0.06	7	3	
	Loblolly pine/hardwood	94	13	0.04	12	33	22	0.02	16	-62	0.0500
	Post oak/blackjack oak	57	33	0.02	16	70	5	0.03	15	13	
	Chestnut oak	113	5	0.04	9	109	13	0.06	5	-3	
	White oak/red oak/hickory	84	2	0.30	1	102	3	0.21	1	19	<0.0001
	White oak	83	6	0.04	10	134	44	0.08	3	52	
	Yellow poplar/white oak/northern red oak	75	7	0.05	8	108	10	0.07	4	32	0.0343
	Sweetgum/yellow poplar	45	21	0.02	17	78	18	0.04	12	33	
	Mixed Upland Hardwoods	91	7	0.05	6	78	8	0.08	2	-13	
	Sugarberry/hackberry/elm/green ash	103	53	0.03	13	38	5	0.01	17	-65	
Northern Cumberland Plateau	Eastern white pine	73	17	0.03	15	164	22	0.05	7	91	
	Eastern hemlock	60	2	0.02	16	145	40	0.05	9	85	
	Shortleaf pine	100	13	0.05	7	89	11	0.03	14	-11	
	Virginia pine	96	7	0.05	5	99	13	0.05	8	3	
	Pitch pine	84	26	0.03	13	18	-	0.01	19	-66	
	Eastern red cedar/hardwood	12	-	0.01	18	69	8	0.02	18	56	
	Shortleaf pine/oak	105	10	0.05	6	76	21	0.02	15	-29	
	Virginia pine/southern red oak	95	9	0.05	8	72	9	0.04	11	-23	
	Other pine/hardwood	74	13	0.03	14	66	19	0.02	16	-8	
	Post oak/blackjack oak	104	19	0.04	11	66	31	0.02	17	-38	
	Chestnut oak	90	6	0.06	4	115	9	0.06	6	25	0.0322
	White oak/red oak/hickory	91	4	0.09	2	101	3	0.18	1	10	
	White oak	85	6	0.05	9	100	4	0.08	4	15	
	Northern red oak	23	-	0.01	17	156	40	0.05	10	133	
	Yellow poplar/white oak/northern red oak	87	4	0.08	3	95	5	0.09	3	7	
	Sweetgum/yellow poplar	11	-	0.00	19	100	17	0.04	12	89	
	Mixed Upland Hardwoods	90	2	0.28	1	78	5	0.09	2	-12	0.0144
	River birch/sycamore	97	16	0.04	12	125	34	0.04	13	28	
	Sugar maple/beech/yellow birch	91	9	0.04	10	99	7	0.07	5	9	
Southern Cumberland Plateau	Longleaf pine	94	-	0.03	14	43	24	0.02	18	-51	
	Loblolly pine	82	4	0.14	2	100	5	0.14	1	18	0.0089
	Shortleaf pine	94	23	0.04	11	118	26	0.04	11	24	
	Virginia pine	80	6	0.06	4	98	7	0.07	4	18	
	Eastern redcedar/hardwood	97	-	0.03	13	107	10	0.04	16	10	
	Longleaf pine/oak	56	13	0.02	18	85	24	0.03	17	29	
	Shortleaf pine/oak	74	7	0.04	6	112	12	0.04	10	38	0.0079
	Virginia pine/southern red oak	82	7	0.05	5	70	7	0.05	9	-12	
	Loblolly pine/hardwood	72	5	0.08	3	80	8	0.08	3	8	
	Post oak/blackjack oak	114	-	0.04	7	78	8	0.04	15	-36	
	Chestnut oak	93	10	0.04	8	101	7	0.06	6	8	
	White oak/red oak/hickory	71	3	0.23	1	94	10	0.12	2	23	0.0045
	White oak	75	-	0.03	17	116	12	0.05	8	41	
	Yellow poplar/white oak/northern red oak	58	11	0.03	15	81	7	0.04	12	23	
	Sweetgum/yellow poplar	71	12	0.03	12	74	7	0.05	7	3	
	Mixed Upland Hardwoods	61	7	0.03	16	52	5	0.07	5	-9	
	Sweetgum/nutall oak/willow oak	86	15	0.04	10	92	12	0.04	13	6	
	Sugarberry/hackberry/elm/green ash	99	20	0.04	9	105	18	0.04	14	6	



Projection: GCS North American
Datum: D North American 1983
Source: USDA Forest Service
Geographic base data are provided by ESRI
By: Christopher M. Oswalt
Disclaimer: Information displayed on map
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Figure 1—Location of the Cumberland Plateau and Mountains (CPM) region for a) historical data and b) contemporary data.

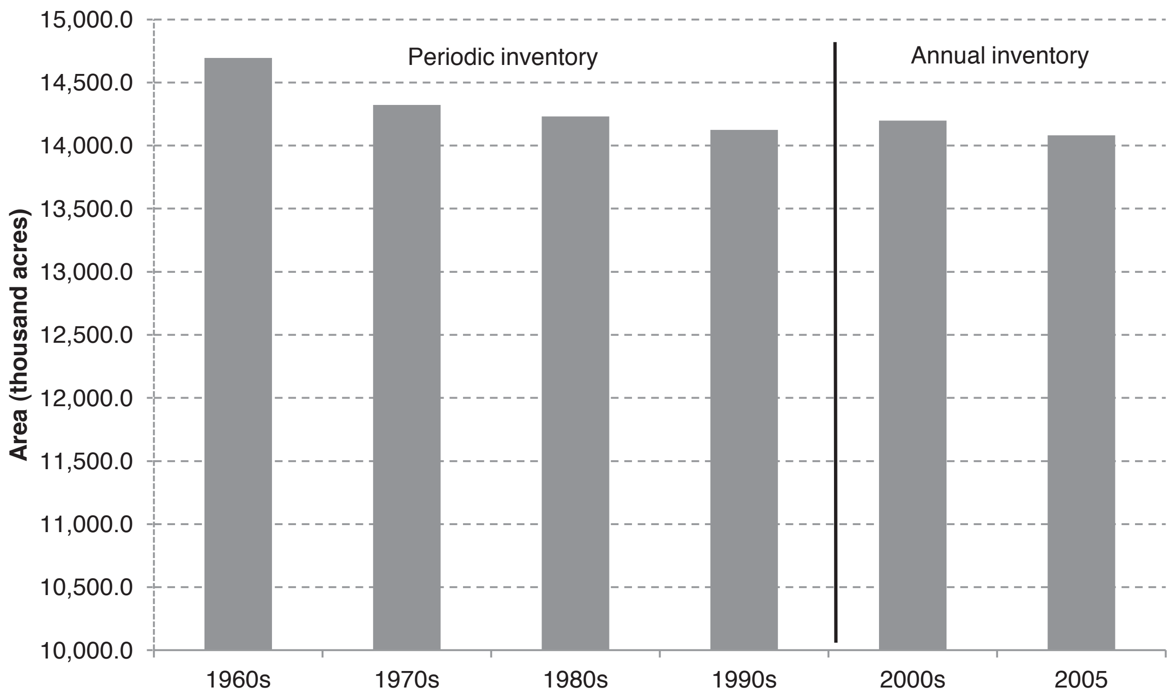

Figure 2—Area of timberland in the counties containing the CPM region from the 1960s to 2005.

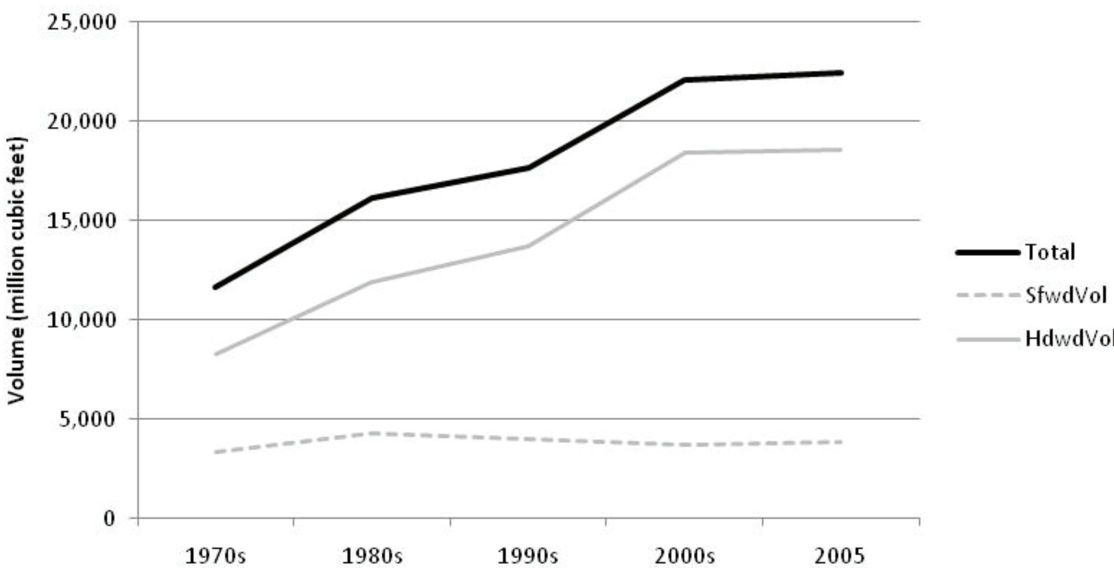

Figure 3—Volume of growing stock trees growing in the counties containing the CPM region from the 1970s to 2005.

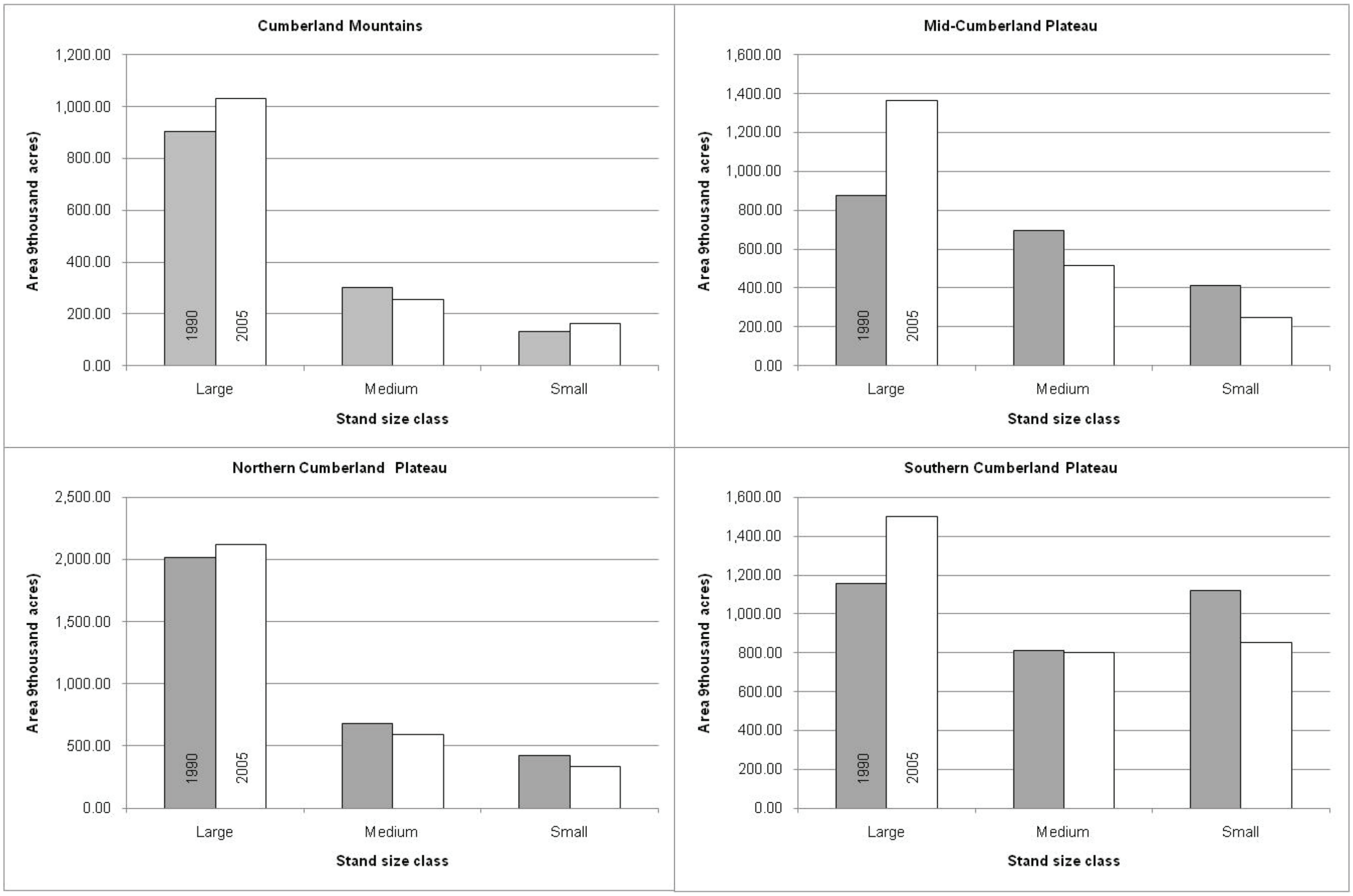

Figure 4—Area of forest land for each subregion of the CPM by stand size class (small = seedlings/saplings, medium = poles, and large = sawtimber) for 1990 and 2005.

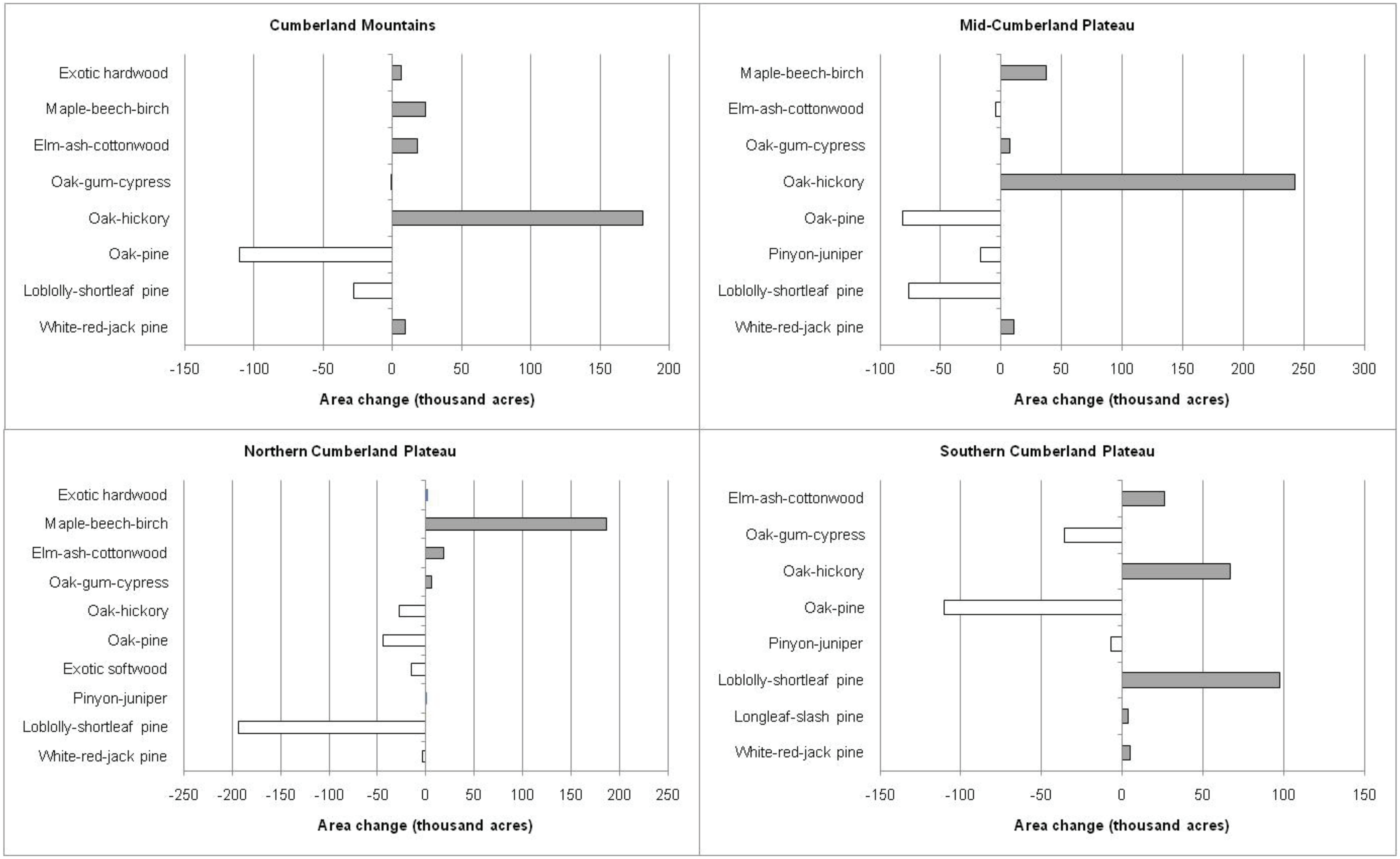

Figure 5—Change in area of forest land for each subregion of the CPM by forest type group for 1990 and 2005.

A COMPARISON OF HERBICIDE TANK MIXTURES FOR MID-ROTATION GALLBERRY COMPETITION RELEASE IN SLASH PINE

Lukas J. Petre, Alan B. Wilson, and William N. Kline

ABSTRACT

Ten different herbicide combinations including Forestry Garlon® 4, Garlon® 4 Ultra, Forestry Garlon® XRT, Chopper®, and Milestone® VM were tested for gallberry (*Ilex glabra*) control. Treatments were applied to the understory of a 9-year-old slash pine (*Pinus elliottii* Engelm.) plantation in South Georgia. Herbicide tank mixture treatments were broadcast foliar applied at a total delivery volume of 20 GPA and replicated three times in a randomized complete block design. One and two years after treatment plots were evaluated and treatments ranked based on level of gallberry control. Forestry Garlon® 4 performed similar to the new formulations, Garlon® 4 Ultra and Forestry Garlon® XRT. The most effective herbicide treatments for gallberry were achieved with 4 quarts/acre of Forestry Garlon® 4 or 3 quarts/acre of Forestry Garlon® 4 (or Garlon® 4 Ultra or Forestry Garlon® XRT) tank-mixed with 16 oz/acre of Arsenal®.

INTRODUCTION

When not controlled at site preparation, woody vegetation competes with crop trees for site resources. A number of studies have shown a pine growth response to the control of this understory woody vegetation (FNC 2005, Oppenheimer et al. 1989). In the flatwoods of Georgia and Florida waxy-leafed species, such as gallberry (*Ilex galbra*) and waxmyrtle (*Myrica cerifera* L.), dominate the understory and can be controlled by herbicide formulations of triclopyr and imazapyr. Since pines are sensitive to triclopyr, waxy-leafed species are best controlled at mid-rotation when the crowns of the crop trees are high enough that herbicides can be applied from below.

Forestry Garlon® 4 is a kerosene-based ester formulation of triclopyr with four pounds of acid equivalent (ae) per gallon. It is widely used for understory release treatments to control waxy-leafed species. Products using kerosene as its solvent are facing regulatory scrutiny by states needing to comply with mandated reductions of volatile organic compounds. Consequently, it would be good to know if other formulations of triclopyr are as effective as Forestry Garlon® 4. Garlon® 3A is an anime formulation with three pounds of ae per gallon which contains ethanol alcohol. Garlon® XRT and Garlon® 4 Ultra, which are ester formulations of triclopyr, use methylated seed oil (MSO) as the solvent as opposed to alcohol or kerosene. Forestry Garlon® XRT contains 6.3 pounds of ae per gallon, whereas Garlon® 4 Ultra contains four pounds ae per gallon. This study evaluates the performance of Forestry Garlon® 4 compared to the newer triclopyr formulations of Forestry Garlon® XRT and Garlon® 4 Ultra. These Garlon formulations were tested with and without imazapyr and Milestone® VM (aminopyralid).

MATERIALS AND METHODS

The study was established in Wayne County Georgia. The soils at the study site are somewhat poorly drained Spodosols (CRIFF C). The site was double-bedded and did not receive any chemical site preparation. The study site was operationally planted in the winter of 1998-99 with slash pine. In April of 2005, 200 lbs/acre of diammonium phosphate and 80 lbs/acre of KCL per acre were operationally applied. The study design was a randomized complete block with three replications of single-row plots. Each row-plot consisted of the inter-bed (10 feet wide) area and measured 100 feet in length. On October 18, 2006, the study was installed with 10 tank mixtures (Table 1). All treatments included a 0.25% non-ionic surfactant with a total application volume of 20 gallons per acre.

Plots were ranked by the effectiveness of gallberry control two growing seasons after treatment. Control of other understory vegetation was also noted. Plots were assigned a ranking of one to five based on the percentage of gallberry control by two reviewers and averaged together. The rankings for gallberry control are: 1 = 100% to 90%, 2 = 90% to 80%, 3 = 80% to 60%, 4 = 60% to 40%, and 5 < 40%. Other species were placed into one of the following three competition control groups: control = > 80%, moderate control 80 to 40%, and resistant = < 40%.

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RESULTS AND DISCUSSION

Results after two years show similar levels of gallberry control among the new formulations of triclopyr (Garlon® XRT and Garlon® 4 Ultra) and Forestry Garlon® 4 (Table 1). Gallberry was effectively controlled by Garlon® 4 (or equivalent formulation) alone at 128 oz per acre. However, at lower rates (< 96 oz/ac) Garlon® 4 and equivalent formulations, failed to provide consistent control of gallberry.

Triclopyr and imazapyr combinations improved gallberry control and provided a larger spectrum of species control than triclopyr alone (Table 1). No antagonism was found between imazapyr and ester formulations of triclopyr at the rates tested in this study. Gallberry control provided by triclopyr and imazapyr tank-mixtures was improved with the use of higher imazapyr rates (Table 1). All tank-mixtures with 16 oz of 4# imazapyr (equivalent to 32 oz 2# imazapyr) and 64 oz Garlon® 4 (or equivalent) ranked "1", on a 1 to 5 scale for gallberry control (Table 1). Poor gallberry control was observed when 16 oz of imazapyr 2# and the equivalent of 64 oz. of Garlon® 4 was applied. No herbicide damage to the slash pine was observed with any of the tank mixtures tested.

The addition of Milestone® VM (aminopyralid) to triclopyr alone did not enhance the control of gallberry. The addition of Milestone® VM to tank mixtures with both triclopyr (ester) and imazapyr controlled yaupon (*Ilex vomitoria*) (Table 1). Although labeled for St. John's wort (*Hypericum* spp), these studies showed no additional control when Milestone® VM was used. Moderate saw palmetto (*Serenoa repens*) control was observed with triclopyr by itself and when tank-mixed with imazapyr but results were inconsistent.

CONCLUSIONS

Based on the results of these studies the broadest spectrum of flatwoods species control was achieved by tank mixtures of triclopyr and imazapyr. New formulations of triclopyr, Forestry Garlon® XRT (6.3#) and Garlon® 4 Ultra (4#) produced similar or better gallberry control as kerosene-based Forestry Garlon® 4 after two years. A tank mixture 16 oz of 4# imazapyr, plus 40 oz 6.3# triclopyr (or equivalent formulation) is recommended for where a broad spectrum of competition control is desired such as renovating stands for pine straw production. This tank-mix will effectively control gallberry and several other understory species which are typically found on Lower Coastal Plain sites. Newer formulations of triclopyr are recommended were reduction of volatile organic compounds is an objective.

ACKNOWLEDGMENTS

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Table 1—Summary of 2006 Dow AgroSciences, Lower Coastal Plain study treated 10/18/06 and evaluated 10/07/08. All treatment costs include 0.25% non-ionic surfactant (v/v). Plot ranking based on gallberry control. Gallberry control ranking assigned on a scale of 1-5, with ratings of 1 and 5 providing the most and least control, respectively. Other species were placed into one of the following four competition control groups: control (C) = > 80%, moderate control (M) = 80 to 40%, resistant (R) = < 40% or not present (-)

Treatment (per acre)	Ranking for Gallberry Control	*Acer rubrum*	*Hypericum* spp.	*Ilex vomitoria*	*Lyonia ferruginea*	*Lyonia lucida*	*Myrica cerifera*	*Persea borbonia*	*Quercus* spp.	*Serenoa repens*	*Smilax*	*Vaccinium* spp.
40 oz Garlon XRT + 16 oz, 4# imazapyr	1.0	-	C	-	C	M	M	C	-	M	-	C
64 oz Garlon 4 Ultra + 16 oz, 4# imazapyr	1.0	-	C	-	C	M	M	C	R	M	-	C
64 oz Garlon 4 Ultra + 16 oz, 4# imazapyr + 7 oz MilestoneVM	1.0	C	C	C	C	M	M	C	-	M	-	C
96 oz Garlon 4 Ultra	1.2	-	M	-	-	-	M	-	-	M	M	M
60 oz Garlon XRT	1.8	-	R	-	M	-	-	M	-	R	-	R
96 oz Garlon 4	2.0	R	R	-	M	M	M	-	R	R	-	R
40 oz Garlon XRT	2.0	-	M	M	M	-	-	-	R	-	R	R
64 oz Garlon 4	2.7	-	R	-	M	-	-	-	R	R	R	R
64 oz Garlon 4 Ultra + 7 oz MilestoneVM	2.7	-	R	-	M	M	M	M	-	R	-	R
64 oz Garlon 4 Ultra	2.8	M	R	M	M	R	-	M	-	R	-	R

EARLY RESULTS OF A CHESTNUT PLANTING IN EASTERN KENTUCKY ILLUSTRATE REINTRODUCTION CHALLENGES

Cornelia C. Pinchot, Scott E. Schlarbaum, Jennifer A. Franklin, David S. Buckley, Stacy L. Clark, Callie J. Schweitzer, Arnold M. Saxton, and Frederick V. Hebard

ABSTRACT

This paper examines the first year results from a silvicultural study of American, hybrid (BC_2F_3) and Chinese chestnut seedlings (*Castanea* spp. Mill.) on the Daniel Boone National Forest in southeastern Kentucky. After one year, no significant differences in growth were found among the silvicultural treatments. Hybrids and Chinese seedlings added significantly more height growth than the American seedlings. American chestnut suffered nearly 40 percent mortality, hybrids 34 percent, while only 5 percent of Chinese seedlings died during the first growing season. High mortality among American and hybrid seedlings is thought to have been caused by the native chestnut sawfly, *Craesus castaneae* (Rowher) and the non-native *Phytophthora cinnamomi* (Rands.), both of which were present at the site. These results illustrate potential challenges facing the reintroduction of American chestnut.

INTRODUCTION

The American chestnut [*Castanea dentata* (Marsh.) Borkh] was a dominant forest tree in the eastern forests of United States until the nonnative chestnut blight fungus [*Cryphonectria parasitica* (Murr.) Barr] virtually eliminated it as a canopy tree species in the early 20th century. The tree was once ecologically important as a source of mast for wildlife (Minser and others 1995, Paillet 2005, Schlarbaum 1989), and economically valuable for its rot-resistant lumber, high-tannin content, and edible nuts (Burnham 1988, Moss 1973).

Limited silvicultural prescriptions for chestnut management were developed before the blight epidemic (Paillet 2002), and the effects of competition on growing space, light, water, and nutrients have not been well defined.
In anticipation of widespread planting of blight resistant American chestnuts, it is important to understand the silvics and competitive ability of the species in order to successfully reintroduce it within the eastern North American forests. Forestry manuals written while American chestnut was still a canopy dominant describe the species' rapid growth and prolific sprouting (Ashe 1911, Mattoon, 1909, Zon 1904), however they lack in-depth analysis of the chestnut silvics. Relatively few experimental studies on chestnut silvics and optimal planting methods have been developed (Anagnostakis 2007, MCCamment and McCarthey 2005, Jacobs and Severeid,2004, McNab 2003 Rhoades and others 2009), and those that exist do not all support the same results.

The overall goal of this study is to assess early establishment success of chestnut seedlings on the Cumberland Plateau of eastern Kentucky by evaluating growth and survival of American, BC_2F_3 hybrids, and Chinese chestnut seedlings grown under three silvicultural treatments: oak shelterwood, thinning, and shelterwood with reserves.

METHODS

STUDY SITE

This study is located on the London Ranger District of the Daniel Boone National Forest (DBNF) on the Cumberland Plateau in southeastern Kentucky (37°03' N, 84°11' W, elevation 370 m). The forest type is classified as upland hardwood and is dominated by mixed oak species (Schweitzer and others 2008). Braun (1950) described this part of Kentucky as part of the mixed-mesophytic forest region, abundant with beech (*Fagus grandifolia* Ehrh.), white oak (*Quercus alba* L.), black oak (*Quercus velutina*

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Lam.), and hickory (*Carya* spp Nutt.). Other common hardwoods include chestnut oak (*Quercus prinus* L.), particularly on ridges, maple (*Acer* spp. L.), and black gum (*Nyssa sylvetica* Marsh). Before the chestnut blight, American chestnut was a dominant timber tree in these forests, particularly in higher elevations (Braun 1950). The former importance of chestnut in the area is further evidenced by its continued presence in the understory (personal observation).

SILVICULTURAL TREATMENTS

This study is nested within a larger USDA Forest Service study, referred to as the Cold Hill Study, which established the goal of improving oak regeneration and forest health prior to the anticipated arrival of gypsy moth to the area (Schweitzer and others 2008). This study utilizes three of the five silvicultural treatments implemented in the Cold Hill study: oak shelterwood (OS), thinning (TH), and shelterwood with reserves (SW). For the OS treatment sites, all stems in the midstory and understory were removed using triclopyr herbicide injection, leaving a basal area of 22 m^2/ha of intact overstory (cf. Loftis 1990). This treatment increases light on the forest floor to favor oak regeneration, while retaining enough overstory to inhibit shade intolerant species, such as yellow-poplar (*Liriodendron tulipifera* L.). The overstory will be removed four to five years following midstory removal. The TH treatment left stands thinned to the B-level of Gingrich stocking (Gingrich 1967), with a basal area of 18.6 m^2/ha of overstory. While thinning is not a standard regeneration treatment, this may provide adequate light for seedling establishment while discouraging shade-intolerant species. The SW treatment left a residual basal area of 5 m^2/ha or overstory. All harvest treatments were completed between 2007 and February 2009.

EXPERIMENTAL MATERIALS

American, BC_2F_3 hybrid, and Chinese chestnut seedlings were used in this study. The open-pollinated American and hybrid nuts were harvested at The American Chestnut Foundation's Meadowview Research Farms, Meadowview, VA, in the fall of 2007, and manually planted at the Flint River Nursery in Byromville, GA in January 2008 at a density of 65 seeds per square meter. Fertilization and irrigation of the seedlings followed guidelines developed by Kormanik and others (1994). The 1-0 seedlings were lifted in February 2009, and stored in a cold room (~1º C) until they were planted. The Chinese chestnut seedlings were purchased from Forrest Keeling Nursery (PO Box 135, Elsberry, MO) in February 2009. Seedlings were processed in February, and the lateral roots were trimmed to 15 centimeters to facilitate planting.

EXPERIMENTAL DESIGN

This study examines the effect of species and silvicultural treatments on chestnut establishment. Silvicultural treatments, arranged in a completely randomized design, were implemented for the USFS's Cold Hill Study (Schweitzer and others 2008). Within the silvicultural treatments, chestnut species were arranged in a randomized block design. Thus the experimental design incorporates a split plot, with silvicultural treatment in the main plot and species in the subplot. Three hundred American, 300 BC_2F_3 hybrid and 150 Chinese chestnut seedlings were planted on the experimental sites between March 2nd and 9th, 2009, using a Jim-Gem© KBC Bar, modified by adding 5 cm to each side of the blade, creating a blade 15 cm at the top, tapering to the tip. The 750 seedlings in the study were planted in transects on 15 different sites. Each of the three silvicultural treatments was replicated three to five times, with the seedlings evenly distributed among the three treatment types. Seedlings were planted at a spacing of 2.44 meters in one transect per site. Transects were located at least 30 m from the treatment edge. The chestnuts were planted randomly in complete blocks of five seedlings.

MEASUREMENTS

Seedling height and root collar diameter (RCD) were measured prior to planting. The height and RCD of each seedling was measured again at the end of the 2009 growing season. The density of naturally regenerated seedlings and height and species of the tallest seedling within a 0.0005 hectare plot surrounding each planted chestnut seedling was recorded. A convex spherical densitometer was used to estimate canopy closure on ten randomly selected treatment sites, representing three to four replicates of each treatment type. Readings were taken on the south side of each chestnut seedling in each of the four cardinal directions and an average canopy closure was recorded. To evaluate the availability of soil water, midday (10:30 am – 12:30 pm) stomotal conductance was recorded on one mature sun-exposed leaf on each chestnut seeding in the same sites sampled for canopy closure. Stomatal conductance was measured with a LiCor 1600 steady-state porometer (LiCor, Inc., Lincoln, NE). To evaluate the availability of soil nutrients, the third healthy leaf down from the terminal bud from 92 seedlings from nine treatment units (three of each treatment type) was taken in August. Leaves were stored in a -70° C refrigerator until processing, at which point 0.2 - 0.4 grams of tissue was cut from each leaf. The leaf tissue was crushed with a mortar and pestle in 85 percent acetone. The extract was centrifuged to remove suspended solids and then enough 85 percent acetone was added to make 15 ml of extract. The optical density of the extract was measured with a Thermospectronic Biomate 3 spectrometer (Thermo Electron Scientific Instruments Corp., Madison, WI), and chlorophyll and total carotinoid concentrations estimated using McKinney equations (Sestak and others 1971). Chlorophyll a and b estimations were used to predict relative foliar nitrogen content for each leaf sample.

Data Analyses SAS software (SAS Institute Inc., Cary, NC, USA) was used for all data analysis. Mixed model analysis of variance (ANOVA) was used to evaluate the effect of silvicultural and species treatments on end-of-season height and RCD, height change (end-of-season height minus initial height), frequency of dieback (negative height change), as well as the effect of silvicultural treatment on canopy cover, stomatal conductance, and chlorophyll and carotinoid levels. Any significant main effects ($\alpha = .05$) were further analyzed using least significant distance tests for means comparisons. Proc Glimmix with binomial distribution was used to evaluate the effect of silvicultural and species treatments on seedling survival and dieback. To ensure the validity of the assumptions of ANOVA, tests for normality and equal variance of the residuals were performed. The square-root of the end-of-season RCD was used in analysis to correct unequal variance.

RESULTS

SURVIVAL

The seedlings experienced substantial mortality during the first growing season. Survival rates differed among species; 40 percent of American and 34 percent of hybrid and seedlings had died by the end of the growing season, while only 5 percent of Chinese chestnuts died ($p < 0.0001$). Survival among silvicultural treatments did not differ ($p=0.9699$).

GROWTH

At the time of planting, American chestnut seedlings averaged 95.68 cm in height and 11.29 in RCD, hybrid seedlings averaged 94.06 cm in height and 11.61 cm in RCD, and Chinese seedlings averaged 110.74 cm in height, and 12.24 cm in diameter. After one growing season, hybrid chestnut seedlings averaged 103.35 cm in height, which was significantly greater than the 98.44 cm average height exhibited by American chestnuts ($p = 0.0355$, but was not different from the 99.6 cm average height of Chinese chestnuts. No differences in height were found among silvicultural treatments ($p=0.4419$; Table 1). Initial height covariate was included in this analysis ($p < 0.0001$).

Hybrid and Chinese chestnut seedling height change was significantly greater than that of the American chestnut seedlings ($p = 0.0010$; Figure 1). Height change did not differ significantly among silvicultural treatments ($p = 0.4419$), however trees in the oak shelterwood decreased in height, on average, by 0.73 cm, while seedlings in the thinning sites added 1.51 cm on average, and seedlings in the shelterwood with reserve sites added 2.86 cm.

Chinese chestnuts exhibited greater RCD than did American and backcross chestnut seedlings ($p < 0.0001$; Figure 2). RCD did not differ among silvicultural treatments ($p = 0.2680$; Table 1). Initial RCD covariate was significant ($p < 0.0001$). Change in RCD from planting to September 2009 was not analyzed due to inconsistencies in RCD measurement between bare-root measurement (before planting) and planted measurement (September 2009).

DIEBACK

American and Chinese chestnut seedlings experienced greater occurrence of dieback than did hybrid chestnut seedlings (42 percent, 54 percent, 26 percent, respectively; $p = 0.0004$). No differences in dieback among silvicultural treatments were found ($p = 0.2060$).

UNDERSTORY COMPETITION

The height of the tallest competitor and the density of competing seedlings within competition plots were not significantly different among silvicultural treatments. Red maple (*Acer rubum* L.) was the tallest competitor in 38 percent of all plots, averaging 176 cm in height. Green briar (*Smilax* spp. L.) was the next most common tallest competitor (17 percent of all plots), averaging 84 cm in height. Red maple was also the most abundant species in the understory (30 percent of plots), followed by green briar (26 percent of plots).

MEASUREMENTS OF AVAILABLE RESOURCES

SW sites exhibited the least canopy closure (47 percent), followed by TH sites (87 percent), followed by OS sites (94 percent; $p < 0.0001$). Transpiration rates did not differ statistically among silvicultural treatments ($p = 0.0679$) or species ($p = 0.5282$). Seedlings in OS sites averaged 3.71 $\mu g\ cm^{-1}\ S^{-1}$, seedlings in TH sites averaged 4.55 $\mu g\ cm^{-1}\ S^{-1}$, and seedlings in SW sites averaged 6.58 $\mu g\ cm^{-1}$ S. Chlorophyll a, b, and total chlorophyll (a + b) all differed significantly among silvicultural treatments ($p = 0.0103$, $p = 0.0289$, $p = 0.0042$, respectively), with all three parameters decreasing from OS to SW treatments (Table 2). Chlorophyll parameters did not, however, differ among species ($p = 0.9033$, $p = 0.4423$, and $p = 0.5877$, respectively). Species by silvicultural interaction was significant for all three variables ($p = 0.0345$, $p = 0.0106$, and $p = 0.0338$, respectively). Carotinoids did not differ among species ($p = 0.6401$) or silvicultural treatment ($p = 0.2495$).

DISCUSSION

While stomatal conductance rates did not differ statistically among silvicultural treatment, the results exhibit a pattern of increasing transpiration with decreasing canopy. Treatment differences in residual basal area may well have affected water balance on these sites through altered evapotranspiration, however seedling response appears to be highly variable. Greater quantities of chlorophyll in leaf samples, from the oak shelterwood sites than those in the thinning and shelterwood with reserve sites may indicate that the oak shelterwood sites have more available soil nutrients than the other silvicultural treatments.

Harvesting usually causes increased rates of organic matter decomposition and nitrogen mineralization, while decreasing evapotranspiration, which together create an initial increase in the amount of available nitrogen (Vitousek and Matson 1985). However in the short term, a high input of woody debris alters soil C:N ratios, resulting in a temporary immobilization of nitrogen (Turner 1977). Based on the amount of canopy cover observed, OS sites clearly provide the least available light, TH sites provide slightly more light, and the SW provided the most light. Seedlings demonstrated a (non-significant) pattern of increased height growth from OS to SW treatments. Future years of data will determine if this pattern reflects a true effect. McCament and McCarthy (2005) found that light was more closely related to increase in chestnut biomass in a forest planting than were soil nutrients, organic matter, soil moisture, and soil texture. In a greenhouse study examining the effect of several light and nutrient treatments on chestnut seedlings, Latham (1992) also found that chestnut growth exhibited a greater sensitivity to light than nutrient availability. More accurate measurements of soil water and nutrients at our sites and future years of growth data are necessary to test this hypothesis for our study.

Reports of unusual chestnut mortality in the southern United States began to appear in the early 1800s (Anagnostakis 2006). At the time, the causal agent was unknown, however, later studies have shown that chestnuts in bottomland or poorly drained sites were being killed by ink disease, *Phytophthora cinnamomi* Rands (Crandall and others 1945), a soil-borne Asian oomycete that attacks and kills the root systems of American chestnut and the related Allegheny and Ozark chinquapins. Chinese chestnuts, in general, are more resistant to *P. cinnamomi* than American chestnuts. Ink disease was most likely transported to the southern United States before 1824, and caused significant loss of chestnut in the Gulf and Atlantic states (Anagnostakis 2006). Ink disease was confirmed in five dead seedlings from this study. This confirmation, and the greater incidence of mortality among American and hybrid, compared to Chinese chestnut seedlings (40 percent, 34 percent, and 5 percent, respectively), leads us to hypothesize that mortality among the American and hybrid chestnuts was caused in part by ink disease. While nursery seedlings may carry ink disease to new locations, soil tests located at least 5 meters from our planting transects also tested positively for *P. cinnamomi*, indicating the pathogen was already present on the sites. This is troubling, as *P. cinnamomi* has not commonly been found on well-drained upland sites. Mortality among American and hybrid chestnuts may have also been aggravated by repeated defoliation by chestnut sawfly (*Craesus castaneae* Rohwer), which favored these species over the Chinese chestnut (Pinchot and others, In Press).

IMPLICATIONS FOR AMERICAN CHESTNUT REINTRODUCTION

The presence of *P. cinnamomi* on these sites indicates that this pathogen may be able to survive in well-drained upland areas, areas where chestnut was once a dominant species and where reintroduction efforts will likely be targeted. Based on the high mortality observed in this study, it is recommended that all reintroduction sites be tested for presence of *P. cinnamomi*, and chestnut planting excluded for sites that test positive. Furthermore, plantings should be observed for presence of chestnut sawfly and if found, seedlings may benefit from the application of a foliar pesticide treatment. The presence of *P. cinnamomi* and *C. castaneae* and the high mortality among chestnut seedlings illustrates additional biotic challenges facing the reintroduction of American chestnut.

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Table 1—2009 mean height, height change, and RCD among the silvicultural treatments. Treatment means followed by the same letter are not significantly different (α = 0.05).

Treatment	Ht (cm)	Ht change (cm)	RCD (mm)
OS	98.47a ± 1.81	-2.14a ± 1.69	10.43b ± 0.17
TH	100.70a ± 1.40	0.09a ± 1.84	10.43b ± 0.17
SW	102.31a ± 1.55	1.70a ± 1.96	12.18a ± 0.17

Table 2—2009 Differences in mean chlorophyll a, chlorophyll b, total chlorophylls (a + b) and carotenoids in mg leaf pigment per g fresh leaf tissue among silvicultural treatments. Treatment means followed by the same letter are not significantly different (α = 0.05)

Treatment	Chlorophyll a	Chlorophyll b	Total Chlorophyll	Carotinoids
OS	1.64a ± 0.10	0.88a ± 0.04	2.40a ± 0.22	1.25a ± 0.07
TH	1.04b ± 0.10	0.70ab ± 0.04	1.48b ± 0.22	1.00a ± 0.08
SW	0.67b ± 0.10	0.55b ± 0.04	0.92c ± 0.22	1.01a ± 0.08

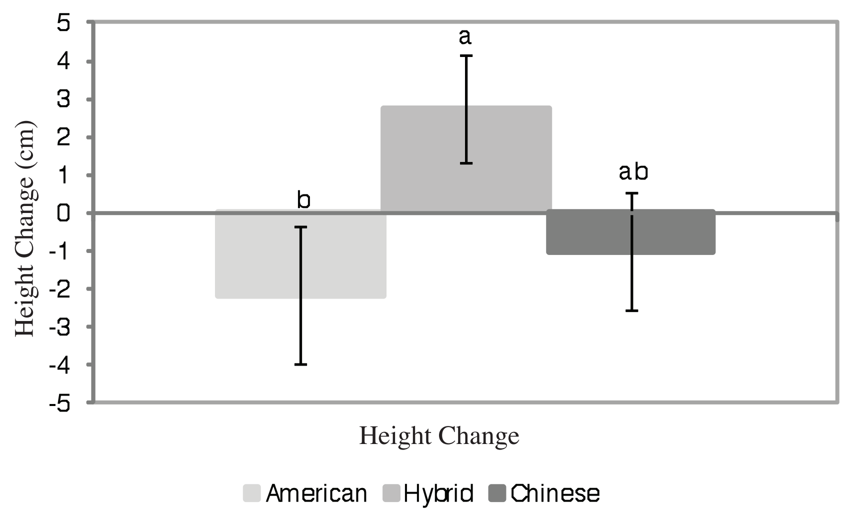

Figure 1—Height at the time of planting, at the end of one growing season, and height change among species after one growing season. Bars with the same letter are not significantly different (α = 0.05)

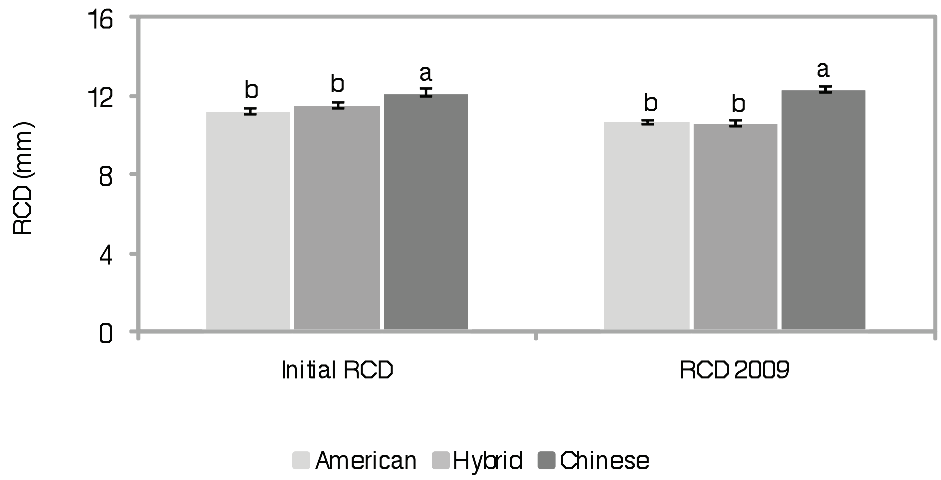

Figure 2—Root collar diameter among species at the time of planting and after one growing season. Bars with the same letter are not significantly different (α = 0.05).

SILVICULTURE AND THE ASSESSMENT OF CLIMATE CHANGE GENETIC RISK FOR SOUTHERN APPALACHIAN FOREST TREE SPECIES

Kevin M. Potter and Barbara S. Crane

Changing climate conditions and increasing insect and pathogen infestations will increase the likelihood that forest trees could experience population-level extirpation or species-level extinction during the next century. Gene conservation and silvicultural efforts to preserve forest tree genetic diversity present a particular challenge in species-rich regions such as the Southern Appalachian Mountains. Funds, however, will be limited for silvicultural management and gene conservation efforts to preserve forest tree genetic diversity. To facilitate the effective use of limited resources and to guide silvicultural activities, we developed the Forest Tree Genetic Risk Assessment System as a framework for users to rank the relative risk of genetic degradation for multiple forest tree species, and applied this framework for the Southern Appalachians.

Species differ in their silvicultural requirements, physiological tolerances, life-history strategies, and population dynamics (extinction, colonization, and dispersal abilities). These differences could drive variation among forest tree species in their potential responses to changing climate conditions and insect and pathogen infestations. Given these potential changes, diverse silvicultural and genetic strategies to support future desired conditions will be needed to ensure successful regeneration and restoration efforts. An important goal will be to safeguard existing adaptedness and create conducive conditions for future evolution, with a focus on the conservation of variability in adaptive traits (Myking 2002).

Following an extensive review of the ecological and life-history traits of tree species that predispose them to genetic degradation, we developed 10 indices to include in the risk assessment framework. These are divided into six intrinsic risk factors (describing characteristics of tree species and their distributions); two external risk factors (describing external threats to tree species) and two conservation modifiers (describing conservation value associated with species, Table 1). The risk factors further consist of several variables: 20 for the intrinsic and five for the external risk factors. Users can decide which of these risk factors and variables to include in their assessments, and how to assign the appropriate relative weights placed on each. The weighted factor scores are summed to give risk ratings for the species within a given region, which are then ranked.

We used this framework to conduct a risk assessment for 131 native forest tree species encompassed within the Southern Appalachian region, defined by seven high-elevation ecoregion sections south of the Mason-Dixon line (Figure 1). We completed this genetic risk assessment in four major steps: (1) determining the area of interest and the species encompassed by that region, (2) selecting risk factors and conservation modifiers to include in the assessment, (3) collecting relevant data for each species and calculating risk factor and conservation modifier index scores, and (4) weighting these index scores, calculating a final score for each species, and ranking the species based on their final scores. A detailed description of these steps is provided in Potter and Crane (2010). Most of the data used in the assessment are from publicly available sources. Several of the Southern Appalachian species at greatest risk of genetic degradation have small distributions, often at high elevations, and/or are currently threatened by insects and diseases.

The highest-ranking species, for example, is Carolina hemlock (*Tsuga caroliniana*), which occurs in a handful of scattered high-elevation populations. Carolina hemlock and eastern hemlock (*T. canadensis*), which also ranked among the top 25 species, are experiencing extensive mortality caused by the exotic hemlock woolly adelgid (*Adelges tsugae*). With funding from the USDA Forest Service, the Camcore gene conservation cooperative at North Carolina State University has collected seeds from both species since 2005 for gene conservation purposes. Fraser fir (*Abies fraseri*), the third most at-risk species, is limited to a few populations at the highest elevations in the Southern Appalachians, where the exotic balsam woolly adelgid (*Adelges piceae*) has killed many trees. Table Mountain pine (*Pinus pungens*), which ranked among the 10 most at-risk species, occurs in high-elevation stands where insufficient fire has proved a challenge for regeneration.

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In summary, we used ecological and life-history traits to rank the predisposition of Southern Appalachian tree species to genetic degradation from climate change and other threats. This approach can serve as a tool for planning silvicultural treatments, conservation efforts, evaluating species' genetic resources and detecting vulnerabilities. A key feature of the Forest Tree Genetic Risk Assessment System framework is its flexibility to suit the needs of users, allowing for its application across any area for which the relevant data exist for the species of interest. Only by considering extinction as a synergistic process of external threats and intrinsic biological traits will it be possible to make predictions of risk that approximate reality for most species, and therefore to increase the likelihood that conservation efforts will be effective (Brook and others 2008).

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Table 1—The intrinsic risk factors, external risk factors and conservation modifiers included in the Forest Tree Genetic Risk Assessment System for the assessment of the 131 tree species of the Southern Appalachians. We assigned a weight of 0.1 to each intrinsic risk factor, 0.15 to the external risk factors, and 0.05 to the conservation modifiers. (Weights sum to 1.)

Intrinsic Risk Factors	External Risk Factors	Conservation Modifiers
A1) Population Structure	B1) Pest and Pathogen Threats	C1) Endemism
A2) Rarity/Density	B2) Habitat Shift Pressure	C2) Conservation Status
A3) Regeneration Capacity		
A4) Dispersal Ability		
A5) Habitat Affinities		
A6) Genetic Variation		

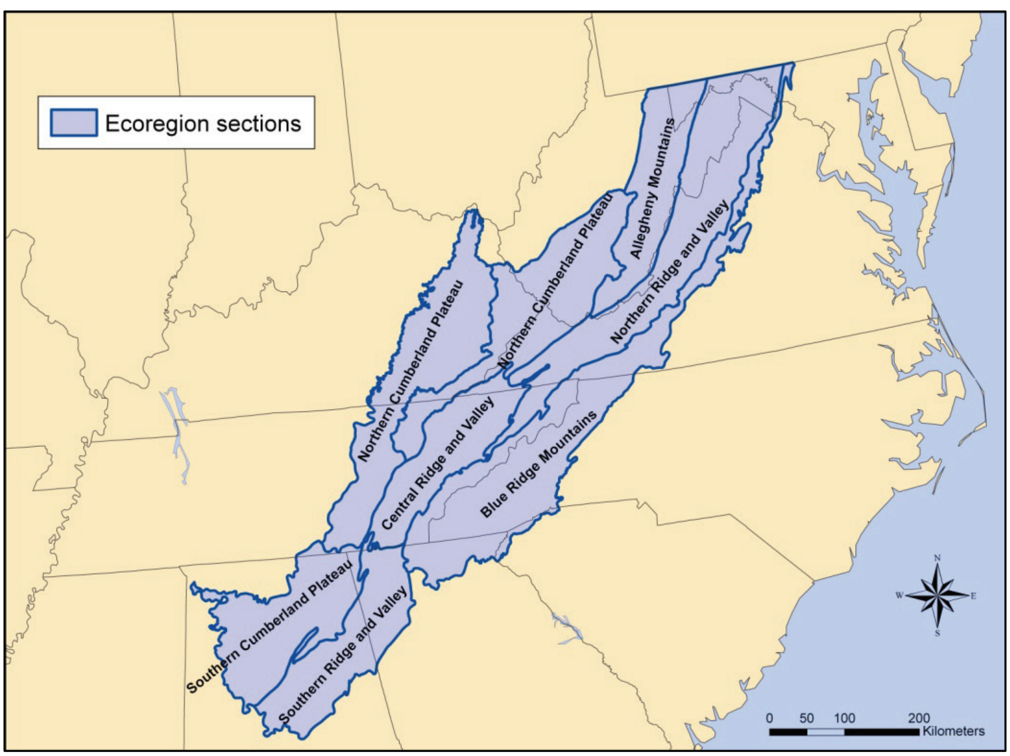

Figure 1—The Southern Appalachian region, as defined for this regional genetic risk assessment.

MANAGEMENT INTENSITY AND GENETICS AFFECT LOBLOLLY PINE SEEDLING PERFORMANCE

Scott D. Roberts, Randall J. Rousseau, and B. Landis Herrin

ABSTRACT

Capturing potential genetic gains from tree improvement programs requires selection of the appropriate genetic stock and application of appropriate silvicultural management techniques. Limited information is available on how specific loblolly pine varietal genotypes perform under differing growing environments and management approaches. This study was established in 2008 to examine the performance of two selected loblolly pine varieties (crop vs. competitor) at different initial planting spacings and management intensities. The two genotypes were selected based on their putative divergent crown architectures. After three growing seasons, neither initial spacing nor management intensity had any effect on tree survival. Survival of the crop tree genotype (98.0 percent) was significantly greater than that of competitor genotype (86.3 percent). Growth of surviving seedlings was affected by both genetics and management intensity. Mean year-three height of the crop genotype (8.4 feet) was significantly greater than that of the competitor genotype (7.3 feet). Mean year-three height in the high intensity management plots (9.3 feet) exceeded that on the low intensity management plots (6.5 feet). Differences in levels of competition between high and low intensity plots, while not affecting survival, appear to have had the greatest impact on seedling height growth. Somewhat surprisingly, the crop tree genotype outperformed the competitor genotype in both survival and height growth.

INTRODUCTION

Dramatic gains in the productivity of southern pine plantations have been realized over the past 30-40 years, with per acre annual increments more than doubling over the past three decades due to increased management intensity. Productivity of loblolly pine (*Pinus taeda* L.) plantations now frequently exceeds 300 ft^3/ac/yr, and in some cases 400 ft^3/ac/yr (Fox and others 2007). A major reason for the increases in productivity has been the genetic improvements that have been made in loblolly pine through the tree improvement cooperatives. However, achieving these increased yields has also required increased intensity of plantation management including improved site preparation techniques, more effective competition control, better understanding of forest nutritional requirements, and greater attention to density management.

Regional tree improvement cooperatives established in the early 1950s began the process of producing genetically improved loblolly pine seedlings, and by the mid-1980s virtually all southern pine plantations were established with seedlings produced from genetically improved seed. Gains in volume from first-generation plantations in the 1980s were generally in the range of 7-12 percent (Li and others 2000), with estimated gains in harvest value exceeding 20 percent (Fox and others 2007). By the early 2000s, over half of all southern pine planting stock was coming from second-generation seed orchards, with average volume gains from second-generation plantations estimated to range from 7-23 percent over first-generation stock (Fox and others 2007, Li and others 1997, 1999, 2000, McKeand and others 2003, 2006a). Improvements in disease resistance, stem form, and wood quality have also resulted in increased harvest levels and value.

Open-pollinated planting stock gains were further enhanced by deployment of the single half-sib family blocks, utilizing offspring of superior female parent trees of high breeding value (Duzan and Williams 1988, McKeand and others 2006b). By the early 2000s, nearly 60 percent of all southern pine plantations, and 80 percent of industrial plantations, were deploying single half-sib family blocks (McKeand and others 2006a). Even further genetic gains have been realized by planting full-sib families produced using mass-controlled pollination (MCP) techniques (Bramlett 2007). Jansson and Li (2004) show potential volume gains from full-sib families of up to 60 percent over unimproved stock.

Over the past decade, the development and refinement of techniques for mass production of clonal loblolly pine planting stock has opened the door to even further gains in plantation forestry. The operational production of elite genotypes, known as varietal planting stock, currently accounts for only a minor proportion of loblolly seedlings planted in Southeast, although this is growing annually. There remain issues, however, that need further investigation. Varietal planting stock is currently much more expensive than other planting stock options, and studies are needed on the economic efficacy of the stock. Field testing across a greater array of sites is also needed to determine appropriate varieties for specific areas, as well as comparisons between the performance of varietal stock to that of other planting stock options. Research is also needed to determine any genetics by environment interactions that

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might exist within loblolly pine varietals. Finally, studies are needed to identify the appropriate silvicultural regimes for maximizing gains when using varietal planting stock.

This paper reports on third-year results from a trial employing two distinct loblolly pine varieties that were selected based on their putative divergent crown architectures. Trees were planted at three spacings providing densities of 519, 346 and 194 trees per acre. Two silvicultural intensity treatments included intensive and sustained control of competition and insects, and standard cultural treatments through the first growing season. The long-term objective of the study is to examine if the selected loblolly pine varietal stock will exhibit their sawtimber quality traits of stem form and crown characteristics when grown at various densities. In the present analysis, age-three survival and height are reported.

MATERIALS AND METHODS

This study was established in 2008 at Mississippi State University's Coastal Plain Branch Experiment Station Experiment Station near Newton, MS (32°20'19"N 89°05 51"W). Soils on the site are a Prentiss very fine sandy loam. The site had previously been in agricultural production resulting in the soils being somewhat compacted. The site received a broadcast application of Glyphosate (64 ounces/ac) in September 2007, and was subsoiled to a depth of approximately 14 inches in October of 2007. The site received a second broadcast application of Glyphosate (32 ounces/ac) in March of 2008 prior to being hand planted with containerized seedlings in late April/early May of 2008.

The study was set up as a 2x2x3 factorial split plot design. Main effects treatments included two genetic varieties of loblolly pine and two levels of management intensity, with main effects treatment plots split by three initial planting spacings. Trees within the spacing subplots were planted in 64 tree blocks (8 x 8 trees) with the inner 36 trees constituting the measurement plots. Each treatment combination was replicated four times.

The two varietal genotypes of loblolly pine included in the study were based on their putative divergent crown architectures. The varieties, produced by ArborGen, LLC, included one considered to be a competitor ideotype (comp) characterized by a wider crown form, and another considered to be a crop tree ideotype (crop) with a more narrow, compact crown form. The two levels of management intensity included a standard intensity (low) and a high intensity (high). In addition to the chemical site preparation and subsoiling described above, both the high and low intensity plots received herbaceous competition control in year 1 through a broadcast application of Oustar® (10 ounces/ac). Additional management inputs applied to the high intensity plots included tipmoth control in the form of a single SilvaShield™ tablet (Bayer Environmental Science) in the planting hole at time of planting, PTM™ insecticide (BASF Corp.) injected 3-6 inches deep in the soil adjacent to each tree (0.05 ounces ai per tree) in years 2 and 3 for additional tipmoth control, herbaceous competition control in year 2 (1 ounces/ac of Escort®, 16 ounces/ac Arrow®, 32 ounces/ac Goal®), and mowing of competing vegetation in year 3. The three initial tree spacings were 6 x 14 feet (519 tpa), 9 x 14 feet (346 tpa), and 16 x 14 feet (194 tpa).

Initial height was measured on each seedling immediately following planting. Survival was assessed and heights measured annually following each of the first three growing seasons (2008-2010). For the analysis presented here, we tested for treatment differences in survival and mean height following the first and third growing seasons. All reported treatment differences are based on a critical value of alpha=0.05.

RESULTS AND DISCUSSION

At the end of the first growing season, overall survival was 94.1 percent (Table 1). There were no significant differences in survival between initial spacings. Surprisingly, plots receiving the lower intensity of management had slightly greater survival than the plots receiving the high intensity treatments. Since the only difference in the management intensity treatments at year 1 was the addition of the SilvaShield™ tablet in the planting hole of each tree on the high intensity plots, we attributed the difference in year-1survival between the high and low intensity treatments to random chance. Trees of the crop tree genotype had better year-1 survival (98.5 percent) than trees of the competitor genotype (89.7 percent). After one growing season, the average height of all surviving seedlings was approximately 1.7 feet, and there were no significant differences in mean height associated with genotype, management intensity, or initial seedling spacing (Table 1).

There was little additional mortality between years 1 and 3. Overall seedling survival at the end of the third growing season was high at over 92 percent (Table 1). By the third year, the initial differences in survival between the two management intensity treatments had disappeared. However, differences in survival between the two genotypes had increased to nearly 12 percent (Figure 1). As expected, initial tree spacing had no effect over the first three years on survival. The 16-feet within row tree spacing did have a slightly lower survival, but this was due primarily to high mortality on a single plot that was attributed mostly to sawfly damage. At this young age, there is no inherent reason to suspect differences in intraspecific competition related to tree spacing that would affect seedling performance.

Average height of all surviving trees after three growing season was nearly 7.9 feet (Table 1). Again, initial seedling spacing had no effect on mean tree height; but the two other treatments did. There were noticeable differences between the high and low management intensity treatments that, while not having much effect on survival, did significantly affect height growth. Mean height at age 3 on plots receiving the high intensity treatment was nearly three feet greater than on plots receiving the low intensity treatment (Figure 2).

As expected, pine tipmoth damage was lower on the high intensity plots, which had received tipmoth control at time of planting and again at the beginning of the second growing season. Observed tipmoth damage generally ranged from about 15 to 18 percent on the low intensity plots but was less than one percent on the high intensity plots. The tipmoth damage did not, however, appear to effect third year survival or heights relative to uninfested trees.

Sawfly damage was also considerably lower on the high intensity plots. As with tipmoth, sawfly damage ranged between about 15 and 18 percent on the low intensity plots and less than one percent on the high intensity plots. The fact a treatment effect on sawfly damage was observed was somewhat surprising, since neither of the chemicals used for tipmoth control have any known effects on sawfly. We were not able to show statistically that sawfly damage affected year-3 survival, largely because cause of mortality was not recorded. If a tree became infested and died in the same season, we would not have a record of the infestation. Observationally, however, we did notice considerable sawfly mortality. For surviving trees, the sawfly damage did result in about a 0.4-0.8 foot decrease in height.

By year 3, the most noticeable difference between the high and low intensity treatments was in the levels of competing vegetation present. This was expected given the extra year of herbaceous competition control in year 2 and the mowing that took place in year 3 on the high intensity plots. The differing levels of competing vegetation did not have a significant effect on survival, since most of the seedling mortality was observed in year 1 when both the high and low intensity treatments had received essentially the same inputs. The differences in competing vegetation did have a large effect on year-3 heights, with the high intensity treatment plots averaging nearly three feet taller than the low intensity plots.

Somewhat surprisingly, the crop tree genotype outperformed the competitor genotype in both survival and height growth over the first three growing seasons. Third-year survival of the crop genotype was nearly 12 percent higher than that of the competitor genotype. Trees of the crop tree genotype average about one foot taller than trees of the competitor genotype (Figure 3). Within each of the genotypes, there were no differences in survival between the high and low intensity treatments; however, genotype differences in year-3 mean heights were four times greater on the high intensity plots (1.6 feet) than on the low intensity plots (0.4 feet).

The results of this analysis support what is generally common knowledge in forestry – to achieve the best performance from a plantation it is important to select the proper genetic planting stock for a given site and set of objectives. To achieve the full potential of the planting stock requires appropriate silvicultural management. In most cases, and especially on old field sites, effective early competition control will be one of the most important, if not the most important factor affecting early seedling performance.

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Table 1—Survival (%) and height (feet) following years 1 and 3 for two genetic varieties of loblolly pine planted at three different spacings and managed at two different management intensities on a site previously managed for agricultural production in central Mississippi

	Survival (%)		Mean Height (feet)	
	Year 1	Year 3	Year 1	Year 3
Overall	94.1	92.2	1.69	7.89
Initial Spacing				
6 x 14 feet	94.8	93.6	1.69	8.07
9 x 14 feet	95.7	94.8	1.71	8.07
16 x 14 feet	91.8	88.2	1.66	7.52
Management Intensity				
Low	96.3*	92.7	1.66	6.53
High	91.9	91.7	1.71	9.25*
Genetic Variety				
Crop	98.5*	98.0*	1.68	8.39*
Competitor	89.7	86.3	1.69	7.38

* Values followed by an asterisk are significantly different from other values in the group at alpha=0.05

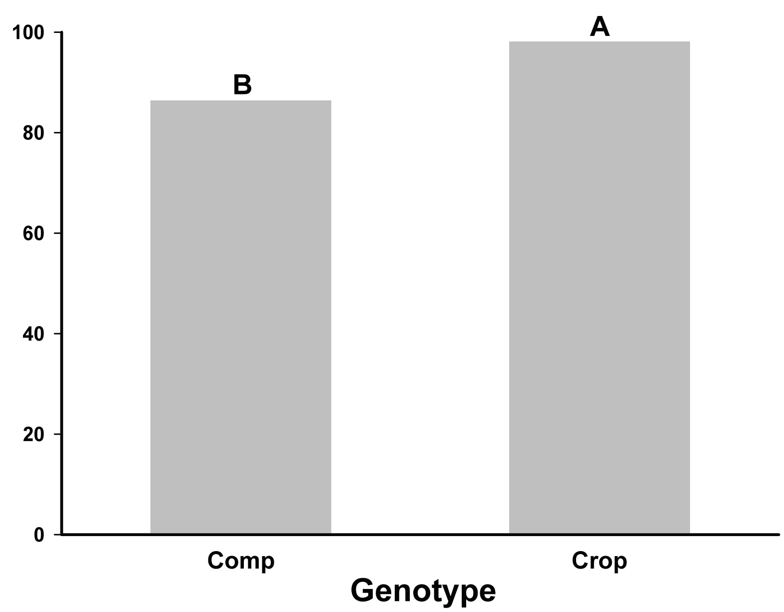

Figure 1—Mean year-3 survival for contrasting loblolly pine varieties planted in a spacing by management intensity trial in central Mississippi.

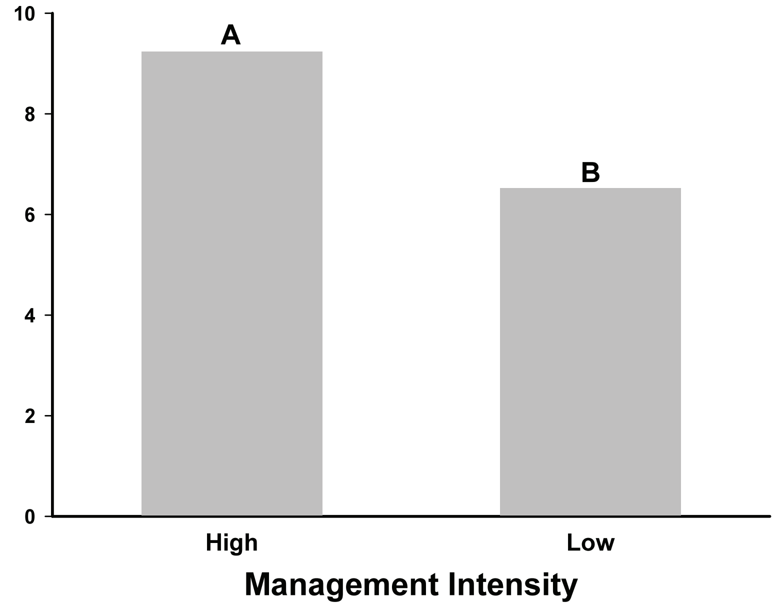

Figure 2—Mean year-3 height for loblolly pine varietal seedlings managed at different management intensities in central Mississippi.

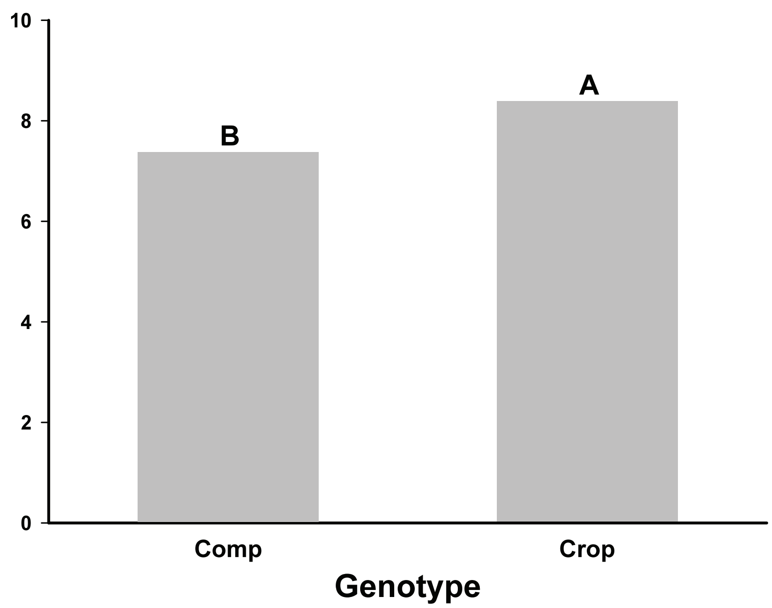

Figure 3—Mean year-3 height for contrasting loblolly pine varietal seedlings planted in a spacing by management intensity trial in central Mississippi.

STAND AND INDIVIDUAL TREE GROWTH RESPONSE TO TREATMENTS IN YOUNG NATURAL HARDWOODS

Daniel J. Robison, Tracy San Filipo, Charlie Lawrence III, Jamie L. Schuler, and Bryan J Berenguer

Young even-aged upland Piedmont mixed hardwood and pine stands were treated with a variety of fertilizer and release (competition control) treatments. The sites studied are on the NC State University Hill Demonstration Forest in central North Carolina, and are characterized by formerly highly eroded agricultural sites (Richter et al. 2000) now in their third rotation of tree cover. Tree growth response was assessed periodically over several years, on both an individual-tree and stand-wide bases. Stand-basis response to fertilizer treatments was vigorous, with treated stands growing more than untreated controls. Whereas individual tree response within treated areas were less. Responses varied between species, with specific consideration of yellow poplar, red/black oak, white oak, and loblolly pine. Significant increases in the rate of stand development can be achieved, thereby reducing the anticipated time to final harvest and number of years necessary to attain commercial size stems. Modest fertilizer inputs on these types of sites have significant effects. The long term response of individual trees at these young ages to release treatments remains difficult to determine. This study adds to the growing body of experience with these kinds of treatments (Auchmoody 1989, Berenguer et al. 2009, Schuler and Robison 2006, others).

Individual Tree Release Study – In summer 1998 we identified three similar adjacent upland mixed hardwood stands regenerated by clearcutting 6, 8, and 13 years prior; aged 18, 20 and 25 years old at the time of the final measurements reported here. About 60 dominant/co-dominant non-stump sprout trees on a 6 x 6m grid across each site of red/black oak, white oak and yellow poplar were identified on each site. About 20 stems of species on each site were treated as:
1) Control,
2) Mechanical – brush saw clearing of a 1.8m radius around the trees in year 1,
3) Mechanical + Chemical Year 1 [Garlon herbicide on cut stems in year 1],
4) Mechanical + Chemical Year 2 [Accord/Oust herbicide mixture in year 2],
5) Mechanical + Chemical Year 1 + Fertilization [DAP fertilizer year 2 (DAP at equivalent of 100 and 112 kg/ha N and P in released area)].

Tree size was measured in 1998, 2000, 2001, 2004 and 2010. Representative results are reported in Figure 1.

Area-Based Treatment and Individual Tree Release Study – In spring 2003, a loblolly pine plantation with a hardwood component was salvage clearcut after ice damage, and in spring 2004 study plots (20.3 x 40.6 m) were established. Trees were measured (in 2 x 30 m strips) and fertilizer was broadcast on 1-year-old regeneration as follows:
1) Untreated Control,
2) Nitrogen fertilizer (N fert),
3) Nitrogen and Phosphorus fertilizer (N+P fert), and
4) Nitrogen, Phosphorus and Potassium fertilizer (N+P+K fert), with nitrogen applied at 200 kg N per ha ammonium nitrate (34-0-0), phosphorus applied at 50 kg per ha triple super phosphate (0-46-0), and potassium applied at 100 kg per ha muriate of potash (0-0-60).

In fall 2005 tree size was measured. In winter 2005/2006 the plots were split, half left alone (non-released) and in half select trees were released. In winter 2008/2009 tree response was measured in both the non-released and released areas. Released trees were five each of loblolly pine, northern red oak, and yellow poplar. In non-released areas five each of the same species were also measured, and trees in 2 x 15 m transects were also measured in the unreleased areas. For all species combined from transect data, the response of stems under the different fertilizer treatments are illustrated in Figure 2. For the individually released trees (and their counterparts in the non-released portion of this study) (data not shown here), for loblolly pine, there were substantive growth gains in diameter and volume index but not height

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under all fertilizer conditions. Also for loblolly pine across fertilizer conditions with respect to the control under release and non-release conditions, the trees treated with N and N+P+K were larger than those in control or N+P conditions. For northern red oak the responses were similar but smaller in magnitude, and the positive fertilizer responses were for the N and N+P treatments. For yellow poplar the responses were similar again, but for height as well as diameter and volume, larger in magnitude than for loblolly pine, and positive for all fertilizer treatments relative to the fertilizer control.

The authors acknowledge the contributions of Larry Jervis, Joe Cox, Emrys Treasure and Matt Gocke of NC State University, the members of the NC State Hardwood Research Cooperative (1997-2004), and The Hardwood Forestry Fund.

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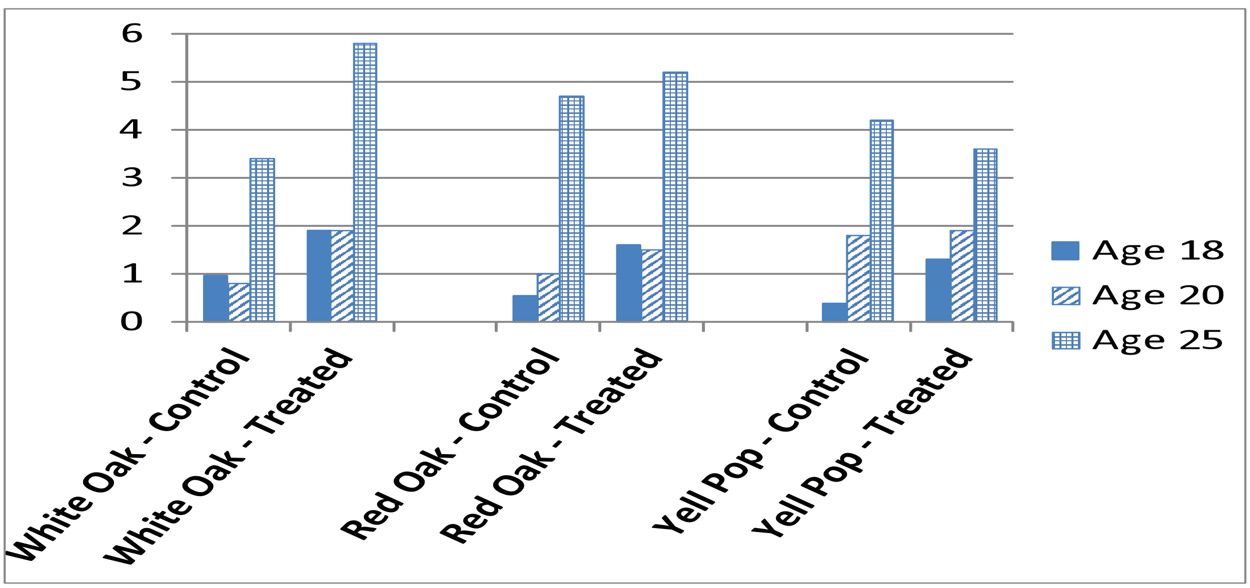

Figure 1—Mean volume index of individual stems 12 years after the maximum Individual Tree Release Treatment of Mechanical Release + Chemical Herbicide + Fertilizer in the Individual Tree Release Study (see text). Volume index was based on the d-squared*height approximation. Results for trees at 18, 20 and 25 years old, were from trees first treated when they were 6, 8 and 13 years old, respectively, 12 years earlier.

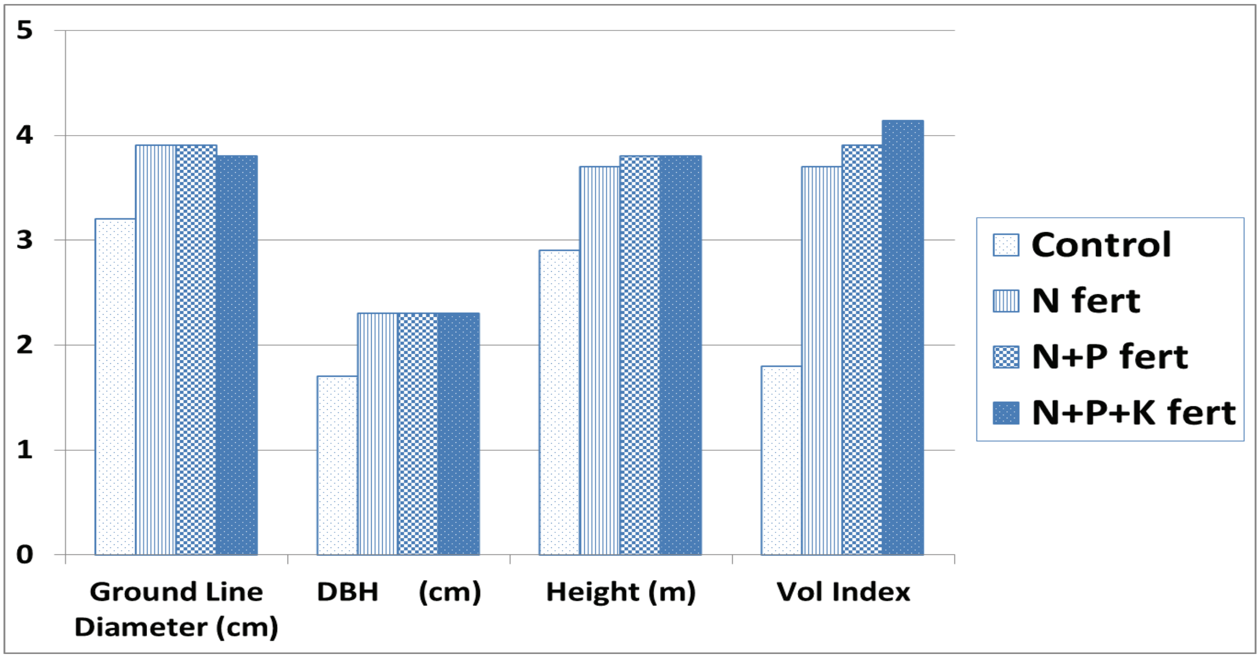

Figure 2 – Mean size of six-year-old stems for all species combined (for stems greater than 60 cm tall) from area-based transect plots 5 years after fertilizer treatments were applied to 1-year-old regeneration in the Area-Based Treatment and Individual Tree Release Study (data for the individual tree portion of this study not shown).

FIELD PERFORMANCE AND BIOENERGY CHARACTERISTICS OF FOUR COMMERCIAL EUCALYPTUS GRANDIS CULTIVARS IN FLORIDA

Donald L. Rockwood, Bijay Tamang, Matias Kirst, and JY Zhu

For several methods utilizing woody biomass for energy (Rockwood and others 2008), one of the challenges is the large, continous fuel supply required. For example, proposed biomass plants in Florida may each require one million tons of biomass/year. When supplies of forest residues and urban wood wastes are limited, short rotation woody crops (SRWC) are a viable alternative (e.g., Langholtz and others 2007). Eucalypts are ideal as SRWCs because of their fast-growth and site tolerance (Rockwood and others 2008). Their coppicing ability also provides 2-5 coppice harvests before replanting (Langholtz and others 2007). Eucalypts could be grown throughout Florida, and their potential uses range from landscape mulch to biofuel production (Rockwood and others 2008).

Resulting from four decades of genetic improvement, E. grandis cultivars E.nergy™ G1, G2, G3, and G4 (US Patents PP21,582, PP21,571, PP21,569, and PP21,570, respectively) were released by the University of Florida in 2009 and are now commercially available. They were selected based on 18 tests across the state on site/soil types including infertile "flatwoods," sandhills, dredged bay soil, muck soil, and clay soil in phosphate-mined lands. These cultivars have fast growth, excellent stem form, tolerance to various site conditions, coppicing ability, freeze resilience, and ease of propagation compared to 4th-generation E. grandis seedlings. We describe 1) the unique characteristics of the four cultivars and 2) report their early field performance.

The four cultivars differ in several characteristics, their genetics, and wood chemistry (Table 1). Cultivar G3 was susceptible to high velocity winds while G4 was resistant. The cultivars showed average to excellent frost tolerance and good coppicing ability. G1 and G2 are 4th-generation selections, while G3 and G4 are 2nd-generation selections. Their "genetic fingerprints" have been determined for eight microsatellite markers. G4 has the densest wood with lowest moisture content, G3 has the lightest wood and highest moisture content, and G2 has more typical E. grandis wood density and moisture content. Based on annual average number of freezes and land types represented by the tests, all four cultivars are suitable for planting in south Florida while only G2, G3, and G4 are suitable for central and even north Florida.

Three cultivars, planted at six peninsular Florida sites ranging from productive agricultural land to underutilized phosphate mined lands in 2009 and another seven sites in 2010, survived well under often adverse weather conditions, were up to 6.9 m tall in 16 months (Figure 1), and typically tolerated the exceptionally cold weather of January-February 2010. The cultivars had minimal to no freeze damage during the 2009-2010 freezes except in one test. Commercial plantings, two in 2009 and two in 2010, further substantiated cultivar performance in the 13 studies.

Wood analyses have identified bioenergy products for which the cultivars may be used. The major saccharides in one cultivar were glucan and xylan at 41.8 and 10.4 percent, respectively, which resulted in a Polydispersity of Plant Biomass Recalcitrance (PPBRg-x) of 4.5 percent, a relatively low value compared to other biomass feedstocks (Zhu and others 2011).

Overall, progress to date with E. grandis and its potential illustrate how genetics and biotechnology can produce optimal tree populations for bioenergy production. Because of their exceptional performance and potential as SRWCs, the G1, G2, G3, and G4 cultivars may be widely planted in Florida for mulchwood, pulpwood, and various bioenergy applications.

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Table 1—Description and recommended planting areas of G1, G2, G3, and G4 cultivars

	Cultivar			
Characteristic	G1	G2	G3	G4
Growth	Fast	Fast	Fast	Fast
Freeze-resilience	Average	Good	Excellent	Excellent
Windfirmness	Susceptible	Average	Average	Resistant
Coppice	Good	Good	Good	Good
Tissue Culture Propagation	Readily	Readily	Readily	Good
Propagation induced variablity	No	No	No	No
Pedigree (generation)	4th	4th	2nd	2nd
Wood density (kg/m^3)	-	522	470	640
Wood moisture content (dry wt)	-	104%	129%	89%
Recommended planting area				
South Florida (<2 freezes)	Yes	Yes	Yes	Yes
Central Florida (2-5 freezes)	No	Yes	Yes	Yes
North Florida (>5 freezes)	No	Yes	Yes	Yes

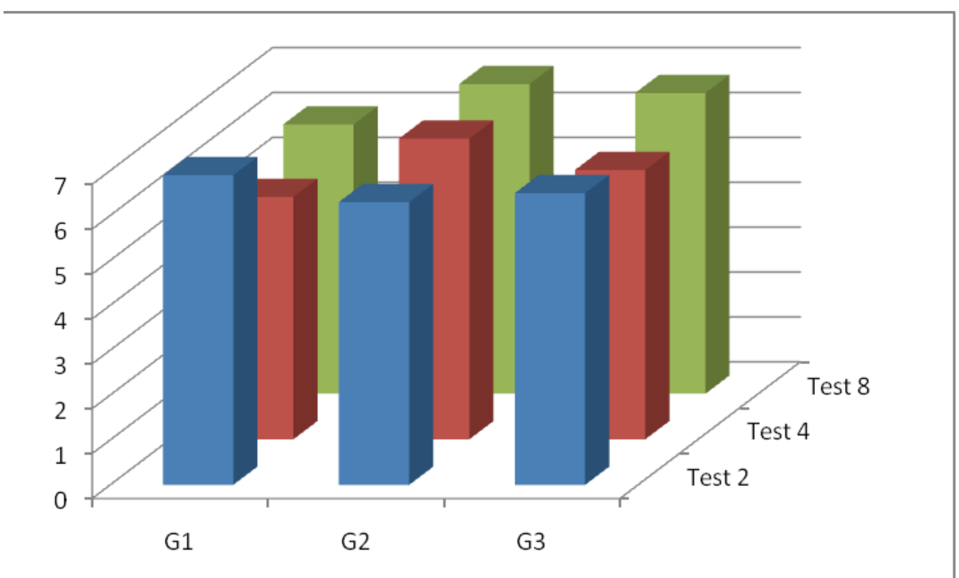

Figure 1—Average height (m) of G1, G2, and G3 cultivars in three tests at 15, 15, and 16 months, respectively.

COMPARISON OF ADVANCED GENETIC LOBLOLLY PINE PLANTING STOCK

R.J. Rousseau[1], S.D. Roberts[2], and B.L. Herrin[3]

ABSTRACT

Forest landowners have several options when it comes to selecting planting stock for loblolly pine plantations. The majority of plantations established over the past two decades have been planted with 2nd-Generation open-pollinated (2nd-Gen) seedling stock. Today, landowners can increase their yields using more sophisticated planting stock such as Mass Control Pollinated (MCP) or Varietal (clonal) stock. Substantial gains have been estimated when using either MCP or Varietal stock. Forest biotechnology firms are currently producing loblolly pine varietal planting stock for deployment in the southeastern US. Currently, however, the cost of varietal planting stock is considerably higher than that of both standard open-pollinated and MCP seedlings. Landowners need to know if the increased gains from the improved genetic material will be great enough to offset increased plantation establishment costs. In 2007, a Loblolly Pine Genetic Level Study was installed in northern Mississippi to examine differences in growth and form among 2nd-Gen, MCP, and Varietal planting stock. Third-year measurements showed that on average, MCP trees were significantly taller than either the Varietal or 2nd-Gen stock types. However, the top five performing varieties averaged nearly 0.5 feet taller than the MCP trees, and 1.0 feet taller than the 2nd-Gen stock. Results from fourth-year measurements will be presented.

INTRODUCTION

Genetics has played a major role in increasing growth rates of forest tree species around the world. Some of the most sophisticated pine tree improvement programs are found in the southeastern United States. Covering this region are three tree improvement cooperatives that have been working on genetically improving pine for over 50 years. Approximately 14 million dollars are spent annually to breed, test, select, and produce improved loblolly and slash pine. The results have been impressive with every analysis showing that the returns on investment from planting genetically improved loblolly and slash pine are very high (McKeand et al. 2007)

Today, over 75% of the United States tree planting occurs in the southeastern United States with over 95% of the loblolly and slash pine seedlings being genetically improved. By 2000, 59% of all the loblolly pine plantations in the South were being planted with open-pollinated (OP) seedlings in single family blocks (McKeand et al. 2006). A single family is defined as seedlings produced from the seed of one specific highly selected individual (genotype) within a seed orchard. Family seed are sown separately in the nursery and planted separately in the field. This is in contrast to a seed orchard mix, where cones from a number of individuals in a seed orchard are collected and mixed together. This mixture of seed is grown in the nursery and planted in the field as a seed orchard mix. Thus, a seed orchard mix would contain a number of OP families which results in a greater degree of genetic variability in comparison to a single OP family. Although reduced genetic variation is of some concern for OP family plantings, there have been no reported problems associated with single family plantings, as long as the seedlings are planted in the correct climatic zones (Schmidtling 2001). Stands established from an OP single family tend to be more uniform than a seed orchard mix. Increased stand uniformity is the result of using only one selection and allowing that selection to exhibit its genetic superiority in the resulting offspring (seedlings).

Currently, approximately 800 million loblolly pine seedlings are planted annually in the southern United States, with a great majority of these seedlings being open-pollinated. The genetic improvement level of loblolly pine has risen considerably, with the standard being either 1.5 generation (i.e. 1st-generation orchard thinned down to only the best genetically superior stock) or 2nd-Generation seedlings (Rousseau 2010). However, we have begun to see more 3rd-generation or 3rd-cycle seedlings being offered. In addition to the typical open-pollinated seedlings, we have also begun to see the emergence of full-sib and varietal pine seedlings.

Full-sib seedlings are the result of crossing two highly selected individuals, which takes advantage of the known genetic quality of both parents. Full-sib seedlings were previously used only for research as they were too expensive and time consuming to produce in great quantities. However, today full-sib seedlings are being produced through an operational scale process known as mass control pollination (MCP) (Figure 1). The increased cost of MCP production results in a higher seedling cost ranging from $120 to $140 per thousand, as compared to OP seedlings that range from $50 to $75 per thousand.

Varietal pine represents the top genetic level of pine tree improvement today. The term varietal was given to the development of pine clones (Rousseau 2010). Varietal pine seedlings are produced through either hedging or somatic embryogenesis. Hedging is a simple technique where young

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juvenile seedlings are cut back to produce numerous growing tips that are harvested and propagated into seedlings. Somatic embryogenesis is a technique where embryos are removed from the seed and placed into a system that allows it to multiply. These embryos are grown on a specialized media to form a seedling, which is an identical copy of the original. In this process it is possible to place the resulting embryos in liquid nitrogen (cryopreservation) until the genetic testing is complete. Although, these techniques are not cheap, as reflected in the seedling cost of $435 per thousand, they do provide the grower with the highest quality genetic material available.

No matter what type of improved pine selected, it is imperative to understand how that material will perform on that particular planting site. Initially, seed orchard mixtures were used to provide a sort of genetic buffer to the variety of sites being planted across the South. Later, with an increased understanding of progeny performance from each seed orchard selection as well as the type of sites these selections performed well on, single family plantings became the norm. However, each year an increasing amount of acreage is being planted to MCP and varietal seedlings. Each landowner should be fully aware of the performance of these advanced genetic seedlings in their general area prior to planting in order to realize the genetic potential.

With this understanding Mississippi State University Department of Forestry installed a test to examine differences among selected open-pollinated 2nd-Generation seedlings, a selected MCP family, and varietal loblolly pine seedlings.

COMPARISON OF LOBLOLLY PINE GENETIC TYPES

Test establishment--The test site is located on the Mississippi Agriculture and Forestry Experiment Station located in north Mississippi near Holly Springs. The soil is a combination of a Loring silt loam and a Cahaba-Providence complex. The test site was primarily in Bermuda grass as it was previously used for cattle grazing as well as hay production. Site preparation included a sub-soiling in March of 2007 to a depth of 14 inches on 12 foot intervals and a March 2007 glyphosate banded treatment directly over the sub-soiled rows. The test was hand planted in April 2007 at a spacing of 12 x 9 feet (i.e. 403 trees per acre). In addition, at the time of planting a single 20mg SilvaShield tablet was placed directly into the planting hole, to control pine tip moth. In May 2008 the test received a broadcast application of Oustar.

The three types of planting stock included a single MeadWestvaco select 2nd-Generation OP family, a single MeadWestvaco select MCP family, and ArborGen Varietals. The seedlings of both the open-pollinated and MCP families were 1-0 bareroot stock while the varietals were containerized stock. The MeadWestvaco 2nd-Generation OP and MCP families were selected based on their known performance in southwest Tennessee. The varietal plots were a mixture of 57 different varieties, making it difficult to directly compare the performance of any single variety to the 2nd-Generation OP and MCP plots. The field design is a randomized complete block where the seedlings of the 3 genetic types were planted in 100 tree blocks across the site and replicated 6 times. Thus, 600 trees of each type of planting stock has been measured and evaluated through the 2010 growing season.

RESULTS

Test survival was 93 percent at the end of the first growing season. Although survival was certainly good, the heavy Bermuda grass competition and the drought played a major role in seedling mortality. The varietal seedlings had the lowest age-one survival at 87 percent. This was probably due to the smaller root system of the type of containerized seedlings used in comparison to the bareroot stock of the 2nd-Generation and MCP seedlings. By age four there was little change to test survival, which dropped to 92 percent. Survival differences among the three genetic types at age four showed no distinguishable trend. The slight change in test survival between age one and four emphasizes the fact that proper site preparation and herbaceous competition control is critical to plantation success.

Total height was measured each winter, to determine early-age performance and later correlate that to more mature performance. At the end of the first growing season there was very little difference among the three genetic types (table 1). The lack of significant genetic differences may have been the result of intense herbaceous (i.e. Bermuda grass) competition outcompeting all the genetic sources for moisture during a very droughty first growing season. By age two, the MCP seedlings were the tallest at 5.4 feet, followed by the 2nd-Generation open-pollinated seedlings and the varietal seedlings. At age three the MCP seedlings were still the tallest at 10.4 feet, followed by the 2nd-Generation open-pollinated seedlings and the varietal seedlings at 9.6 feet. The MCP seedlings remain the tallest at age four at 15.8 feet, with the 2nd-Generation open-pollinated seedlings 1.1 feet shorter at 14.7 feet, and the varietal seedlings 1.6 feet shorter at 14.2 feet. Diameter at breast height (DBH) also followed the same trend as seen in total height, where the MCP seedlings were the largest at ages three (2.0 inches) and four (3.5 inches) (table 1).

Height growth increased on a yearly basis from approximately 3 feet between age one and two, to over 4.5 feet between age two and three, to over 5 feet between age three and four. As expected height growth followed the same pattern as total height, with MCP seedlings exhibiting the most rapid growth.

The superior performance of the MCP seedlings to the 2nd-Generation OP seedlings was expected, since both parents are selected. This higher genetic level resulting from a specific mating has manifested itself through greater diameter and height performance, at least through age four. It is unfortunate that the test did not include a single highly selected varietal, which would have made a more valid comparison to the other two genetic types. However, the inclusion of the 57 individual varietals provides an insight to difficulty of selecting the one correct varietal that would be best for this northern Mississippi site or for that case any particular site.

Age-four height of the varietal seedlings indicated a wide variation in performance, ranging from 11.0 to 17.0 ft. This variation is expected when 57 varieties are being evaluated. Varietal 329 is among the three tallest varieties from age two to age four. Although, varietal 228 was not among the tallest varietal at age two, it was the tallest varietal at ages three and four (table 2). In comparison to the MCP seedlings, varietal 228 was 1.2 ft. taller. However, DBH of 228 was a little smaller than the MCP seedlings averaging 3.1 in., in comparison to the average DBH of the MCP seedlings of 3.5 inches (table 2).

CONCLUSION AND MANAGEMENT IMPLICATIONS

The comparison of the MCP family to the select 2nd-Generation OP family is certainly valid and indicates that this specific MCP family easily outperforms the 2nd-Generation OP family, with faster growth through age four. In addition, the MCP family performed equally well with the top performing varieties. However, landowners must recognize the fact that this is only one test and that it may not apply to their property. In addition, form and wood characteristic traits are extremely important to the sawtimber market. To date, these traits have yet to be adequately measured but will be included as the test ages.

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Table 1—Mean total height and dbh of the three genetic types from age one to age four tested on the MAFES site near Holly Springs, MS

	-------Total Height------- (ft)				----DBH---- (in)	
Genetic Type	Age 1	Age 2	Age 3	Age 4	Age 3	Age 4
Single 2nd-Gen. OP	1.9a[1]	5.0b	9.6b	14.7b	1.7b	3.1a
MCP	2.0a	5.4a	10.4a	15.8a	2.0a	3.5a
Varietal	1.9a	4.9b	9.6b	14.2b	1.5b	2.7b

[1] – Different letters following the means represents significant differences at the 0.05 level

Table 2—Comparison of total height between the MCP type and selected varietal types from age two to age four on the MAFES site near Holly Springs, MS

Genetic Type	------------Total Height------------ (ft) Age 2	Age 3	Age 4
MCP	5.4	10.4	15.8
Top 3 Varietal	6.2	11.2	16.4
Best Varietal	6.3 (329)[1]	11.6 (228)	17.0 (228)

[1] – Number within the parentheses represents the specific varietal number of the top performer

Figure 1—Mass control pollinations taking place in a seed orchard (left), here a worker applies pollen from a single selection inside the bag to a selected female thus making a full-sib cross; Seed orchard photo showing bags that isolate those selections from any outside pollen source, eventually the bags will decompose allowing the mass control pollinated cones to mature (right). Photos by MeadWestvaco.

DEVELOPMENT OF AN APPLIED BLACK WILLOW TREE IMPROVEMENT PROGRAM FOR BIOMASS PRODUCTION IN THE SOUTH

Randall J. Rousseau, Emile S. Gardiner, and Theodor D. Leininger

ABSTRACT

The development of rapidly growing biomass woody crops is imperative as the United States strives to meet renewable energy goals. The Department of Energy has indicated that biomass is a prime source for renewable energy for the southern United States. Black Willow (*Salix nigra* Marsh.) is a potential bioenergy/biofuels crop for dedicated short-rotation plantations. However, there has been very little genetic development of this species. In 2009, 100 individual one to two year-old whips were selected from five geographic areas and grown in a stool bed near Stoneville, MS. One year-old whips were harvested in February 2010, cut into 14-inch dormant unrooted cuttings, and graded by diameter. The initial study in determining genetic worth is a screening trial where all clones are tested, but with a limited number of ramets per clone. The 2010 black willow screening trial consists of two locations, four blocks, and 100 clones arranged in two tree-row plots at a spacing of 10 x 3 feet. While age-three selections will be used to determine genetic potential, age-one performance will provide insight into clonal performance among the five geographic areas. Selections from the screening trial will be included in highly replicated clone tests. Selections from the screening trial will provide the first genetically improved black willow clones for use in short-rotation plantations.

INTRODUCTION

As the United States moves to increase its production of renewable energy, biomass must play a greater role, especially in the Southeast. Fast-growth tree species, such as poplars (*Populus* spp.) and willows (*Salix* spp.), have been included with energy crops, such as switchgrass (*Panicum virgatum* L.), giant miscanthus (*Miscanthus* x *giganteus*), and energy cane (*Saccharum* spp. L.). Like any crop, tree species grow best when carefully matched to suitable soils. It is important to remember that the production of biomass must be sustainable, must be done with limited inputs, such as fertilizer or irrigation, and must not compete with food sources for land use.

Unlike annual crops, perennial energy grasses, and poplars, black willow (*Salix nigra* Marsh.) grows well on soils that remain wet for long periods during the year. While this type of site is considered marginal for agriculture, it is exactly what is needed to be included in the portfolio of renewable energy options. In essence, black willow biomass production would not remove land from food production and it would utilize sites previously limited in income potential.

Very little research has been undertaken on black willow or willows in general for the southeastern United States, primarily due to its limited economic value. However, the State University of New York College of Environmental Science and Forestry (SUNY-ESF) has had an on-going willow research effort dating back to the 1980s, which has focused on shrub willows, many of which are suited to much colder environments (Abrahamson 2002, Kopp et al. 2001). Since that time, over 20 organizations have formed a Salix Consortium to develop a willow biomass program. Willows represent a viable model for the northeastern and north central United States as a canker disease, (*Septoria musiva* Peck), has severely limited the use of hybrid poplars. Although this program has been successful in the northeastern United States, a willow program has yet to be adopted in other parts of the United States (Volk et. al 2004, Perlack et al. 2005).

Black willow has several key traits that may prove beneficial as a candidate biomass species. These include rapid growth, excellent rootability, ease of vegetative propagation, coppice ability, and exceptional growth on wet sites. Currently, no disease is known that would significantly impact operational use of black willow. Although, cottonwood leaf rust (*Melampsora medusae* Thüm.) will infect willows in the Lower Mississippi Alluvial Valley (LMAV), as it does eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.), the extent of this disease on black willow is an unknown. The ability of black willow to grow and seemingly thrive on poorly drained sites with little impact from diseases is a major reason to look into the development of this species for biomass production. Hybrid poplars have also been discussed as a possibility in the LMAV, but their lack of resistance to *Septoria* canker makes them an impractical choice at this time. Considering all of these factors, black willow seems to be an obvious choice on the heavy clay soils characteristic of poorly drained sites.

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The purpose of this paper is to provide landowners and others interested in growing biomass for bioenergy an initial look into current black willow research. In cooperation with the USDA Forest Service's, Center for Bottomland Hardwoods Research, Mississippi State University has been examining the propagation, silviculture, and genetics of black willow as a viable woody biomass source.

METHOD

The ease of vegetative propagation using dormant unrooted cuttings in *Salix spp.* allows for capture of the total genetic component through the use of clones. But, since black willow is being evaluated as a biomass species, the determination of suitable dimensions of planting stock must precede any other work.

CUTTING LENGTH STUDY

This study was designed to determine the optimal size of dormant unrooted cuttings to be used in experimental trials and operational plantations. It was established in the spring of 2009 on the Mississippi Agricultural Experiment Station (MAFES) near Stoneville, MS. The study design was a 3 x 4 x 3 factorial that included three cutting lengths, four cutting diameters, and three planting depths. Planting material used in this study was harvested from a single geographic source in Oktibbeha Co., MS. Whips were cut into lengths of 9, 15 and 21 inches and separated into diameters of ⅜, ½, ¾, and 1-inch. Planting depth was set by the length of the cutting left out of the ground. Thus, 9-inch cuttings were planted to a depth of 4 and 7 inches, 15-inch cuttings were planted to a depth of 7, 10, and 13 inches, and 21-inch cuttings were planted to a depth of 13, 16, and 19 inches. Prior to planting, the area was disked and sub-soil plowed to a depth of 21 inches. Cuttings were hand planted on a 6 x 10 ft spacing. A broadcast application of Goal® 2XL (oxyfluorfen) was used prior to black willow bud break to reduce herbaceous competition early in the first growing season. For the remainder of the first year, competing vegetation was controlled mechanically at a two-week interval. Canopy closure reduced competing vegetation during the second growing season minimizing the need for weed control. Measurements included total sprout height and basal diameter (one foot above the cutting) at age one, and sprout height and dbh at year two.

GENETIC TRIALS

The initial step in examining the genetic components of black willow is a clonal trial, which is labeled a genetic screening trial and encompasses a total of four sites. Two sites were established in each of 2010 and 2011 using clonal stock from a limited geographic area. The four sites chosen for the Genetic Screening Trial were selected because of their soil and moisture characteristics, which are poorly drained heavy clay sites. These types of sites are exactly where willow is expected to be planted for biomass production. Genetic stock studied in the Genetic Screening Trial was a collection of dormant black willow juvenile seedlings (i.e. called whips) from five different geographic sources in the winter of 2008-2009 (Table 1). The areas selected corresponded to those where some of the historically top performing eastern cottonwood clones originated. From each geographic source, four stands were located and from each of the four stands five individuals were harvested and placed into a stoolbed (i.e. nursery or cutting orchard) during the spring of 2009.

Material for the first two locations of the Genetic Screening Trial planted in 2010 were harvested from the one-year-old stoolbed established in 2009. During the original collection shown in Table 1, some sandbar willow (*Salix interior* Rowlee) was unknowingly collected. This material was maintained in the stoolbed and included in the test. Whips were harvested in the winter of 2010 and cut into 15-inch unrooted cuttings. The experimental design for the Genetic Screening Trial was a split-plot consisting of four blocks, with the main plots within each block designated by geographic origin except for the sandbar clones, which were grouped together. Clones within geographic origin were the sub-plot unit with each clone represented by a two-tree row plot and planted at a spacing of 3 x 10 feet.

The 2010 Genetic Screening Trial included two test sites, one located on the MAFES site near Stoneville, MS and the other located on a MAFES site near Prairie, MS. Site preparation at the Stoneville, MS location included disking and sub-soil plowing on 10-foot centers. Site preparation at the Prairie, MS location included an application of Accord® (glyphosate) at 2 quarts per acre in the summer of 2009, followed by disking, and sub-soil plowing at 10-foot centers. The Stoneville location was planted on April 22, 2010 and included 98 black willow clones and 13 sandbar willow clones. The Prairie, location was planted on April 28, 2010 and included 72 black willow clones and 10 sandbar willow clones. Immediately following the planting of each test location, the area was sprayed with a broadcast application of Goal® 2XL to control herbaceous competition. Survival, total height, and number of shoots were measured at the end of the first growing season.

The 2011 Genetic Screening Trial also included two test sites, one located at the MAFES site near Prairie, MS, and the other on a former rice (*Oryza sativa* L.) field near Hollandale, MS. Site preparation for the Prairie, MS location included disking, and sub-soil plowing at 10-foot centers. Site preparation of the Hollandale location included a chemical application of Roundup ProMax® (glyphosate) and sub-soil plowing at 10-foot centers. The Prairie location was planted on April 25-26, 2011, while the Hollandale, MS location was planted on April 27-28, 2011. Following planting at each location, Goal® 2XL was broadcast applied to control herbaceous competition.

RESULTS AND DISCUSSION

The Cutting Length Study indicated that the longer cuttings tended to result in better age-one and age-two height and that there were no significant age-one and age-two height difference based on cutting diameter. Age-three measurements will complete this study and from that information we will be able to conclude exactly what the optimal dimensions of the dormant unrooted cutting would be for biomass production.

The genetic screening efforts represent a good starting point as over 100 clones from five geographic areas have been included in four field trials over a two-year period. Survival of all four test sites has been good despite very little rainfall during the summer of 2010. However, the sandbar willow tested showed decreased survival at the end of age one when compared to black willow (Table 2). Although not reported here, preliminary rooting studies showed reduced rooting capacity of sandbar willow when compared to black willow. This reduced rooting capacity appeared to manifest itself in mortality in the field trials during moisture stress conditions.

There was very little survival differences among the five black willow geographic sources, with only a two percent range among the sources. This exceptional survival fulfills the first aspect of determining the potential of a biomass species. When used as a dedicated energy crop plantation, high survival rates of planting stock are imperative in maximizing yields. High survival rates are also necessary for possible future coppice regeneration.

Currently, there is no defined rotation length for black willow biomass plantations. However, estimates have suggested that for a black willow dedicated biomass plantation of 1,452 trees per acre, three years may be suitable. These trials will help define age/age correlations and maximum genetic gain per unit of time. During this time frame (i.e. age two) selections will be made and propagated for inclusion into highly replicated clone tests.

Determination of what geographic sources, if any, prove to be superior for the Lower Mississippi River Alluvial Valley would allow for an infusion of new clones into the willow testing scheme. Currently, the 100 plus clones barely scratches the surface of the test population needed to insure that selected clones are genetically superior. To this end, we hope to include additional germplasm into additional screening trials, along with the better clones selected from the first round of testing that will be used as controls. The entire process of clonal infusion, testing, and selection will follow similar processes used in the early stages of *Populus* improvement (Riemenschneider et al. 2001, Robison et al. 2006).

At this point, breeding of improved black willow is not being considered, as the first stage is to simply develop improved clones for operational deployment. But, with a fast-growth species like black willow, hopefully the clonal refinement program can be expanded and accelerated so that breeding may become an integral portion of the program.

SUMMARY

The work described in this manuscript represents an effort to evaluate and develop the potential of black willow as a biomass crop for bioenergy and biofuels. It is imperative to the attainment of renewable energy goals that marginal crop lands sustainably produce biomass crops that can be used for renewable energy. The ability of black willow to grow well on heavy clay sites that have proven difficult for other species makes it a prime candidate for biomass production. However, these sites are not without difficulty, since they are difficult to work due to the high amount of clay and ponding of water that will no doubt affect harvesting, planting, and silviculture practices.

In a little over two years we have been able to establish studies to determine optimal cutting size of unrooted cuttings, genetic screening trials of various geographic origins, stands, and clones, examine rooting architecture, determine that black willow clones are superior to sandbar willow clones on heavy clay sites, and begin to investigate additional propagule types. While the first round of testing has provided some useful guidelines, it has also raised a number of questions that must be answered prior to operational deployment of black willow into dedicated biomass plantations.

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Table 1—Geographic areas, river systems, and coordinates of the black willow cutting collection for the Mississippi State University – USDA Forest Service, Center for Bottomland Hardwoods Research Genetic Screening Trial

Geographic Area	River System	Latitude and Longitude Coordinates
Tunica, MS	Mississippi	34°50'N 90°16'W
Rosedale, MS	Mississippi	32°48'N 91°03'W
Morgan City, LA	Atchafalaya	29°41'N 91°12'W
College Station, TX	Brazos	30°37'N 96°32'W
Liberty, TX	Trinity	30°03'N 94°49'W

Table 2—Age-one survival of the Black Willow Genetic Screening Trial planted in 2010. The table shows comparison between the Prairie and Stoneville locations as well as black willow versus sandbar willow, and geographic sources of black willow

	-------------------Age–1 Survival------------------- (%)		
Location	Test	Blk vs Sbar[1]	Geographic Sources
Prairie, MS	88		
Black Willow		99	
Sandbar Willow		3	
Geographic Sources			
Tunica, MS			98
Rosedale, MS			100
Morgan City, LA			100
College Station, TX			98
Liberty, TX			100
Stoneville, MS	99		
Black Willow		99	
Sandbar Willow		99	
Geographic Sources			
Tunica, MS			100
Rosedale, MS			99
Morgan City, LA			99
College Station, TX			100
Liberty, TX			99

[1] Blk is the abbreviation for black willow, and Sbar is the abbreviation for sandbar willow.

TECHNOLOGY FOR BIOMASS FEEDSTOCK PRODUCTION IN SOUTHERN FORESTS AND GHG IMPLICATIONS

Bob Rummer, John Klepac, and Jason Thompson

ABSTRACT

Woody biomass production in the South can come from four distinct feedstocks—logging residues, thinnings, understory harvesting, or energywood plantations. A range of new technology has been developed to collect, process and transport biomass and a key element of technology development has been to reduce energy consumption. We examined three different woody feedstock production systems with detailed field studies including logging residues in central hardwoods, whole-tree pine thinning and clearcuts, and understory baling. Productivity ranged from 5 Mg per hour to over 23 Mg. However the corresponding energy consumption (diesel fuel) was very similar ranging from about 4 to 5.5 l/Mg. Intensive management technology for short rotation woody crops will have additional energy inputs for planting and stand management. Equipment manufacturers are working on even more efficient technology such as energy recovery swing systems, new powertrain designs, and improved productivity. This comparison suggests that intensive energywood production systems and understory harvesting may have the lowest harvesting energy input per ton of wood produced.

INTRODUCTION

The use of woody biomass for energy has the potential to become a major output from southern forests. In the Southern Forest Futures Project, Alavatapati and others (2011) evaluated biomass use over a range of potential scenarios reflecting population, markets, and forest stocks. By 2050 their analysis suggests that woody biomass use for energy would be somewhere between 50 and 100 percent of the volume used for conventional forest products. Some of this volume could come from shifts in demand for traditional pulp and sawlog harvest, other material will come from increased recovery of logging residues, energywood thinning and purpose-grown energywood plantations. The driving factors behind increasing woody biomass utilization are energy demand, policy developments encouraging renewable energy sources, and forest owners seeking new markets for biobased products.

While there are always concerns about the environmental effects of forest operations and wood utilization, the fact that woody biomass may be used for energy production has raised interest in the greenhouse gas (GHG) implications of these types of operations. For example, the Energy Independence and Security Act of 2007 sets threshold GHG levels for qualifying renewable fuels relative to conventional petroleum-based fuels. The EPA is mandated to conduct full life-cycle emission assessments for alternative fuel production processes. Similarly, the European Union developed a goal of a 20 percent reduction in GHG emissions concurrent with a 20 percent increase in renewable energy generation by 2020. In California, a timber company was recently sued for inadequately considering GHG implications of harvesting plans (Winship 2011). Ultimately the suit was dismissed although it highlights the need to have scientific assessments to quantify GHG implications of resource use.

There have been many studies examining the life-cycle impacts of forest production. Table 1 summarizes a sample. The Consortium on Research for Renewable Industrial Materials (CORRIM) developed life-cycle assessment metrics for biomass-based products (pulpwood and sawlogs) in the U.S. (Puettman and others 2010). For wood utilization in the southeast U.S. CORRIM considered a system boundary that encompassed stand establishment through harvesting and loading onto trucks. They modeled two harvesting systems—a small feller-buncher and grapple skidder working in thinning and a larger feller-buncher with a skidder working in final sawlog harvests. Athanassiadis (2000) performed similar calculations for cut-to-length harvesting in Sweden and Klvac and others (2003) evaluated cut-to-length operations in Ireland. These studies found CO_2 emission rates ranging from 9.7 to 15.0 kg/Mg_{dry} for felling and moving biomass from stump to truck. Trucking likely consumes as much energy as felling and skidding. Johnson and others (2005) estimated transport emissions for hauling forest products in the US South as 19.7 kg/Mg_{dry}.

Conventional forest harvesting systems typically focus on collecting and moving merchantable roundwood material. In cut-to-length harvesting biomass material is left in the woods and only solid logs are carried to roadside. Southern whole-tree harvesting systems may remove the stem with limbs and tops to roadside, but production effort is focused on recovering the stem. By contrast, biomass harvesting

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systems will add some activities to collect and transport the smaller components such as limbs and tops or even smaller typically non-merchantable trees. Because these materials have relatively low volume in each piece that is handled there is tendency for productivity to drop and the energy input per unit of volume output to increase. The objective of this paper is to review the types of forest operations that might be employed to recover woody biomass in southern forests specifically for energy and to compare estimated CO_2 emission values with conventional forest operations.

SOUTHERN WOODY BIOMASS HARVESTING SYSTEMS

Woody biomass in the South can come from four primary sources of material: logging residues, thinnings, restoration treatments, or purpose-grown wood. Each of these sources represents a unique combination of operating conditions, piece sizes, and potential energy applications. The systems that are evolving to operate efficiently involve highly specialized machines matched to the stand and materials.

LOGGING RESIDUES

Many studies have documented logging residues left behind after conventional product harvest. Bentley and Johnson (2008) measured harvest recovery factors on 80 active logging operations in Alabama for example. They found that about 12 percent of total softwood harvest volume was left as logging residue. Applying that value to annual harvest rates suggests that about 3.1M Mg_{dry} of softwood logging residues are generated each year in Alabama. There are similar studies for other southern states. The residue material is often the limbs and tops along with other non-merchantable material such as small trees or cull logs. With typical whole-tree logging systems the residues have been dragged on the ground, pushed into piles, driven over, and otherwise roughly handled. Because of this logging residues will often carry high ash content and are generally only useful for direct combustion as hogfuel.

The challenge is to collect logging residues in a cost-effective manner. Most southern harvesting systems are whole-tree operations that fell trees, drag them to roadside, and then process out the merchantable volume leaving limbs and tops in piles at roadside. Some operations will drag the residues back into the woods and scatter them while others will leave residues piles for later disposal or burning. A logging residue recovery system will either chip or grind material at roadside to reduce material to a form that improves truck transport and handling. If chipping occurs after logging is completed (cold chipping) then the residue recovery operation would likely use a large chipper or grinder with a separate loader. Cold chipping production is limited by the capacity of the chipper. Chipping concurrently with the logging operation (hot chipping) is limited by the production rate of residues and large chippers are often underutilized. One solution for hot chipping is to use a smaller less expensive chipper to better match residue production and improve machine utilization.

Westbrook and others (2007) compared a logging crew with and without residue recovery while clearcutting a 33-year-old pine plantation. The conventional operation recovered about 150 Mg/ha of sawlogs and only used about 2.7 l of fuel/Mg_{dry}. They tested residue recovery by adding a 260-hp chipper at the landing to hot chip residues. Residue recovery added 8.5 Mg/ha of chips with an additional 2.9 l/Mg_{dry} fuel consumption to operate the chipper. A final treatment added additional felling and skidding to collect even more of unmerchantable stand volume. Residue volume increased to 24.2 Mg/ha (about 15 percent of total stand volume). Fuel consumption per unit chip output in the most intensive recovery system was 5.6 l/Mg. The small chipper was well-matched to the production rate of residues in this system.

Logging residues are considered the “low-hanging” fruit of woody biomass feedstocks. Residues are generally available with little or no cost for felling or skidding because they are a by-product of the logging operation. In some management plans residue utilization actually creates savings on site preparation by avoiding additional clearing or pile burning. There have been concerns raised however about nutrient removals, erosion, and impacts on site productivity. Westbrook and others (2007) also analyzed chip samples in the study described above and estimated that in the most intensively utilized treatment an additional 27.0 kg/ha N, 2.8 kg/ha P, and 8.0 kg/ha K were removed.

BIOMASS THINNING

Southern forests are commonly prescribed thinning treatments to reduce competition and stress, address disease or insect outbreaks, and to maximize rotation productivity. For silvicultural reasons, there is a window of opportunity with earlier thinning favored to maximize biological response. Later thinning however improves the economics of the operation by getting higher product value and lower operational costs per acre. Generally the timing of thinning is determined by the combination of market and stand conditions. Thus a market for woody biomass in energy products may affect southern thinning opportunities by providing more economic value in smaller trees.

Munsell and Fox (2010) modeled various management scenarios for loblolly pine plantations. The analysis considered variation in planting density, management intensity, product recovery options and site classification. They concluded that an intensive management regime (fertilization, competition control) with integrated product recovery over a 24-year rotation was the most financially attractive scenario. Thinning entries were generated whenever the stand reached a basal area of 30 m^2/ha. Harvest volumes were segregated to the highest product values with a mix of biomass, pulp and sawlog outputs. They also modeled an energy-only management regime of

8-year rotations planted at 1835 trees/ha. With a biomass stumpage price of about \$11.50/Mg_{green} landowners would breakeven between the integrated or energy-only management regimes. The conclusion of such analysis shows that given a market for energy products, forest landowners would have new options for treatments, product recovery and financial return.

The general pine thinning model has even been refined to optimize production of multiple products. In this scheme, rows of open-pollinated pines (biomass crop) are alternated with rows of genetically selected pine for sawlog production (Arborgen 2009). This trademarked management system optimizes economic inputs of planting stock, fertilization and vegetation control.

Conventional mechanized thinning systems are well-adapted to biomass thinning treatments. Smaller wheeled feller-bunchers equipped with sawheads are the most common felling machine. Grapple skidders efficiently move piles of wood to roadside. This system would have energy input like the southern thinning operation modeled by the CORRIM study (approximately 4.8 l/Mg). A simple variation would add roadside processing to convert the feedstock to chips prior to transport.

RESTORATION TREATMENTS

Biomass markets may give forest landowners new options for vegetation removal to accomplish objectives like invasives control, fuel reduction, or stocking manipulation. Traditionally such treatments generate unmerchantable material that has to be shredded or burned for disposal. Mulching machines are commonly used to clear vegetation up to about 15 cm diameter. Several manufacturers have developed modified versions that can collect the chopped biomass. One manufacturer's design cuts and chops and then blows the chips into a trailer for transport to roadside. Two alternative designs collect the chopped material in baling systems that create dense round bales like agricultural material.

Klepac and Rummer (2010) evaluated a baling machine harvesting understory biomass from a 28-year-old pine plantation in south Georgia. The baler cut and baled vegetation between planting rows including a mix of understory shrubs (i.e., wax myrtle, gallberry, saw palmetto, red maple). Pre-treatment sampling estimated 12.6 Mg/ha of total understory aboveground biomass. About one-third of the total biomass was recovered in bales with the remainder left as uncut stems, stumps and down material. At a production rate of 4.9 Mg/hr the net fuel input for the baler was 2.7 l/Mg_{dry} and bale forwarding added 1.4 l/Mg for a total of 4.1 l/Mg. Because the baler produces a very coarse material additional energy input may be necessary to re-chip the bales at the point of use.

Understory biomass can be available for zero or negative cost since its removal accomplishes other valuable management objectives. An understory treatment may be used in lieu of burning to reduce fuels. It may also be used to reduce vegetative competition or improve herbaceous composition for wildlife. The value of these treatments should be combined with the value of the removed biomass in determining economic feasibility of this type of biomass recovery.

PURPOSE-GROWN ENERGYWOOD

Biomass assessments like the Billion Ton report (Perlack and others 2005) suggest that potential energy demands could exceed available biomass from existing sources such as thinning, logging residues, and fuelwood. Depending on how market demand develops there may be opportunities for purpose-grown energywood. There are many options for short-rotation woody crop (SRWC) plantations in the South including eucalypts, hybrid poplar, willow and pine (Schuler and others 2009). The selection of the most appropriate species is affected by many factors and there are still many uncertainties about how and where short rotation woody crops could be deployed. A generic model however could be a hardwood, grown on 3-year coppiced rotations. The Oak Ridge Energy Crop County Level database (Graham and others 1997) estimates woody crop growth rates in the South of about 10 Mg_{dry}/ha/yr.

Harvesting technology for coppicing SRWC plantations is still in its infancy. The most developed approach is a modified forage harvester that cuts and chips into a shuttle trailer system (Volk and others 2010). Recent tests have demonstrated a production rate of up to 0.7 ha per hour with willow stems up to 10 cm in diameter. The development team is working to improve performance for both willow and hybrid poplar. A current estimate of energy input would be about 3 l/Mg for the cut-and-chip operation. To get the chips to roadside would require an additional 1.5 l/Mg for a chip forwarding system.

There are other forms of purpose-grown wood that may be applicable for the South. For example, Scott and Tiarks (2008) describe a trial of direct-seeded pine grown between rows in a conventional pine plantation. The energy wood planting harvested at age 5 produced an additional 10 Mg/ha without reducing conventional plantation yield at final harvest. Like coppice systems however production harvesting technology is not fully developed. Another concept is the "flex stand."

SUMMARY

The development of woody biomass markets will change management practices in southern forests. The option to remove material that has previously been unmerchantable will allow forest managers more flexibility in prescriptions. Early thinnings may be more economically viable, initial planting density and intermediate treatments can be reconsidered. At the extreme, purpose-grown energywood plantations may be developed to meet demand for energy products. Biomass markets could return additional value to landowners. By adding additional value to management, biomass markets could help maintain southern forests.

This review of biomass production studies suggests that direct energy inputs for producing woody biomass are not greatly different from conventional forest products harvesting, ranging from about 4 to 6 l/Mg (Table 2). Logging residues are the least energy-intensive feedstock when the residues are available at roadside. Chipping is currently energy-intensive and requires about as much energy input as felling and skidding combined. Stump-to-truck energy inputs will be about half of the total delivered energy input of woody biomass feedstocks. Efforts to reduce GHG emissions from biomass utilization must address transportation efficiencies as well as in-woods operations.

Finally, forest operations are evolving. Off-highway equipment engineers are finding new ways to operate more efficiently and these developments are beginning to show up in forest machinery. Improved operator interface systems, more efficient hydraulics, and new off-road engine designs will reduce fuel use per unit of work. Diesel-electric hybrids have even been introduced for construction applications. The basic operational technology of handling wood is also being reconsidered. Purpose-grown wood, with smaller piece size, offers new opportunities for alternative methods of cutting and handling. Balers, swath cutters and modified agricultural machines may find new applications in forest management.

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Table 1—Direct energy input and CO_2 emissions for production forest operations (per Mg_{dry})

Reference	Region	Harvesting system	Fuel Use (l/Mg)	CO_2 output (kg/Mg)
Johnson and	Southeast	Thinning with small feller-	4.8	13.0
others (2005)	U.S.	buncher/skidder	5.2	14.0
Johnson and	Southeast	Final harvest large feller-	7.3	19.7
others (2005)	U.S.	buncher/skidder	3.6	9.7
Johnson and	Southeast	Truck transportation	5.7	15.4
others (2005)	U.S.	Cut-to-length harvester/forwarder		
Athanassiadis	Sweden	Cut-to-length harvester/forwarder		
(2000)	Ireland			
Klvac and others				
(2003)				

Table 2—Direct energy input and CO_2 emissions for woody biomass harvesting (per Mg_{dry})

Feedstock	Reference	Harvesting system	Fuel use (l/Mg)	CO_2 output (kg/Mg)
Logging	Westbrook and others	Chipping only roadside residues	2.7	7.3
residues	(2007)	Felling, skidding and chipping	5.6	15.1
		residuals	4.8	13.0
Pine thinning	Johnson and others	Wheeled feller-buncher, grapple	4.1	11.1
Understory	(2005)	skidder	4.5	12.2
Short rotation	Klepac and Rummer	Baling harvester with forwarder		
	(2010)	Coppice harvesting		
	Volk and others			
	(2010)			

EFFECTIVENESS AND COSTS OF OVERLAND SKID TRAIL BMPS

Clay Sawyers[a], W. Michael Aust[b], M. Chad Bolding[c], and William A. Lakel, III[d]

ABSTRACT

Forestry Best Management Practices (BMPs) are designed to protect water quality; however, little data exists comparing the efficacy and costs of different BMP options for skid trail closure. Study objectives were to evaluate erosion control effectiveness and implementation costs of five overland skid trail closure techniques. Closure techniques were: waterbar only (Control), waterbar plus seed (Seed), waterbar plus seed and mulch (Mulch), waterbar plus hardwood slash (Hardwood), and waterbar plus pine slash (Pine). Techniques were replicated on four skid trails. Sediment traps were used to capture sediment for 13 months. Data indicated that Mulch was the most effective for controlling erosion (1.5 tons/acre/year), followed by Hardwood (2.3 tons/acre/year), Pine (2.4 tons/acre/year), Seed (6.1 tons/acre/year), and Control (10.8 tons/acre/year). Incorporating slash dispersal and compaction onto overland skid trails during harvesting activities may be the best option for reducing BMP costs and potential erosion, but all treatments may be appropriate for certain situations.

INTRODUCTION

Major sources of sediment associated with timber harvesting are haul roads, skid trails, and log landings (Megahan and Kidd 1972, Yoho 1980, Madej 2001). Large sediment yields result from timber harvesting with poor planning and execution, and water quality considerations are necessary when developing logging access (Yoho 1980). Kochenderfer (1977) found that roads, trails, and landings accounted for 10% of a skidder harvested area. Martin (1988) found similar numbers at harvest sites in New England where 8–18% of mineral soil was exposed. Jackson et al. (2002) found that roads, decks, and skid trails accounted for 25% of the area within a harvest in Bolivia. Litschert and MacDonald (2009) evaluated nearly 200 logging units from 2 to 18 years old and found that 83% of erosion features connected to stream channels originated from skid trails. State forestry BMP recommendations specify skid trail closure techniques that can be used to minimize erosion (Shepard 2006), but few studies have been conducted to show the actual amount of erosion prevented by specific treatments (Aust and Blinn 2004, Anderson and Lockaby 2011).

Costs to install BMPs are important to loggers, forest landowners, and the forest industry (Shaffer et al. 1998). Implementation time and associated BMP costs have been evaluated in the past through surveys and questionnaires (Shaffer et al. 1998, Montgomery et al. 2005, Bolding et al. 2010), literature reviews (Aust et al. 1996), and engineering approaches using available maps (Ellefson and Miles 1985, Lickwar et al. 1992). Ellefson and Miles (1985) found that loggers could lose as much as 60% of their net revenue when all BMPs are applied. Logging contractors in West Virginia also paid an average of $1,426 per employee for formal BMP training (Egan et al. 1996). Loggers directly incur most of the BMP costs in both the lumber and paper sectors of the forest products industry (Sun 2006), but these costs are typically passed to the land or timber owner through lower stumpage prices (Cubbage 2004). Montgomery et al. (2005) found that BMP implementation and compliance in Arkansas led to a 3.5% decrease in annual tonnage produced from 1998 to 2005. BMPs are the key to maintaining water quality and site productivity; therefore, understanding the most cost-effective implementation methods prior to harvest is a great advantage for operators (Shaffer and Meade 1997).

The primary objectives of this study were to evaluate the effectiveness and costs of five closure techniques on overland skid trails. Erosion rates were directly measured from different BMP treatments: 1) waterbar only, 2) waterbar plus grass seed, 3) waterbar plus grass seed and straw mulch, 4) waterbar plus pine slash, and 5) waterbar plus hardwood slash. Actual costs to install the BMP treatments were recorded and were provided cost estimates for skid trail closure.

METHODS

STUDY SITE

This study was conducted near Critz, VA at the Reynolds Homestead Forest Resources Research Center in the western Piedmont physiographic region. The topography of the area consists of rolling hills with sideslopes typically ranging from 10-30 percent. Average annual rainfall is 49.3 inches with additional snowfall accumulations of 10.5 inches annually (Patrick County, VA 2011). The principal soil series on the site is Fairview sandy clay loam (Fine, kaolinitic, mesic Typic Kanhapludults) (NRCS 2011).

To facilitate data collection, a timber harvest was conducted on a 29 acre stand. The forest stand was a combination of old-field Virginia pine (*Pinus virginiana*) on the ridgetops

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and mixed upland hardwoods with scattered Eastern white pine (*Pinus strobes L.*) on the sideslopes. Approximately 106 tons/acre were harvested and 4,997 feet of primary overland skid trails were established during the operation. The total area of skid trail was approximately 1.4 acres or 4.9% of the harvested area.

TREATMENTS AND DATA COLLECTION

After harvesting, four primary overland skid trails with similar soils and slope were selected for treatment with each trail representing a designed block. Five BMP closure treatments were randomly applied to each of the four trails (blocks) to provide 20 treatment plots or experimental units. The five treatments were: (1) waterbars only (Control); (2) waterbars plus lime, fertilizer, and seed (Seed); (3) waterbars plus lime, fertilizer, seed, and coverage with straw (Mulch); (4) waterbars plus coverage with pine slash (Pine); and (5) waterbars plus coverage with hardwood slash (Hardwood). The segment of skid trail between the crest of two consecutive waterbars formed a treatment area approximately 12 feet wide and 50 feet long.

A sediment collection system was designed for each experimental unit (20) using geotextile sediment traps known as Dirtbags® and PVC (ACF Environmental, Richmond, Virginia). The custom ordered Dirtbags® used in this study were approximately 4 feet wide and 6 feet long. To facilitate sediment flow, a gutter was constructed from a 20 foot piece of 6 inch Schedule 40 PVC by cutting out the top half of the circular piece of pipe. Three feet of the downslope end of the pipe remained intact to connect to the fill spout of the Dirtbag®. After harvest completion, a logging contractor was hired to apply pine slash and hardwood slash treatments to the respective experimental units. All logging slash used was on site from the recently completed timber harvest. A John Deere 648E rubber-tired grapple skidder was used to gather, place, and compact the slash in the treatment areas.

The Seed and Mulch treatments each had grass seed, lime, and 10-10-10 fertilizer applications. The grass seed, Contractor's Utility Mixture, consisted of 50% tall fescue and 50% annual ryegrass; a mixture that is commonly used for seeding skid trails in the area (Virginia Department of Forestry 2002). Grass seed was broadcast on Seed and Mulch treatments at a rate of 265 lbs/acre. Fertilizer was applied at the equivalent of 200 lbs/acre and lime was spread at the equivalent of one ton/acre per appropriate treatment area. These soil amendments are typically recommended to facilitate grass establishment on Piedmont skid trails (Virginia Department of Forestry 2002). The Mulch treatments received a complete coverage of wheat straw mulch, which generally required two square bales per treatment area. The grass seed, fertilizer, and lime were broadcast with a hand-crank spreader, and the straw mulch was spread by hand.

Erosion quantities from each of the 20 treatment areas were evaluated monthly from August 2009 through August 2010 for a total of 12 measurement periods; February 2010 was delayed due to snow cover. Each treatment sediment trap was detached from the gutter and weighed to the nearest 0.2 pounds with a digital, 1,200 lb capacity crane scale (Citizen Scales Inc., Edison, New Jersey). Monthly sediment weights were adjusted for soil moisture, bag moisture, and sediment trapping efficiency.

Costs for installations of the five BMP treatments to the four overland skid trails were recorded and compiled. The skid trail closure techniques were installed or directly supervised by the researchers; therefore, all time and expenses were recorded. Equipment and labor rates for slash treatments were based on the actual charges by the skidding contractor who placed and compacted slash on the appropriate treatments. The equipment rate was \$50 per hour and the labor rate was \$25 per hour. Expenses were then converted to a cost per mile basis to produce cost estimate tables for the particular BMP applications.

STATISTICAL ANALYSIS

Data from the overland skid trails were analyzed as a Randomized Complete Block Design with four blocks of five BMP treatments for a total of 20 treatment areas and 12 repeated measures in each treatment area. The twelve monthly measurement periods required the use of repeated measures within the design. Analyses were performed with Number Cruncher Statistical Systems software (Hintze 2001) using the GLM ANOVA Repeated Measures procedures and the Tukey-Kramer mean separation test to verify significant differences between treatments. All significant differences were based on an alpha level of 0.05.

RESULTS AND DISCUSSION

EROSION CONTROL

The sediment trap data indicated that erosion rates for the overland skid trail closure treatments were significantly different ($p < 0.0001$) (Figure 1). The Mulch (1.5 t/a/y), Hardwood (2.3 t/a/y), and Pine (2.4 t/a/y) treatments had similarly low erosion rates and were effective at minimizing skid trail erosion. The Control treatment had the highest erosion rate (10.8 t/a/y) followed by the Seed treatment (6.1 t/a/y). The Control and Seed treatments had significantly different erosion rates from all other treatments while the Mulch, Hardwood, and Pine treatments showed no significant differences from each other

Monthly soil erosion by treatment and precipitation are displayed in Figure 1. The soil remained relatively stable in all treatments during the first half of the study, even though some months had considerable rainfall. The November 2009 collection period received 8.35 inches of precipitation, but the soils still had low rates of displacement. Warmer spring temperatures, which thawed frozen soils, and intense rainfalls preceded an increase in soil erosion. Ferrick and Gatto (2005) demonstrated that freeze-thaw actions that disrupt soil structure, coinciding with high soil moisture following thaw, caused significant increases in soil erosion during runoff events. Another period of reduced soil erosion occurred in the early summer months of 2010 when precipitation totals were low. July and August 2010 experienced strong summer thunderstorm activity and erosion dramatically increased as rainfall totals approached 10 inches for the period.

The Mulch treatment had the lowest erosion rate and reduced soil erosion by 86% when compared to the Control. Erosion on the Mulch treatments remained low during the entire study. For the first six months, the highest monthly total was 0.06 tons/acre; then rates started to fluctuate due to monthly precipitation. Erosion patterns spiked during March 2010 and again in August 2010 when rainfall intensity increased (Figure 1). The average erosion rate for all Mulch treatments was 1.47 tons/acre/year. Grushecky et al. (2009) evaluated the influence of fiber mats on soil erosion from skid trails in West Virginia as compared to waterbars and seed and concluded that the cover provided by the mat reduced erosion by 88%. The Mulch treatment of this study provided very similar results, but the Fiber mats would be much more expensive.

The Hardwood and Pine slash treatments provided very similar erosion rates during the entire study period. Either form of logging slash added immediate cover to the soil which reduced erosion in a manner similar to Mulch. By compacting the slash, ground contact minimized sheet erosion underneath the slash. Logging slash on skid trails has been shown to significantly reduce soil erosion on volcanic soils in the west (McGreer 1981) and on harvest sites in New York (Schuler and Briggs 2000). The average erosion rate for Hardwood was 2.27 tons/acre/year and Pine was 2.41 tons/acre/year. The Hardwood and Pine treatments reduced erosion by 79% and 78%, respectively, as compared to the Control.

Grass cover on the Seed treatments never reached desired BMP establishment levels (70%) according to the Virginia Department of Forestry (2002) even though multiple reseeding attempts occurred. Erosion for this treatment averaged 6.06 tons/acre/year, or a 44% decrease in annual erosion when compared to the Control.

The overall average erosion rate for the Control was 10.82 tons/acre/year. The Control treatment had nominal erosion during the first six months, 0.31 tons/acre or less, even without any added soil protection. Soil loss dramatically increased after the freeze-thaw actions of winter had churned and loosened exposed soil layers. As expected, the greatest erosion coincided with the highest precipitation totals. The March 5, 2010 collection period received 9.18 inches of rainfall while soil loss averaged 2.35 tons/acre. The most erosion occurred during the final collection period; rainfall accumulations were 9.87 inches and soil erosion averaged 5.82 tons/acre (Figure 1). Soil erosion data collected by Quinton et al. (1997) also showed that variations in soil losses increase when bare soil is more prominent.

CLOSURE COSTS

Overland skid trail closure costs for the specific components of the installed BMPs are summarized in Table 1. Table 2 shows a more detailed analysis of costs for the 29 acre harvest site. These costs combine each component by treatment for the five closure techniques. The Control treatment of only water bars may be an adequate level of BMP compliance in some instances, and the Control was the least expensive treatment. It should be noted that waterbars were a component of all other treatments. Of the other treatments in the study, Slash (Hardwood and Pine) was the most expensive per mile followed by Mulch, Seed, and Control. Based on observations of other harvest operations, it was speculated that the Slash component could be four times more efficient if the transport of slash was incorporated into the harvest operation. The Integrated Slash treatment, including water bar construction, could be $2,970 per mile, or 51% less than our Slash treatment installed after harvest completion. A Slash treatment would only be cost effective when grapple skidders are used in the harvest operation and if slash is readily available, such as when operations use a mechanized or gate de-limber.

The logging contractor utilized 0.95 miles of skid trails to harvest 3,074 tons on the 29 acre site. The skid trail length was used to produce a cost by treatment for the harvest. While many factors are involved in skid trail layout, similar quantities were found by Kochenderfer (1977) when loggers averaged 1 mile of skid trail for every 22.3 acres harvested. Lickwar et al. (1992) calculated cost estimates for enhanced BMPs on Piedmont sites in the Southeast to be $32.33/acre (comparable to approximately $68 in 2010). At current prices on a small tract, we determined skid trail closure costs alone to be $137/acre for the Mulch treatment which is comparable to their enhanced BMP scenario. A treatment cost per ton of wood harvested was also calculated. The Slash treatments were the most expensive at $1.88/ton, followed by Mulch ($1.29/ton), Seed ($1.19/ton), and Integrated Slash ($0.92/ton). A combination of treatment efficacy and costs is shown Table 2. Logging slash is already being used as a protective cover for exposed soils on timber harvest sites, and our calculations show it to be the least expensive choice ($203/ton of erosion) for preventing erosion if integrated into the harvest operation. However, if slash is spread after harvesting, the Slash treatment becomes more expensive than either the Seed or the Mulch treatments.

SUMMARY AND CONCLUSIONS

Timber harvesting has a huge economic impact in Virginia and the southeastern United States, and BMP implementation costs can influence potential profits. The minimum BMPs typically considered for skid trails are waterbars, but waterbars may need to be supplemented with other practices when slopes exceed 5%. Of the four additional treatments evaluated, the Seed treatment had the lowest costs but was not the best option for minimizing erosion. The Mulch, Hardwood slash, and Pine slash treatments are effective at lowering soil erosion on overland skid trails but are expensive and labor intensive. The Integrated Slash approach is already being implemented by many logging contractors, and it may be the best option for expenses and long term effectiveness. Overall, it appears that all of the BMPs evaluated may be appropriate under certain conditions and final selection should be determined by landowner goals, operator capabilities, environmental sensitivity, and cost effectiveness.

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Table 1—Cost estimates for specific components of skid trail BMP treatments installed during 2009

Component	Information	Equipment - Supply Costs ($/mile)	Operator - Labor Costs ($/mile)	Total Installation Costs ($/mile)
Water Bar	$18.75/bar	$1,320	$660	$1,980
Seed	265 lbs/acre @ $1.11/lb	$442	$33	$475
Mulch	2 bales/50 feet @ $4.99/bale	$1,054	$ 220	$1,274
Lime	1 ton/acre @ $200/ton	$300	$33	$333
Fertilizer	200 lbs/acre @ $0.259/lb	$78	$33	$111
Slash	Cover 100 feet/hour	$2,790	$1,320	$4,110

Table 2—Cost estimates for skid trail closure techniques used for overland skid trails on a 29 acre site in the Virginia Piedmont during 2009

Treatment	Costs per mile	Costs for 29 acre site	Costs per ton of wood harvested	Costs per ton of erosion prevented (Year 1)
Mulch (WB,S,L,F,M)	$4,173/mi	$3,964	$1.29/ton	$262/ton
Slash (WB,X)	$6,090/mi	$5,786	$1.88/ton	$416/ton
Seed* (WB,S,L,F)	$3,849/mi	$3,657	$1.19/ton	$486/ton
Control (WB)	$1,980/mi	$1,881	$0.61/ton	NA
Integrated Slash (WB,X)	$2,970/mi	$2,822	$0.92/ton	$203/ton

WB = Water Bar; S = Seed; L = Lime; F = Fertilizer; M = Mulch; X = Slash
*The seed treatment includes costs for 3 seed applications.

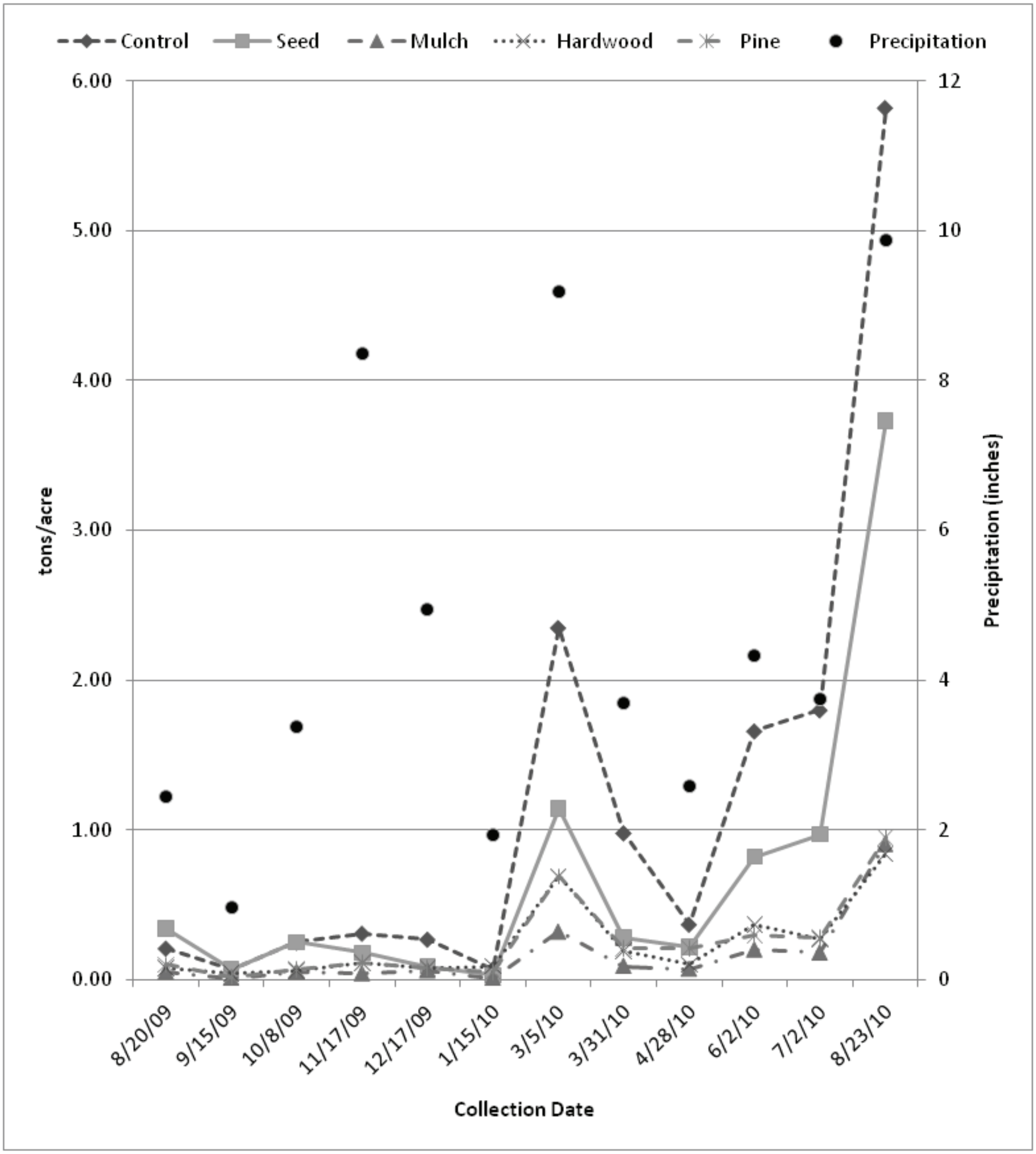

Figure 1—Average erosion and precipitation by treatment and collection period.

COMPARING SECOND YEAR GROWTH OF AMERICAN SYCAMORE, BLACK WILLOW, AND EASTERN COTTONWOOD WITH AND WITHOUT FERTILIZATION

Jamie L. Schuler

Interest in developing domestically produced bio-based fuel systems has been responsible for a large increase in short rotation woody crop (SRWC) research. Much of this work has been used in developing regional production estimates for woody crops like cottonwood (*Populus deltoides* Bartr. ex Marsh.) and eucalyptus (*Eucalyptus* spp.) in the Southeast. SRWC systems are designed as purpose-grown bioenergy crops that are intensively managed and utilize fast-growing tree species (White 2010). These systems are characterized by high planting densities of advanced genetic material with high inputs (e.g., fertilizer, irrigation) and short rotations to produce yields that can exceed 50 oven dry tons/ha/yr (Adegbidi and others 2003).

The advantages of this system are the very high yield potential, short rotations, and rapid returns. Despite the numerous reports of extremely high yields, SRWCs typically yield 7.5-15 oven dry tons/ha/yr in commercial plantings (Volk and others 2006). Also, if one considers the land available for SWRCs, most planting is expected to occur on “marginal agriculture lands”, which generally refers to non-irrigated, non-leveled lands with restricted internal drainage. Yields associated with SRWCs on these sites are not well-represented in the literature. A study was initiated in 2009 to address questions related to productivity on these marginal sites.

The study site was located in St. Francis County near Colt, AR. The site had been under long-term cultivation for row crops (for example, soybeans, rice). Dominant soil series include Henry silt loam and Calloway silt loams. Soils have restricted drainage due to both a plow pan and a natural fragipan that occurs within 18 inches of the soil surface. The site was disked and ripped on rows 8 feet apart in the fall 2008 after a soybean crop was harvested. Trees were planted in February 2009 on 8 feet by 8 feet spacing. Goal 2XL™ herbicide was applied at 96 ounces/acre following planting for pre-emergence weed control. Disking and directed sprays of herbicides were used to control vegetation for two growing seasons.

Two treatment factors were arranged in a split plot design with four replications. Whole plots consisted of two levels of fertilization. The fertilization treatments were 0 or 56 kg N/ha/yr as urea. A 50 foot grass buffer was maintained between fertilized and non-fertilized plots. Whole plots were divided into three split plots, with three tree species planted in 196-tree single species plots. The tree species utilized were American sycamore (*Platanus occidentalis* L.), black willow (*Salix nigra* Marsh.), and eastern cottonwood. American sycamore was purchased as 1-0 bareroot seedlings from a large private nursery in Arkansas and represented an unimproved and unknown source. Black willow was planted using 35-cm unrooted cuttings that were collected from a natural population along a tributary of the Arkansas River. The eastern cottonwood was planted as a single clone (ST-66) using 46-cm unrooted cuttings that were purchased from a Louisiana state nursery.

The measurement plots consisted of the center 36 trees in each treatment plot. Total height and stem diameter were measured at the end of the second growing season. Stems with heights less than 137 cm had dbh recorded as zero. Growth was assessed using Analysis of Variance (SAS 9.2 software) at a significance level of alpha=0.05.

Species was the only significant factor influencing year two diameter ($P=0.0005$) and height growth ($P<0.0001$), respectively). At a minimum, American sycamore diameter growth was 90 percent greater and height growth was 49 percent greater than both eastern cottonwood and black willow (Table 1). No differences were detected between the later two species. Even though fertilization generally produced greater diameter and height growth, no significant effect was detected for second year growth rates on any species (Table 1).

My current recommendation for these kinds of sites is to plant sycamore combined with early fertilization. Even though fertilization has yet to demonstrate a significant growth response, the competition control has been much

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easier due to their expanding crowns. Operationally, these stands may not require second year weed control, whereas non-fertilized stems almost certainly will.

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Table 1—Average height and diameter growth for the second growing season for each species grown with and without fertilization

	Non-fertilized			Fertilized		
	Cottonwood	Sycamore	Willow	Cottonwood	Sycamore	Willow
Dbh (mm)*	4.0	9.9	5.4	9.4	15.4	6.3
Height (cm)	54.3	91.7	70.7	78.8	119.0	70.7

*Diameters of stems less than 137 cm were recorded as “0”.

THE APPLICATION OF SINGLE-TREE SELECTION COMPARED TO DIAMETER-LIMIT CUTTING IN AN UPLAND OAK-HICKORY FOREST ON THE CUMBERLAND PLATEAU IN JACKSON COUNTY, ALABAMA

Callie Jo Schweitzer and Greg Janzen

ABSTRACT

Cumberland Plateau region upland oak forests have undergone a myriad of disturbances (including periods of few and minor disturbances). Traditional timber harvesting practices such as diameter-limit cutting have negatively altered species composition and skewed stand structure, especially on medium-quality sites. We assessed the ability of single-tree selection to improve stand characteristics by comparing species structural and compositional responses, and assessing changes in productivity and quality with stands harvested by diameter-limit cutting. The single-tree selection marking guidelines specified a minimum diameter at breast height (d.b.h.) of 6 inches, a maximum d.b.h. of 30 inches, and a q-value of 1.4. The diameter-limit cut targeted stems 14 inches d.b.h. and greater. Both treatments had a target residual basal area of 65 square feet per acre, a density level that approximates the B-level stocking for upland oaks. All stands were harvested in 2005. Observed residual basal area averaged 61.5 square feet per acre with 66 stems per acre in the single-tree selection stands. The diameter-limit cut left a residual basal area of 39 square feet per acre with 64 stems per acre; there were no residual trees 16 inches d.b.h. and greater. The single-tree selection targeted all species, and the proportion of hickory and yellow-poplar declined following the harvest. For the diameter-limit cut, all chestnut oak and most white oaks were removed.

Keywords: Cumberland Plateau , diameter-limit cut, single-tree selection, uneven-aged management

INTRODUCTION

The upland oak forests of the Cumberland Plateau region have undergone a myriad of disturbances. These past disturbances (and sometimes lack of disturbance) on medium-to-high quality sites have resulted in stands of less desirable species compositions and stand structures that indicate populations of desirable species are unsustainable. Although generally considered even-aged systems, the majority of these stands contain a mixed or irregular age structure: old, cull trees remain from prior entries and young, intolerant species capitalized on openings created in "high-grade" harvests, where the most desirable stems were removed. The lack of adequate oak regeneration, and the desired future condition of a predominance of oak, makes managing these stands a challenge.

Even-aged systems are recommended for regenerating oak forests. The shelterwood method of regeneration continues to be touted as the preferred method for accomplishing oak regeneration on higher quality sites (Sander 1979; Smith 1986; Hannah 1987; Loftis 1983; Loftis 1990; Beck 1991). Reducing overstory and midstory densities alters light levels so that mid-tolerant species such as oak will respond while the establishment of highly intolerant species such as yellow-poplar will be limited. The response of tolerant species such as sugar maple may be stimulated under these light conditions. For example, Goodburn and Lorimer (1999) found that sugar maple reached close to its maximum height growth under light intensities of 2-15 percent full sunlight. In a study in forested stands typical in the Cumberland region, a shelterwood method that targeted the deadening of midstory structure increased light levels to 16 percent of that in open conditions, and sugar maple seedlings present pre-treatment showed a height response one year post-treatment (Schweitzer 2004). It is also well established that disturbances on productive sites where yellow-poplar is present will enhance its regeneration potential, as it readily seeds in as new individuals.

The response of Cumberland Plateau forests to varying levels of overstory and midstory disturbance is currently under assessment in several studies (Schweitzer and others 2004; Schweitzer 2004; Schweitzer 2010). Shelterwood harvests of various basal area retentions are being tested to relate differing levels of understory light and competition and the response of desired species. All studies in this area thus far have been under the auspices of even-aged management. This case study of single-tree selection will allow for the comparison of light levels and seedling and sapling recruitment, growth, and survival between it and several other studies of even-aged methods of regeneration.

An uneven-aged management system is one that contains stands with trees of three or more distinct age classes (Society of American Foresters 1998). Regeneration

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prescriptions that drive uneven-aged management include single-tree selection and group selection. In the Cumberland Plateau region, which is dominated by private forest landowners, diameter-limit cutting is often alluded to as "selection" cutting, and some are confused by the semantics of "selection." Diameter-limit cutting has resulted in the degradation of many stands, due to the removal of the majority of the commercially valuable trees, the retention of small, old trees that do not respond to the disturbance, and the increase in the percentage of poor quality and traditionally low value species. True uneven-aged management is not common in the Cumberland Plateau region. The lack of the use of uneven-aged management is driven by several factors, including the difficulty of implementation, the expense related to maintaining road infrastructure for multiple entries, and the inability to commercially sell hardwoods of smaller stem diameters. Creating conditions for regeneration of desirable species, which includes oaks, is also a challenge. However, the potential for a land owner to have more frequent income flows via timber sales, and the aesthetics associated with partial harvests, are appealing to some landowners.

Single-tree selection has been reported as inappropriate for managing upland oak forests in Southern Appalachian upland hardwood forests, as canopy gaps are deemed too small to allow enough light for oak reproduction (Sander and Clark 1971; Sander and Graney 1993; Loftis 2004). However, it has been recently reported in an oak-hickory forest in the Missouri Ozarks that after 40 years of applied single-tree selection, stand quality and vigor were improving, and there was sufficient recruitment to perpetuate the oak-hickory type (Lowenstein and others 1995). The use of uneven-aged management is receiving heightened attention in the Cumberland region by mostly private land owners and environmental groups who wish to avoid the visual impact associated with clearcutting, as well as the desire to create unique forest stand structures.

Another difficulty in implementing single-tree selection in Cumberland Plateau stands is that we often do not know the developmental history of the stands. We assume the stands are of the same age, although we also know that diameter-limit cutting is rampant, and many stands have been partially harvested using this type of cutting practice. So the use of stem diameters as a surrogate for age in developing single-tree selection prescriptions may be even more exaggerated in our forests. Nevertheless, we are interested in the applicability of single-tree selection, including implementation procedures in our mixed species, and mixed shade tolerance, stands. We examined residual stand structure and composition following the first entry of a single-tree selection harvest and compared this to that obtained with a diameter-limit cut. We are interested in documenting the light levels and canopy conditions under each treatment, and the initial regeneration response.

METHODS

STUDY REGION

Forested stands chosen for this study are owned by the Stevenson Land Company, Stevenson, AL. The stands are located near Blue Spring, Jackson County, on strongly dissected margins and sides of the Cumberland Plateau (the escarpment). On the escarpment study sites, soils are characterized as deep to very deep and loamy. They are considered well-drained, with moderate to moderately low soil fertility. Slopes range from 15 to 30 percent. Upland oak site index is 75 to 80, and yellow-poplar (*Liriodendron tulipifera* L.) site index is 100 [base age 50 years, Smalley Landtype 16, Plateau escarpment and upper sandstone slopes and benches – north aspect (Smalley 1982)]. Canopies are dominated by oaks, including black, northern red, white and chestnut (*Quercus velutina* Lamarck, *Q. rubra* L., *Q. alba* L., *Q. prinus* L.), yellow-poplar, hickories (*Carya* spp.), and sugar maple (*Acer saccharum* Marsh.), with a lesser proportion of white ash (*Fraxinus americana* L.) and blackgum (*Nyssa sylvatica* Marsh.). Depending on the site, dogwood (*Cornus florida* L.), sourwood (*Oxydendrum arboreum* DC.), Carolina buckthorn (*Rhamnus caroliniana* Walt.), and eastern redbud (*Cercis canadensis* L.) are common understory species. Beneath mature stands oak reproduction is small and sparse, and competition by yellow-poplar and sugar maple is great.

TREATMENTS

This area was chosen as a study site because of its typical stand history and composition for the region. Our assumption was that these stands were essentially even-aged at approximately 80-100 years old. A history of site disturbance does not exist. Two case studies of approximately 30 acres each are being implemented on this site as a response to results observed in a larger stand manipulation study also located in Jackson County, Alabama.

To begin the process of moving these stands towards an uneven-aged stem distribution, we set our harvest parameters to control the growing stock so that we would have a progression of stems of various sizes. The residual stocking level was set at 60 ft^2/a of basal area (BA), the diameter of the largest tree was 30 inches, and the number of trees desired in each diameter class was determined by the diminution quotient (q) of 1.4. The q expresses the ratio of the number of trees in any diameter class to the number of trees in the next higher diameter class. We also had a minimum diameter of 6 inches, a merchantable constraint for our systems. A 65 BA density level approximates the B-level stocking for upland oaks (Gingrich 1967). Smith and Lamson (1982) recommended a 1.3 q-value for sawtimber production and higher q-values for smaller product objectives.

Residual structure was obtained by marking trees after division into four size classes: (1) small poletimber (6-8 inches d.b.h.) (2) large poletimber (9-11 inches d.b.h.) (3) small sawtimber (12-15 inches d.b.h.) and (4) large sawtimber (>15 inches d.b.h.). Target residual basal area for each class was calculated and the stand marked to meet these targets. Removal tree priority followed (1) large cull and defective trees (2) competing trees of poor form and quality (3) intermediate and suppressed tress of lower quality and value.

The diameter-limit cut was implemented by removing all trees 14 inches d.b.h. and larger. All harvesting was done by chainsaw felling and cable skidding by Chisenall Timber in the summer of 2005.

FIELD METHODS

Prior to treatment, 25 measurement plots were systematically located in the treatment area. These plots were used to collect pre-prescription data in order to develop the single-tree selection marking criteria. All trees 5.6 inches d.b.h. and greater on 0.2-acre plots were tallied by species and diameter.

We then randomly chose 5 of these plots to use as measurement subplots, which consisted of three concentric circles. Five plots were also established in the diameter-limit cut stand. Subplot centers were permanently marked with a 2-foot piece of reinforcing steel, and geographic coordinate pairs were recorded using a hand GPS receiver. A hand-held spherical densiometer was used to measure canopy cover. Densiometer counts were made in four cardinal directions from each permanent plot center and averaged.

Regeneration was sampled on 0.01-acre circular plots. Seedlings were tallied by species in each regeneration plot by 1-foot height classes, up to 1.5 feet d.b.h., and then by diameter.

Using the same plot center, a 0.025-acre plot was established and all trees 1.6 inches d.b.h. and greater were monumented (distance and azimuth measured and recorded from plot center, each tree tagged with a numbered aluminum tag) and species and d.b.h. recorded. An additional 0.2-acre plot, located concentrically, was established, and all trees 5.6 inches d.b.h. were measured and monumented as described previously. We measured all plots prior to harvesting in 2005, and then remeasured them in 2009

RESULTS

OVERSTORY COMPOSITION AND STRUCTURE

Twenty-five dominant or codominant tree species were tallied in the stands. Oak species included black, white, northern red, chestnut, scarlet (*Q. coccinea* Muench.) and post (*Q. stellata* Wang.), and hickory species included mockernut (*Carya tomentosa* Nutt.), pignut (*C. glabra* Sweet.), red (*C. ovalis* Sarg.) and shagbark (*C. ovata* K. Koch.). A gradient of shade tolerance of canopy species included extremely tolerant sugar maple, intermediately tolerant red maple (*A. rubrum* L.) and extremely intolerant yellow-poplar. For the single-tree selection stand, the pretreatment basal area was 121 BA with 123 stems per acre (SPA), and this stand was dominated by oaks, hickories and yellow-poplar (Table 1). The diameter-limit cut stand had a similar structure and composition, with 108 BA and 117 SPA, also dominated by oaks and hickories (Table 1). Both stands contained a number of other species, including white ash, American beech (*Fagus grandifolia* Ehrh.), sourwood, common persimmon (*Diospyros virginiana* L.), Eastern redcedar (*Juniperus virginiana* L.) and elms (*Ulmus* spp.).

An examination of the diameter distribution of the single-tree selection stand shows that this mixed species stand had a diameter distribution curve that resembled the uneven-aged system, with more stems in the smaller size classes (assumed to be "younger") and fewer stems in the larger (assumed to be "older") diameter class (Figure 1). Thus the potential to harvest and maintain a reversed J-shaped diameter distribution existed in this even-aged stratified mixture stand. Following harvest, we had 6 fewer SPA than desired in the 10-inch d.b.h. class, and 4 greater SPA than desired in the 18-inch d.b.h. class. After 32.8 ft^2/a of BA was removed from the stand, oak was still a significant overstory species, accounting for 37.7 of the of the residual basal area (57.7 ft^2/a). There were 64 SPA in the residual stand, of which oak comprised 59 percent comprised of the stems (Table 1). The distribution of oak across diameter classes is show in Figure 2a; except for the 12-inch d.b.h. class, there is balance in the distribution of oak residual BA with diameter (Figure 2b).

The diameter-limit cut successfully removed all trees greater than 14 inches d.b.h. (Figure 3a). The residual BA was 39.0 ft^2/a, with 49.5 BA of oak removed and a residual oak BA of 12.3 (Figure 3b). The diameter-limit cut had 64 SPA in the residual stand with 32 percent of these stems oaks (Table 1).

Canopy cover was similar between the two stands, with the single-tree selection stand having an average 83.4 percent cover (standard deviation 13.9) and the diameter-limit cut having an average cover of 80.9 (std 10.8). The range of recorded cover was 30.3-97.9 percent for the single-tree selection and 47.0-99.0 percent for the diameter-limit cut.

REGENERATION COMPOSITION AND STRUCTURE

The regeneration cohort, which included all stems from 1 foot tall to 1.5 inches d.b.h., contained 44 different species. Several of these were shrubs that included devil's walking stick (*Aralia spinosa* L.), beauty berry (*Callicarpa americana* L.), *Euonymus* spp., oak-leaf hydrangea (*Hydrangea quercifolia* Bartram), Vaccinium spp., and maple-leaf viburnum (*Viburnum acerifolium* L.). Also present were many midstory tree species, including blackhaw (*V. prunifolium* L.), Carolina buckthorn, Eastern hophornbeam (*Ostyra virgniana* (Mill.) K. Koch), Eastern redbud, flowering dogwood and winged sumac (*Rhus copallina* L.). Potential canopy species were also present and included black, white, northern red, scarlet, chestnut and Chinkapin oak (*Q. muehlenbergii* Engelm.), hickories (mockernut, pignut and red), yellow-poplar, white ash, blackgum, sourwood, red maple and sugar maple.

For all stems considered in the regeneration cohort (including shrubs and midcanopy species), total numbers increased after both harvests. For the single-tree selection, SPA changed from 6,880 pre-harvest to 13,740 post-harvest, and for the diameter-limit cut stand, SPA changed from 8,760 pre-harvest to 12,400 post-harvest. The single-tree selection stand had increased SPA in all size classes; for the diameter-limit cut stand, regeneration less than one foot tall decreased by 3,840 SPA; all other size classes increased, with the 4-ft tall to 1.5 inch d.b.h. class having the greatest increase, from 420 SPA to 3,200 SPA. The largest increase by size class for the single-tree selection was in the 2-3 ft class, which increased from 220 to 2,440 SPA.

Total oak SPA declined post-harvest for both treatments (Table 2). Small (less than one foot tall) oak regeneration was impacted most by both harvesting treatments, declining by 860 SPA in the single-tree selection and by 1,580 SPA in the diameter-limit cut stand. The single-tree selection also resulted in a decline of oak in the 1-to-2-ft height class, from 440 to 320 SPA. However, both the 2-3 ft height class and the 3-4 ft height class of oak increased by 160 and 40 SPA, respectively. There were no oak tallied greater than 4 ft tall in the single-tree selection stand. For the diameter-limit cut stand, oak increased in all other size classes, with the largest increase occurring in the 2-3 ft height class. Oak regeneration that was 4 ft tall-to 1.5 inch d.b.h. increased by 40 stems to a total of 120 SPA post-harvest in the diameter-limit cut stand.

Sugar maple, red maple and white ash all experienced a decline in the smallest regeneration class for both treatments (Table 2). The single-tree selection had 440 SPA of sugar maple regeneration compared to 80 in the diameter-limit cut. Post-harvest, there were also more white ash regeneration in the single-tree selection compared to the diameter-limit cut, with 520 SPA compared to 40 SPA, respectively. Red maple SPA declined overall for the single-tree selection and increased for the diameter-limit cut. Both treatments had an increase in the largest regeneration size classes, resulting in 440 SPA of red maple in the single-tree selection and 800 SPA in the diameter-limit cut. The most prominent change in the regeneration cohort was observed for yellow-poplar. Yellow-poplar increased in all size classes for both treatments, resulting in 4080 SPA for the single-tree selection and 2060 for the diameter-limit cut. Yellow-poplar regeneration in both treatments was well represented in all size classes post-treatment.

DISCUSSION

We used stem diameter as a surrogate for tree age in designing a prescription to initiate the process of moving an assumed even-aged upland hardwood forest towards an uneven-aged system. The initial diameter distribution lent itself well towards this goal, as we had adequate numbers of stems of desirable species across size classes to both conduct a commercial harvest and to produce a residual stand that has adequate growing stock. Implementing the prescription was difficult. Following an intensive cruise of the entire stand, a spreadsheet was used to determine the desired residual stand and harvest component, by size class and then species. Although we marked the cut stand and had some checks in place, most of the 12-inch trees were removed (from 15 SPA to 2 SPA), and more 16 and 18 d.b.h. trees were left than prescribed. In contrast, the diameter-limit cut did not remove trees consistently in all diameter classes, but did remove most stems that were greater than 14 inches d.b.h. Only 6 stems per acre of 14 inch d.b.h. trees remained, and these were blackgum, yellow-poplar and hickory.

When single-tree selection is applied in stands that contain shade intolerant species, a shift in species composition can occur. It is difficult to discern this response after only one harvest entry, but we did attempt to remove trees of all species. Following the initial harvest, the overstory species composition retained a dominance of oak, remained consistent with both BA and SPA of hickory, and decreased in the proportion of sugar maple, red maple and yellow-poplar. For the diameter-limit cut stand, the residual stand was depleted of oak, with no oak equal to or greater than 16 inch d.b.h. in the residual stand, and only 2 SPA of oak in the 14 inch d.b.h. class. Although both stands are projected to have enough commercial volume to sustain at least one more harvest entry, without substantial recruitment and growth of the oak growing stock in the diameter-limit cut stand additional harvesting may have to be subsidized.

Stem quality may respond negatively to these partial harvests. With high stand densities, branchless boles are encouraged. The decrease in density in these stands may affect a few individual trees in the canopy, but these trees of higher vigor left in the single-tree selection stand should be less prone to epicormic branching (Trimble and Seegrist 1973; Meadows 1995). Inferior crown classes, especially overtopped white oak, may have the propensity to form epicormic branches (Miller 1996). Because only diameter was considered in the diameter-limit cut (not residual stand species composition or vigor), this practice could severely contribute to stand degradation via epicormic branching.

Few examples of sustained single-tree selection management have been reported for upland hardwood systems. In Missouri, on more xeric oak sites, uneven-aged management with single-tree selection has been shown to be viable if overstory density is maintained at 63 BA over a 20-year cutting cycle (Larsen and others 1999). In the Pioneer Forest of Missouri, Loewenstein and others (2000) have shown that over 40 years of single-tree selection management, there has been no discernable shift in species composition and the diameter distributions have remained stable for dominant species groups, especially oaks. In contrast, Della-Bianca and Beck (1985) and Loftis (2004) have reported that on a productive, mesic upland hardwood site, following 50 years and four cutting cycles, a diameter distribution approximating uneven-aged structure is present, but the majority of the smaller diameter stems are noncanopy, shade tolerant species. On our site, we have the potential to develop a commercially valuable species that is shade tolerant, sugar maple, under single-tree selection management. However, maintaining species composition congruent with the original stand, dominated by oak, is a primary management goal. How this stand continues to develop over time, with subsequent harvest entries, will rely on the ability of desirable species to recruit into larger size classes.

As a regeneration method, single-tree selection promotes shade-tolerant species. The initial disturbance in our stands allowed for an ephemeral increase in the amount of light beneath the main canopy. This increase pulse of light was around 20 percent of full sunlight, below the 30-50 percent of full sunlight needed to promote oak reproduction (Dey and Parker 1996; Hodges and Gardiner 1993, Ashton and Berlyn 1994, Gottschalk 1994). Oak reproduction between 2-to-4 ft in height increased in both the single-tree selection and diameter-limit harvest stands. A cohort of sugar maple in the reproduction exists, as does the potential for these stems to either remain viable over time, or respond to the next disturbance and occupy growing space in intermediate to dominant canopy positions. In another study on the Cumberland Plateau escarpment, in which the midstory was deadened to allow growing space and light to promote oak, sugar maple regeneration responded positively (Schweitzer 2004). She observed that the amount of full sunlight was 16 percent, similar to that in the single-tree selection stand in this study. The disturbances created by both the single-tree selection and diameter-limit cutting resulted in a variable light environment across the stands. In response, we observed a pulse of reproduction for shade intolerant yellow-poplar, as well as red maple and white ash. The potential for this cohort of mixed species to develop into mid- and overstory canopy species will be followed. We are also interested in how stump sprouting, especially oak stump sprouts, may contribute to sustained oak densities. Dey and others (2008) found that under single-tree selection in the Missouri Ozarks recruitment of oak stump sprouts into the overstory was reduced.

CONCLUSION

On productive sites on the Cumberland Plateau escarpment, managing for a suite of species presents some interesting challenges. In reality, forested stands that are primarily owned by non-industrial private landowners are being high-graded using diameter-limit cutting disguised as "selection" harvesting. Contrasting this practice with true single-tree selection will allow us to discern how these stands respond to these practices, and provide insight on how sustainable these practices are in terms of overstory species composition and regeneration recruitment. Constructing resultant stand structures that allocate sufficient growing space to all ages with representation across all desirable species is challenging. For example, we do not know the proper length of the cutting cycle for uneven-aged management in these systems, so this study will serve as a template to assist in developing prescription parameters. Residual stand degradation as determined by tree grade will assist in determining the economic feasibility of these practices.

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Table 1—Relative stems per acre (SPA) and basal area (BA) presented as a percentage of total, for single-tree selection and diameter-limit cut stands in Jackson County, AL

	Single-tree selection				Diameter limit cut			
	% SPA	% SPA	% BA	% BA	% SPA	% SPA	% BA	% BA
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Oaks	44	48	58.3	58.9	42	28	57.2	31.5
Hickories	13	7	12.7	6.3	14	19	11.2	17.2
Red maple	2	3	1	2	1	2	0.2	0.5
Sugar maple	6	6	2	2	8	13	3.3	10
Yellow-poplar	12	6	14	5	3	6	3.3	6.9
Others	33	30	12	25.8	22	22	24.8	33.9

oak species included red (*Quercus rubra*), black (*Q. velutina*), white (*Q. alba*), and chestnut (*Q. prinus*)
hickory species included mockernut (*Carya tomentosa*), pignut (*C. glabra*), red (*C. ovalis*), and shagbark (*C. ovata*)

Table 2—Average regeneration stems per acre (standard deviation) by 5 size classes for selected species in a stand subjected to Single-tree selection (STS) and a stand cut using a diameter-limit (DLC)

		<1' ht		1' to 2' ht		2' to 3' ht		3' to 4' ht		4' ht-1.5 " d.b.h.	
		pre	post	pre	post	pre	post	pre	post	pre	post
Oaks	STS	1520 (1880)	660 (168)	440 (632)	320 (120)	20 (38)	180 (81)	0 (0)	40 (18)	0 (0)	0 (0)
	DLC	2520 (3168)	940 (302)	580 (1004)	740 (257)	40 (76)	220 (82)	0 (0)	60 (25)	80 (136)	120 (54)
Sugar maple	STS	580 (496)	240 (280)	20 (32)	180 (216)	0 (0)	0 (0)	0 (0)	0 (0)	20 (32)	20 (32)
	DLC	60 (48)	20 (32)	20 (32)	40 (48)	20 (32)	20 (32)	0 (0)	0 (0)	60 (96)	0 (0)
White ash	STS	520 (792)	60 (96)	180 (248)	100 (128)	60 (72)	200 (320)	0 (0)	60 (96)	80 (128)	100 (160)
	DLC	60 (32)	0 (0)	60 (32)	0 (0)	0 (0)	20 (32)	0 (0)	20 (32)	0 (0)	0 (0)
Red maple	STS	1220 (102)	660 736)	40 (48)	60 (96)	20 (32)	40 (64)	0 (0)	0 (0)	80 (96)	440 (624)
	DLC	600 (760)	160 (192)	40 (64)	180 (216)	40 (48)	120 (64)	40 (48)	80 (64)	420 (472)	800 (680)
Yellow-poplar	STS	60 (72)	2100 (520)	60 (96)	900 (640)	0 (0)	700 (840)	0 (0)	240 (248)	0 (0)	140 (168)
	DLC	40 (64)	580 (696)	0 (0)	800 (704)	0 (0)	340 (472)	0 (0)	160 (168)	20 (32)	180 (184)

oak species included red (*Quercus rubra*), black (*Q. velutina*), white (*Q. alba*), and chestnut (*Q. prinus*)

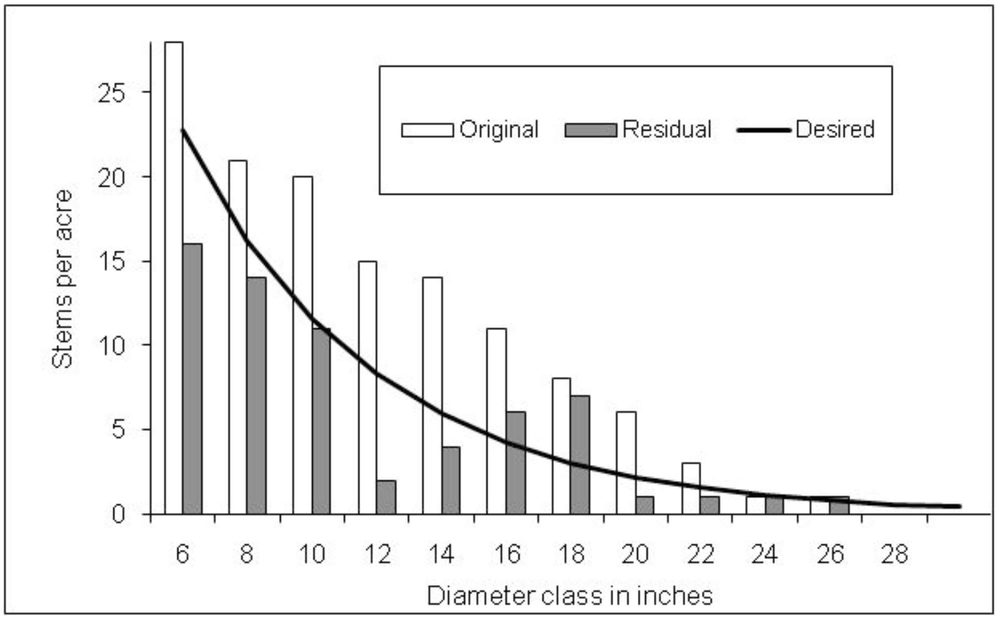


Figure 1—Diameter distribution of stems per acre by size classes for the single-tree selection stand, depicting the original stand's diameter distribution, the desired stand's distribution using the parameter of 65 ft2 of basal area, maximum stem diameter of 30 inches, and a q of 1.3, and the resultant residual stand's distribution.

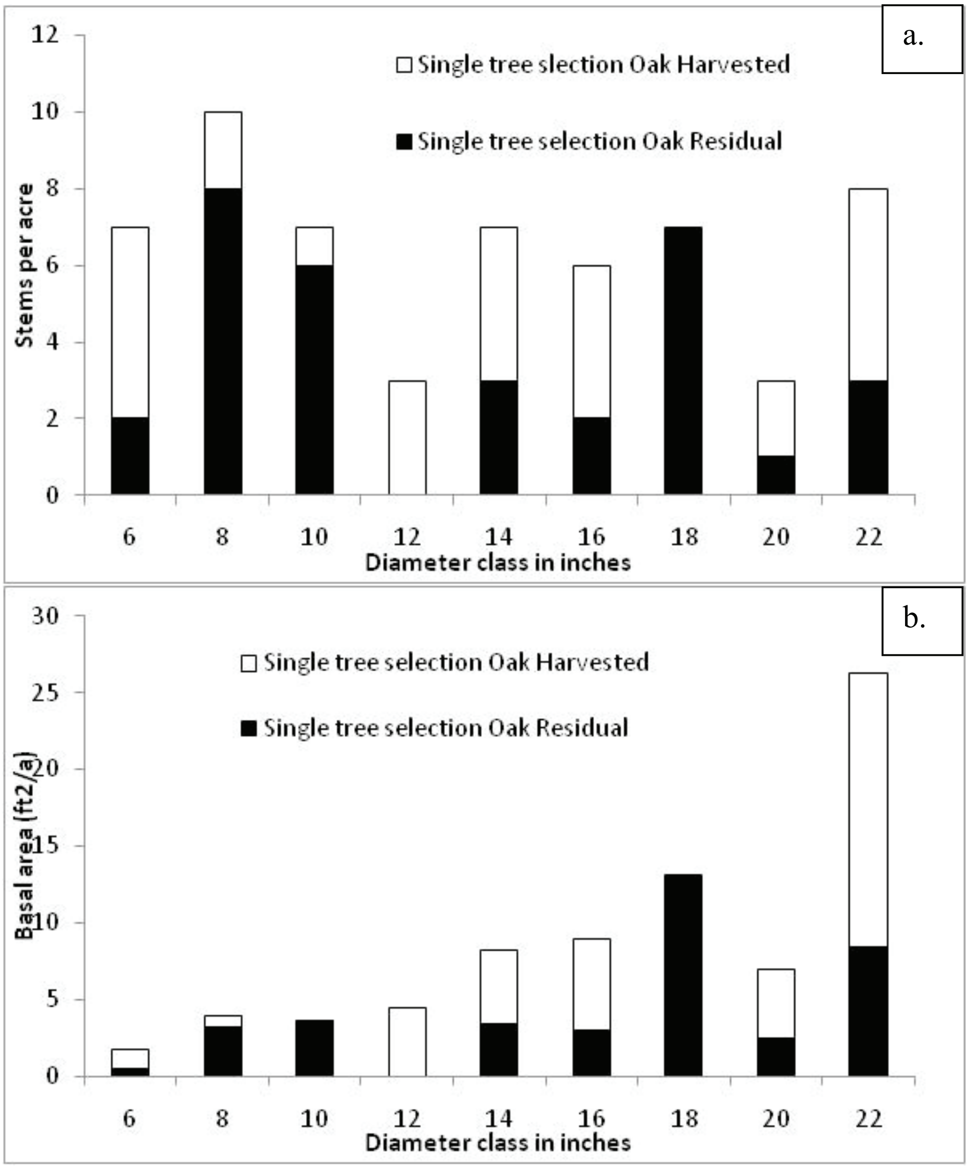
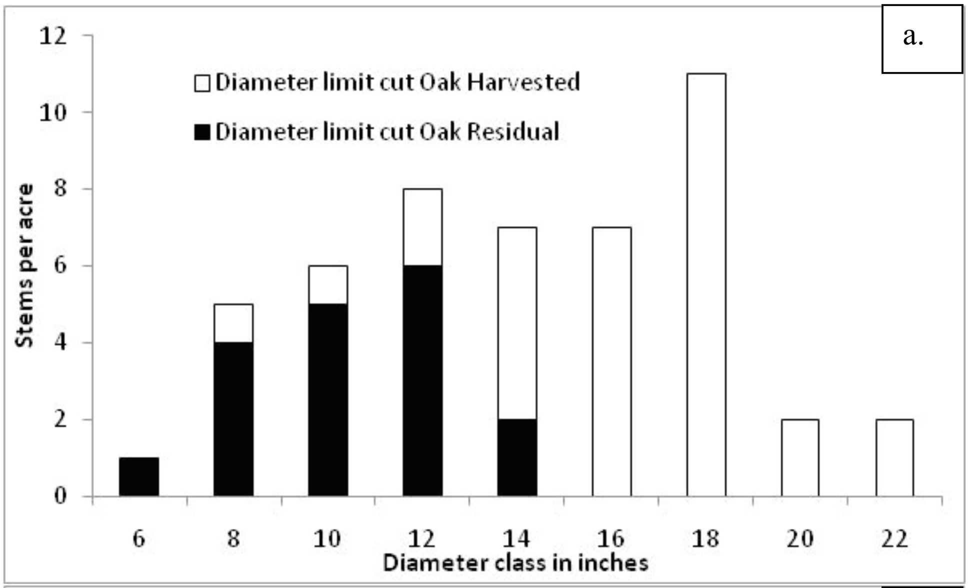


Figure 2—Distribution of all oak (*Quercus rubra, velutina, alba* and *prinus*) in the single-tree selection stand by stems per acre (a) and basal area (b) by diameter classes showing the harvested and residual stand.



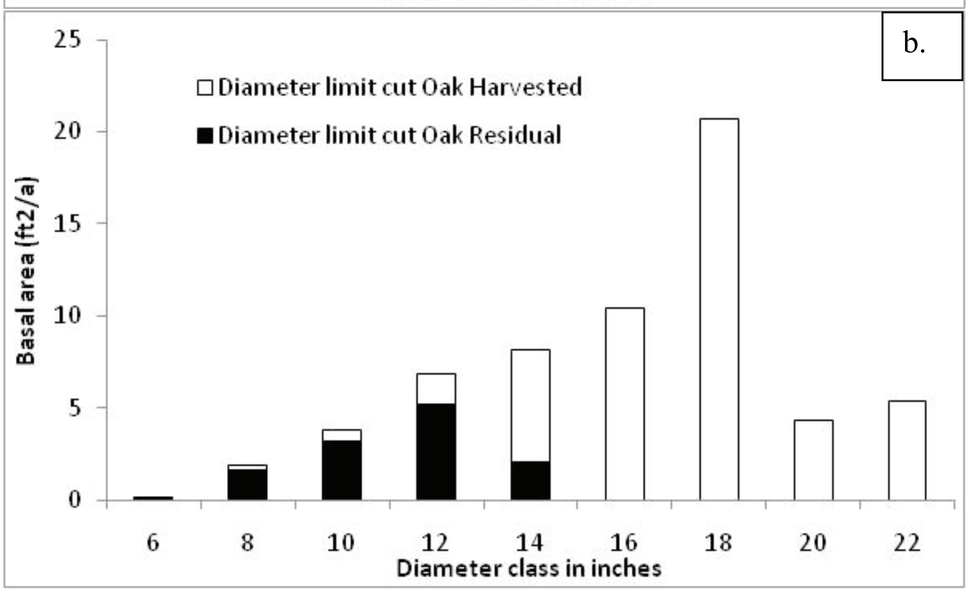


Figure 3—Distribution of all oak (*Quercus rubra, velutina, alba* and *prinus*) in the diameter-limit cut stand by stems per acre (a) and basal area (b) by diameter classes showing the harvested and residual stand.

EFFECTS OF CHEMICAL SITE PREPARATION ON HERBACEOUS VEGETATION PRIOR TO HARDWOOD PLANTATION ESTABLISHMENT

Andrew B. Self, Andrew W. Ezell, Andrew J. Londo, John D. Hodges, and Derek K. Alkire

ABSTRACT

Chemical site preparation is sometimes prescribed when attempting hardwood afforestation in the South. However, adequate research has not been conducted regarding the efficacy of various herbicide treatments often recommended. For practical purposes, the question of whether chemical site preparation provides residual control of herbaceous vegetation in retired agricultural fields has not been answered. This study was performed near Port Barre, Louisiana. Four commonly used chemical site preparation treatments were applied during July 2004. Percent herbaceous coverage was estimated occularly May 2005 - August 2005. Herbaceous components were separated into grass/sedge or broadleaf categories and then further delineated into major species. Means separation was used to determine changes in herbaceous coverage percentages as the growing season progressed. Differences were found among average herbaceous coverage percentages among treatments and within individual treatments on a monthly basis. As the growing season progressed, an inverse relationship between grass/sedge and broadleaf categories was noted. Grass/sedge coverage decreased while broadleaf coverage increased in the treated areas.

INTRODUCTION

Government cost share programs, such as the Wetlands Reserve Program (WRP) and the Conservation Reserve Program (CRP), have increased public interest in afforestation of retired agricultural sites across the Lower Mississippi Alluvial Valley (LMAV). These programs offer financial incentives to aid in recovery of costs incurred by artificially regenerating forests (Schweitzer and Stanturf 1999). The vast majority of these lands are being afforested with hardwood species, and survival of planted hardwood seedlings has been very low in many of these areas (Schweitzer and others 1997). While seedling quality and planting quality are important considerations, the most influential factor in the failure of these plantings may be competing vegetation (Russell and others 1997). Both herbaceous and woody competition may pose a threat to seedling survival in afforestation attempts, with herbaceous competition posing the greater threat in the first years of establishment (Peltzer and Kochy 2001, Smith and others 1997). Increased growth and/or survival of hardwood plantings receiving herbicide treatments for competition control have been documented (Ezell and others 2007, Ezell and Catchot 1997, Ezell and Hodges 2002, Schuler and others 2005).

Many attempts have been made to reduce seedling mortality observed across the LMAV resulting from problems with competing vegetation. Some of these attempts have involved the use of chemical site preparation to achieve control of vegetation on sites where noxious species exist. However, land managers must consider that in highly productive areas, an extremely aggressive herbaceous weed complex can completely invade a site after effective chemical site preparation (Self and others 2010). When site conditions include more aggressive herbaceous complexes, a post plant growing season application using a broad spectrum herbaceous herbicide should be considered and utilized, if possible (Schuler and others 2005, Self and others 2010, Stanturf and others 2004).

In the past, some form of initial vegetation control was generally considered necessary on retired agricultural sites in the LMAV. These agricultural sites are invaded quickly by herbaceous species which decrease the amount of light and moisture available to seedlings (Gardiner and others 2002). Both mechanical and chemical treatments have been used in attempts to manage competing vegetation on these sites. However, due to increased fuel and labor costs, landowners may find chemical site preparation to be the more economical option. Many herbicidal compounds have been tested for use in site preparation. However, relatively few compounds are labeled for use in site preparation efforts for hardwood afforestation due to hardwood intolerance to herbicides commonly used in site preparation.

While imazapyr products are not typically used in established hardwood stands, several are sometimes used in chemical site preparation prior to hardwood afforestation. Non proprietary research testing the efficacy of imazapyr

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usage as a chemical site preparation compound in hardwood establishment is somewhat lacking. However, some studies have shown that if label rates for conifers are used and an adequate amount of time is allowed for compound breakdown, subsequent damage of hardwood seedlings is negligible or non existent (Schuler and others 2005, Yeiser 2003). At this study's initiation, Chopper®, Arsenal AC®, and OneStep® herbicides were the three most commonly encountered imazapyr products in forestry. For this reason, they were selected for application in this project. The objective of this study was to evaluate the efficacy of three chemical site preparation herbicides for providing residual control of herbaceous species during the growing season following application.

MATERIALS AND METHODS

SITE DESCRIPTION

The study area is located five miles northeast of Port Barre, Louisiana (30° 35' 15.19" N, - 91° 52' 41.88" W). The site was fallow for two years following extended soybean production. Watercourses border the site on all sides. The study area encompasses 80 acres within a 250 acre retired agricultural field. The soil is Sharkey clay (very fine, montmorillonitic, nonacid, thermic Vertic Haplaquepts), with slopes less than one percent. These soils are poorly drained and very slowly permeable. Average yearly temperature is 77.9 °F, and average yearly precipitation is 53.56 inches. Soil saturation was observed across the study area from January 2005 until early June 2005, but by October, cumulative precipitation was 16.58 inches lower than the yearly average for the area.

At the time of site selection and chemical site preparation application during July 2004, there was a well established and relatively even herbaceous groundcover with a scattered woody component. The entire research area was surveyed to determine initial herbaceous composition. Herbaceous coverage was estimated occularly and recorded by species and herbaceous categories (grass/sedge and broadleaf). Herbaceous species with coverage encompassing ten percent or more of the total area for any given treatment were designated as dominant species. Dominant herbaceous species onsite included: vaseygrass (Paspalum urvillei Steud.), sumpweed (Iva annua L.), Bermuda grass (Cynodon dactylon L.), beaked rush (Rhynchospora corniculata (Lam.) Gray), soft rush (Juncus effusus L.), curly dock (Rumex crispus L.), coffeeweed (Senna obtusifolia (L.) Irwin & Barneby), and Pennsylvania smartweed (Polygonum pensylvanicum L.). These species comprised approximately 95 percent of the herbaceous competition onsite. An additional 47 herbaceous species and seven woody species were present in small quantities, but did not comprise a significant component of the species complex.

STUDY DESIGN AND PLOT ESTABLISHMENT

A split plot design was used in this experiment. The research was conducted on a 72 acre rectangular area divided into three 24 acre replicates. Each replicate was split into four site preparation areas. Then each site preparation area was divided into four plots encompassing 1.5 acres each which served as the experimental units. All exterior and interior boundary lines were delineated using a transit and a 100 foot surveying tape. Plot corners were marked with five foot sections of one inch PVC pipe.

SITE PREPARATION TREATMENTS

Four chemical site preparation treatments were utilized in this study: (1) no herbicide application (untreated), (2) 32 ounces Chopper EC®/acre + one percent (v/v) Timbersurf 90®, (3) 16 ounces Arsenal AC®/acre + one percent (v/v) Timbersurf 90®, and (4) 16 ounces OneStep®/acre + one percent (v/v) Timbersurf 90®. These herbicides are commonly used at these rates for chemical site preparation and were applied using 20 gallons per acre total spray volume. Applications were completed using a cluster nozzle sprayer with a Radiarc® nozzle system and 0.048 tips mounted on an agricultural tractor. All chemical site preparation treatments were applied on July 26 and 27, 2004.

HERBACEOUS COVERAGE ESTIMATES

Herbaceous coverage estimates were recorded monthly from May 2005 through August 2005. Coverage percentage estimates were not completed during the month of September due to logistical complications arising from Hurricane Katrina. Percent ground cover of herbaceous categories (grass/sedge and broadleaves) was estimated occularly. Coverage percentages were recorded in one percent increments up to ten percent and in five percent intervals thereafter.

DATA ANALYSIS

Field coverage data were tested for normality and homogeneity of variances using univariate analysis in Statistical Analysis System (SAS) version 9.1®. Coverage percentages were arcsine square root transformed to normalize the data. However, actual means are presented in tables for ease of interpretation of percent change throughout the growing season. Analysis of variance was performed using PROC MIXED to test for main effects and to estimate least square means (LSMEANS) by treatment and among months by treatment. When main effects were significant, means separation was performed using Duncan's Multiple Range Test. Differences were considered significant at □ = 0.05.

RESULTS

PERCENT COVERAGE OF GRASS/SEDGE COMPONENT

Chemical site preparation treatments provided excellent initial herbaceous control in Chopper EC®, Arsenal AC®, and OneStep® treatment areas. Untreated areas retained the initial species complex comprised predominately of grasses/sedges through the end of the growing season. Herbaceous coverage in chemically treated areas ranged from zero to one percent from August 2004 through March 2005. In April 2005, a general estimate of herbaceous cover of between one and two percent with plants ranging between one and two inches in height was observed. Herbaceous coverage estimates were initiated May 2005.

The major grass species observed in all site preparation areas throughout the growing season were vaseygrass and bermudagrass. The most notable difference in May observations of grass/sedge coverage was found between chemical site preparation treatment areas and the untreated area (Table 1). There was greater coverage of grasses and sedges in the untreated area (97.0 percent) than in the Chopper EC®, Arsenal AC®, or OneStep® treatment areas (32.3 percent, 19.7 percent, and 16.0 percent, respectively). While lower than in the untreated area, grass/sedge coverage in Chopper EC® areas was greater than observed in Arsenal AC® and OneStep® areas. This pattern continued in June and July estimates. By August, grass/sedge coverage in the untreated area (90.0 percent) was greater than in the Chopper EC®, Arsenal AC®, and OneStep® treated areas (8.0 percent, 3.0 percent, and 2.3 percent, respectively). However, observed grass/sedge coverage in the chemical site preparation areas no longer differed.

Significant differences were observed within individual site preparation treatments from month to month (Table 1). Grass/sedge coverage in the untreated area did not differ from May to August (97.0 percent and 90.0 percent, respectively). Chopper EC® and Arsenal AC® grass/sedge coverage did not differ within treatment between May and June, but grass/sedge coverage for both treatments was lower in July and August. Observed grass/sedge coverage for the OneStep® treated area was lower in May than in June. July and August observations were the same (2.3 percent) and lower than those observed in May or June for the OneStep® site preparation area. Chemically treated areas exhibited August grass/sedge coverage estimates between 14.4 and 24.8 percent of those observed in May.

PERCENT COVERAGE OF BROADLEAF COMPONENT

Unlike grass/sedge coverage, broadleaf coverage was significantly lower in untreated areas than in any of the chemically treated areas (Table 2). The greatest broadleaf coverage in May was observed in Chopper EC® treatment areas (65.0 percent). Arsenal AC® and OneStep® areas exhibited similar broadleaf coverage (50.0 percent and 39.0 percent, respectively), but all were greater than the 7.3 percent coverage observed in the untreated areas. At this time, the major broadleaf competitor observed in all site preparation treatment areas was Pennsylvania smartweed. By June, broadleaf coverage in the Chopper EC® and Arsenal AC® areas was similar, and coverage in the Arsenal AC® areas was similar to the coverage in the OneStep® areas. The June broadleaf coverage estimate in the untreated area was lower than coverage in the three other treatment areas. The only major broadleaf species observed on site preparation treatment areas in June was still Pennsylvania smartweed.

By July, significant changes in percent broadleaf coverage were observed. At this point, a major influx of sumpweed, coffeeweed and Brazil vervain (Verbena brasiliensis Vell.) was observed with the established Pennsylvania smartweed across treated areas. July and August broadleaf coverage for the untreated area (53.3 percent and 50.0 percent, respectively) was roughly one half of the coverage observed in chemically treated areas (Table 2). Broadleaf coverage in the untreated area was lower than in any of the chemically treated areas for both months. None of the three chemical site preparation areas exhibited statistically different broadleaf coverage for the months of July or August.

Significant differences in broadleaf coverage were found within individual treatments on a monthly basis (Table 2). May broadleaf coverage observations for the three chemical site preparation treatments were lower than their corresponding estimates in June, July, or August. Observations in untreated areas differed in that May and June broadleaf coverage (7.3 percent and 13.3 percent, respectively) were not different. Both were lower than coverage estimates in July or August (53.3 percent and 50.0 percent, respectively). All treatment areas exhibited similar broadleaf coverage within their respective treatment during July and August. Each area exhibited broadleaf coverage greater than coverage estimates for May or June. By August, all site preparation treatment areas exhibited approximately two to seven times greater broadleaf coverage than observed in May.

TOTAL HERBACEOUS COVERAGE

By May, herbaceous plants (grasses/sedges and broadleaves) covered 104.3 percent of the untreated areas, with cumulative coverage in treated areas ranging from 55.0 percent to 97.3 percent (Table 3). Coverage increased in June and July, and by August, cumulative coverage in treated areas ranged from 100.0 percent to 108.0 percent compared to 140.0 percent in untreated areas. In essence, complete coverage was observed for all treatments with only the species composition varying by treatment. Chemical site preparation treatments did not provide long term residual control of herbaceous species on this site. The treatments merely shifted the species complex from a predominately grass/sedge coverage to one of broadleaves.

DISCUSSION

All site preparation treatments performed as expected. The Chopper EC®, Arsenal AC®, and OneStep® site preparation treatments provided excellent initial herbaceous and woody control. No significant changes were observed in the grass/sedge herbaceous component for the untreated areas from the time of treatment through the next growing season. The differential of grass coverage between treated and untreated areas demonstrated the efficacy of the herbicides on these species. However, grass/sedge coverage continued to decrease throughout the growing season in treated areas, indicating that the increase in the broadleaf component was limiting resources.

Broadleaf coverage increased across all treatments throughout the growing season. By August, chemically treated areas were observed to exhibit nearly complete vegetative coverage by broadleaf species. An important aspect of the broadleaf coverage in chemically treated areas was the existence of multiple canopies for different broadleaf species. For instance, in many areas both Pennsylvania smartweed and coffeeweed would exhibit coverage of 100 percent. In these situations coffeeweed would form a complete canopy ranging from six to nine feet in height and Pennsylvania smartweed would form an additional complete canopy ranging from two to three feet in height. Other broadleaf species were often intermixed within and between these canopies. This layering effect could severely impact the ability of planted seedlings to compete for the both light and soil moisture. Generally, in untreated areas, layering of grasses and sedges was not observed. In the few untreated areas that multiple canopies were observed, the layering effect did not appear to have a substantial impact on planted seedlings.

In this study, an inverse relationship between grass/sedge and broadleaf herbaceous components was observed. As grass/sedge coverage decreased, broadleaf coverage increased. Due to highly aggressive broadleaf species in the seedbed, nearly complete coverage of areas treated with chemical site preparation was observed by July. The lower broadleaf coverage observed in untreated areas was a result of established grass/sedge species maintaining coverage through July and August. Areas that received chemical treatment were relieved of the grass/sedge component and experienced significant increases of broadleaf encroachment compared to the untreated areas. By July, cumulative coverage of grass/sedge and broadleaf components was substantially greater in untreated areas compared to treated areas. However, the competitive nature of this coverage was reduced due to the greater percentage of the grass/sedge component in the species complex.

CONCLUSIONS

Interest in afforesting retired agricultural sites is increasing. Nearly 200,000 acres of retired agricultural fields were afforested during the 1990s (King and Keeland 1999). An additional 220,000 to 260,000 acres of retired fields were expected to be planted to forest by 2005, and over 30 million acres of retired agricultural fields are expected to be afforested by the year 2040 (Stanturf and others 1998, Wear and Greis 2002). Much of this acreage is expected to be regenerated with hardwood species.

Chemical site preparation should be used to control species which cannot be eliminated through the use of a post plant, broad spectrum, growing season herbicide application. Thus, when chemical treatment is deemed necessary to control existing onsite vegetation prior to planting, it should be part of an herbicide regime which includes a first growing season herbaceous weed control application. Additionally, with millions of acres of afforestation projected across the LMAV in the next few decades, the seriousness of aggressive herbaceous competition on retired agricultural sites can not be understated. Chemical site preparation is of limited efficacy on these plants, and disregarding this potential problem could have vast economical consequences. Of the three imazapyr formulations tested in this study, all provided excellent initial control of onsite herbaceous vegetation. However, by June broadleaf coverage had reached 65 percent or greater across all treatments. At the end of the growing season all treated areas were at or near 100 percent coverage. These increased levels of broadleaf coverage indicate an inadequacy of the initial chemical site preparation treatments in providing first growing season herbaceous control. Broadleaf coverage of this magnitude has been observed to significantly reduce seedling survival in comparison to areas of lower broadleaf and greater grass coverage (Self and others 2010).

If chemical site preparation is used as the only form of competition control on these sites, severe herbaceous competition can be expected by the following growing season. A post plant, pre emergence, broad spectrum herbicide application has the greatest potential to adequately control herbaceous vegetation on sites such as the one utilized in this study. Drawing from the authors experiences, if a late winter/early growing season broad spectrum herbicide application (i.e. 2 oz/acre Oust XP® in February or March) is used in conjunction with, or in place of, chemical site preparation chemical competition control will be practical and effective on most sites comparable to the test area.

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Table 1—Percent coverage of grass/sedge species by time of observation during the 2005 growing season

Treatment	Time of observation: May	June	July	August
	---percent---			
Untreated	97.0a[1]A[2]	98.7aA	96.7aA	90.0aA
Chopper EC®	32.3bA	32.7bA	10.7bB	8.0bB
Arsenal AC®	19.7cA	22.3cA	3.3cB	3.0bB
OneStep®	16.0cB	25.0cA	2.3cC	2.3bC

[1]values followed by different lowercase letters within a column are significantly different at the α = 0.05 level according to Duncan's Multiple Range Test.

[2]values followed by different uppercase letters within a row are significantly different at the α = 0.05 level according to Duncan's Multiple Range Test.

Table 2—Percent coverage of broadleaf species by time of observation during the 2005 growing season

	Time of observation			
Treatment	May	June	July	August
	--------------------percent--------------------			
Untreated	7.3c[1]B[2]	13.3cB	53.3bA	50.0bA
Chopper EC®	65.0aC	85.0aB	95.0aA	100.0aA
Arsenal AC®	50.0bC	73.9abB	100.0aA	100.0aA
OneStep®	39.0bC	65.0bB	93.3aA	97.7aA

[1]values followed by different lowercase letters within a column are significantly different at the α = 0.05 level according to Duncan's Multiple Range Test.

[2]values followed by different uppercase letters within a row are significantly different at the α = 0.05 level according to Duncan's Multiple Range Test.

Table 3—Cumulative average coverage of herbaceous species* by time of observation during the 2005 growing season

	Time of observation			
Treatment	May	June	July	August
	-----------------percent-----------------			
Untreated	104.3	112.0	150.0	140.0
Chopper EC®	97.3	117.7	105.7	108.0
Arsenal AC®	69.7	96.2	103.3	103.0
OneStep®	55.0	90.0	95.6	100.0

*grass/sedge and broadleaf species combined

EVALUATION OF SITE PREPARATION AND PLANTING STOCK ON NUTTALL OAK AND CHERRYBARK OAK GROWTH ON A FORMER AGRICULTURE AREA

Andrew B. Self, Andrew W. Ezell, Andrew J. Londo, John D. Hodges, Derek K. Alkire, and Damon B. Hollis

ABSTRACT

Oaks are an important component of the southern landscape, and are planted on thousands of acres across the region annually. Federal cost share programs, such as the Wetland Reserve Program (WRP), have increased public interest in afforestation of retired agricultural sites in the Lower Mississippi Alluvial Valley. Acorns, bare root, containerized, and potted seedlings of Nuttall oak (*Quercus texana* Buckl.) and cherrybark oak (*Quercus pagoda* Raf.) were tested in a WRP planting near Port Barre, Louisiana to evaluate both groundline diameter and height growth following four mechanical/chemical site preparation treatments. These acorns/seedlings were planted on 16 foot by 36 foot centers. The research site was subsoiled on 16 foot centers with acorn/seedlings planted in subsoil trenches. Control (no mechanical/chemical treatment), subsoil only, subsoil/Chopper EC®, subsoil/Arsenal AC®, and subsoil/OneStep® treatments were applied in an attempt to evaluate which treatment combination provided greatest growth. Growth was measured for the 2005 growing season. No height or GLD differences were observed between species. However, height growth differences were detected among planting stocks types and GLD growth differences were detected among site preparation treatments and planting stocks.

INTRODUCTION

Oaks (*Quercus* spp.) are an ecologically and economically important component of the southern landscape, and many landowners are opting to regenerate their lands with these species. Implementation of federal cost share programs, such as the Wetland Reserve Program (WRP) and the Conservation Reserve Program (CRP), have resulted in increased public interest afforestation of retired agricultural sites in the Lower Mississippi Alluvial Valley (LMAV). Subsequently many thousands of acres across the region have undergone afforestation attempts. According to Schoenholtz and others (2001), survival of planted seedlings and acorns has been low in these areas, resulting in a low percentage of oaks in established stands. This is possibly a corollary of poor soil conditions, poor planting techniques, poor seedling quality, and problems with competing vegetation. These problems can be alleviated through proper planting of high quality seedlings and through the application of proper silvicultural treatments needed to achieve enhanced survival and growth.

Survival and growth of seedlings could potentially be improved by using both mechanical and chemical site preparation treatments. Many retired fields have substantial levels of compaction due to past land use practices (Allen et al. 2001). Subsoiling can correct some of the problems associated with these sites. Subsoiling has been found to improve growth and possibly survival of various oak species in several studies (Ezell and Shankle 2004, Moree et al. 2010, Self et al. 2010). Potential increases in survival and growth from subsoiling can be the result of improved moisture and nutrient uptake, as well as enhanced root formation. These advantages could be critical on many sites where environmental conditions are stressful.

Possibly the most influential agent in the failure of oak plantings is competing vegetation, and an increase in oak survival and/or growth as a response to herbicide treatment has been documented in several studies (Russell et al. 1997, Ezell and Catchot 1997, Ezell and Hodges 2002, Schuler et al. 2005, Ezell et al. 2007). Both herbaceous and woody competition may pose a threat to the survival of planted oak seedlings, with herbaceous competition posing the greatest threat in the first years of establishment (Smith et al. 1997, Peltzer and Kochy 2001). Many attempts have been made to reduce mortality and increase growth of oak seedlings in plantings across the LMAV that result from competing vegetation problems. Some of these attempts have involved the use of chemical site preparation to achieve control of vegetation on sites where noxious species exist.

In the past, some form of initial vegetation control was generally considered necessary on retired agricultural sites in the LMAV. These agricultural sites are typically

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invaded quickly by herbaceous species which decrease the amount of light and moisture available to seedlings (Gardiner et al. 2002). Land managers must consider that in highly productive areas, an extremely aggressive herbaceous weed complex can completely invade a site after effective chemical site preparation (Self et al. 2010). When site conditions include more aggressive herbaceous complexes, a post-plant growing season application using a broad spectrum herbaceous herbicide should be considered (Stanturf et al. 2004, Schuler et al. 2005, Self et al. 2010).

OBJECTIVES

The objectives of the study were:
1. To evaluate effects of subsoiling on first-year growth in Nuttall and cherrybark oak.
2. To evaluate effects of competition control on first-year growth of Nuttall and cherrybark oak.
3. To evaluate first-year growth of different planting stock types.

MATERIALS AND METHODS

SITE DESCRIPTION

The study area is located five miles northeast of Port Barre, Louisiana (30° 35' 15.19" N, - 91° 52' 41.88" W). The site was fallow for two years following extended soybean production. Watercourses border the site on all sides. The study area encompasses 80 acres within a 250 acre retired agricultural field. The soil is Sharkey clay (very-fine, montmorillonitic, nonacid, thermic Vertic Haplaquepts), with slopes less than one percent. These soils are poorly drained and very slowly permeable. Average yearly temperature is 77.9°F, and average yearly precipitation is 53.56 inches. Soil saturation was observed across the study area from January 2005 until early June 2005. However, by October, drought conditions resulted in a cumulative precipitation deficit of 16.58 inches compared to the area's yearly average.

At site selection and chemical site preparation application during July 2004, there was a well established herbaceous groundcover with a scattered woody component. Dominant herbaceous species onsite included: vaseygrass (*Paspalum urvillei* Steud.), sumpweed (*Iva annua* L.), Bermuda grass (*Cynodon dactylon* L.), beaked rush (*Rhynchospora corniculata* (Lam.) Gray), soft rush (*Juncus effusus* L.), curly dock (*Rumex crispus* L.), coffeeweed (*Senna obtusifolia* (L.) Irwin & Barneby), and Pennsylvania smartweed (*Polygonum pensylvanicum* L.). These species comprised approximately 95 percent of the herbaceous competition onsite. An additional 47 herbaceous species and seven woody species were present in small quantities, but did not comprise a significant component of the species complex. The dominant woody species onsite was tallowtree (*Sapium sebiferum* L.). There were also small components of green ash (*Fraxinus pennsylvanica* Marsh.), black willow (*Salix nigra* Marsh.), sugarberry (*Celtis laevigata* Willd.), eastern baccharis (*Baccharis halimifolia* L.), honeylocust (*Gleditsia triacanthos* L.), and sweetgum (*Liquidambar styraciflua* L.).

STUDY DESIGN AND PLOT ESTABLISHMENT

Operational constraints strongly influenced the design of this study. Herbicide treatments, planting stocks, and species could not be randomly allocated for reasons of equipment and personnel efficiency. A split, split strip-plot design was utilized in this experiment. The research was conducted on a rectangular area of approximately 72 acres. This area was divided in a vertical (north/south) direction into four, 18-acre blocks. These blocks were established for the purpose of applying site preparation treatments. For replication purposes, the site was divided horizontally (east/west) into three, 24-acre blocks. A total of 48 data cells comprising 1.5 acres each, were established on the research site. Six control (no site preparation, no herbicide application) data cells were established immediately adjacent to study area boundaries. These data cells were used to determine survival of seedlings in areas without chemical or mechanical silvicultural treatment. All exterior and interior boundary lines were delineated using a transit and a 300 foot surveyor's tape.

Data cell corners were marked with five foot sections of one inch PVC pipe. Individual tree rows were marked with two foot sections of one inch PVC pipe. Tree row pipes were also marked with 36 inch pin flags color specific to species. Individual tree/acorn planting locations were determined and marked with 36 inch pin flags color specific to species.

SITE PREPARATION TREATMENTS

Both mechanical and chemical treatments were used in initial site preparation efforts. Mechanical site preparation consisted of subsoiling the entire area using a 16-foot spacing across the site. This subsoiling treatment was performed to reduce "restriction layers" or compaction commonly found in retired agricultural fields. Subsoiling was also utilized to evaluate its effect on survival in oak establishment attempts. The subsoil treatment was performed using a three inch wide single shank subsoil plow pulled by a skidder. The subsoil plow was tipped with an eight inch tiger wing tip followed by two 16 inch closing wheels attached to the rear. Subsoil trenches were installed on December 1-2, 2004.

Four chemical site preparation treatments were utilized in this study: (1) no herbicide application (untreated), (2) 32 oz. Chopper EC®/acre + one percent (v/v) Timbersurf 90®, (3) 16 oz. Arsenal AC®/acre + one percent (v/v) Timbersurf 90®, and (4) 16 oz. OneStep®/acre + one percent (v/v) Timbersurf 90®. These herbicides are commonly used at these rates for chemical site preparation. Site preparation herbicides were applied using 20 gpa total spray volume. Applications were completed using a cluster nozzle sprayer with a Radiarc® nozzle system and 0.048 tips mounted on an agricultural tractor. All chemical site preparation treatments were applied on July 26-27, 2004.

SEEDLING ESTABLISHMENT

There were 14 subsoil trenches in each data cell. These served as planting rows with the two outside rows being used as buffers (no measurements). The twelve internal rows were specified as evaluation rows. Individual oak seedling/acorn planting sites were spaced using a 36 foot interval along the subsoiled row. Nuttall oak and cherrybark oak seedlings/acorns were planted. Four planting stock types were used: acorns, bare root seedlings, containerized seedlings, and potted seedlings. A total of 4,212 seedlings/acorns were planted. Twelve-inch diameter holes were augered for seedlings planted on potted or bare root stock rows. The purpose of this augering treatment was to facilitate planting of the large root systems of potted and large caliper bare root seedlings. These holes were backfilled to a depth that placed individual seedling root collars at or slightly below ground level. Seedlings were then placed in their respective holes and the holes were refilled with soil being packed around the root systems. Containerized seedlings were planted at or slightly below root collar depth using planting shovels. Acorns were planted approximately one half to one inch deep using a piece of PVC pipe to open a hole, placing the acorn in the hole, and then packing soil over the acorn.

Potted and containerized seedlings were purchased from Five Oaks Tree Nursery in Dewitt, Arkansas and were lifted December 16, 2004. These seedlings were planted on December 18-20, 2004. Bare root seedlings were purchased from Delta Wildlife Consulting, Inc. in Winnesboro, Louisiana and were lifted December 27, 2004. These seedlings were planted on December 28-29, 2004. Acorns were purchased form the Louisiana Forest Seed Company, and were collected from sources within Louisiana. The acorns were float tested and guaranteed 95 percent sound. Acorns were planted April 8, 2005. Bare root green ash, winged elm (*Ulmus alata* Michx.), red maple (*Acer rubrum* L.), hackberry (*Celtis occidentalis* L.), common persimmon (*Diospyros virginiana* L.), and sweetgum seedlings were interplanted between oak seedlings/acorns on nine foot intervals to achieve WRP tree number specifications. These seedlings were not measured, nor assessed for this study.

SEEDLING MEASUREMENTS

Initial seedling measurements were completed January 6-7, 2005. Height was measured to the nearest tenth of a foot using height sticks. Groundline diameter (GLD) was measured to the nearest 0.001 inch using digital calipers. Acorn germinants were sought, but not found throughout the growing season. Final seedling measurements were taken October 8-18, 2005 on surviving seedlings. In situations where resprouting was encountered, GLD was measured one of two ways. If the resprout grew from the base of the original stem, GLD was taken on the original stem. If the resprout sprouted from subterranean root stock, GLD was taken on the resprout. Data were collected in the same manner as initial measurements.

DATA ANALYSIS

Growth averages were calculated using Statistical Analysis System (SAS) version 9.1®. PROC mixed was used to perform ANOVA to test for main effects and to estimate least square means (LSMEANS) for variables and interactions. When main effects were significant, means separation was performed using Duncan's Multiple Range Test. Differences were considered significant at the $\alpha = 0.05$ level of significance.

RESULTS AND DISCUSSION

HEIGHT GROWTH VARIATION BY PLANTING STOCK

No height growth difference was detected between Nuttall oak and cherrybark oak seedlings regarding planting stock performance. There was no difference in height growth between potted and bare root planting stocks (Table 1). Containerized seedlings exhibited less height growth (0.17 feet) than bare root or potted seedlings, both of which exhibited 0.34 feet of height growth. Overall, growth observed in the containerized seedlings was one half the height growth observed in potted and bare root seedlings.

GLD GROWTH BY PLANTING STOCK

No GLD growth difference was detected between Nuttall oak and cherrybark oak seedlings regarding planting stock performance. Bare root seedlings exhibited greater GLD growth compared to containerized or potted seedlings (0.079 inches, 0.043 inches, and 0.062 inches, respectively) (Table 2). Containerized seedlings exhibited the least GLD growth. Less GLD growth in containerized stock compared to bare root stock is not typically expected. Williams and Craft (1997) found that containerized seedlings exhibited approximately twice the growth of that observed in bare root seedlings after one growing season. Greater GLD growth observed in bare root seedlings compared to containerized or potted seedlings is added evidence that if vigorous bare root seedlings are planted properly, afforestation attempts on retired agriculture areas can be successful using such seedlings.

GLD GROWTH BY SITE PREPARATION TREATMENT

No GLD growth difference was detected between Nuttall oak and cherrybark oak seedlings regarding site preparation effects. Overall, seedlings in Subsoil/Chopper EC® treatment areas exhibited greater GLD growth (0.077 inches) compared to seedlings in all other site preparation treatment areas (Table 3). Seedlings in Control, Subsoil only, Subsoil/Arsenal AC®, and Subsoil/OneStep® areas did not exhibit significantly different GLD growth (0.053 inches, 0.051 inches, 0.058 inches, and 0.055 inches, respectively).

Greater GLD growth observed in the Subsoil/Chopper EC® areas cannot be readily explained. Initial or growing season vegetative control did not differ substantially among herbicide treatments, site condition differences were not observed among treatment areas, and herbaceous species did not differ appreciably among treatment areas. Subsoil only treatment areas received no chemical site preparation treatment, and seedling GLD growth did not statistically differ between these areas and Subsoil/Arsenal AC®, or Subsoil/OneStep® areas. Lack of statistical differentiation is likely due to inadequate vegetative control provided by these treatments into the growing season following application.

It should be noted that chemical site preparation treatments used in this study provided excellent short term control of competing vegetation. However, adequate control of vegetation was not expected or achieved. A shift in species complex was observed in onsite herbaceous vegetation between initial observations and observations made at the end of the first growing season (Self 2006). Initial herbaceous coverages were comprised primarily of grass species. Coverage composition shifted to one comprised of predominantly broadleaf species. The extremely dense coverage of broadleaf species was thought to negate possible benefits of herbicide treatments. Chemical site preparation should be used only to control species which cannot be eliminated by growing season herbaceous weed control efforts. It is these herbaceous release applications that typically provide longer term control of competition if the proper herbicide is used.

Subsoiling has proven effective in increasing GLD growth in hardwood plantings. Ezell and Shankle (2004) found that subsoiling significantly increased GLD growth in Shumard oak, water oak, willow oak, and green ash seedlings. Russell et al. (1997) reported that subsoiling increased first-year diameter growth of cherrybark oak seedlings. While very little difference in seedling growth was noted among chemical site preparation treatments in this study, greatest survival was observed in areas that received subsoiling as the only form of treatment (68.8 percent) (Self et al. 2010). Ultimately survival prevails, and the much higher survival would generally be more important than slightly less growth in establishing oak plantings.

CONCLUSION

Conventional wisdom assumes that potted and containerized planting stocks will outperform traditional bare root stock. However, results of this study found bare root seedlings to exhibit greater height and GLD growth than containerized seedlings grown under similar site preparation treatments. Furthermore, bare root stock outperformed potted stock with greater GLD growth.

Better growth results would be expected in areas receiving both subsoiling and effective competition control. While seedlings grown in areas treated with the Subsoil/Chopper EC® treatment exhibited greater GLD growth compared to seedlings in other treatment areas, this is not thought to result from any inherent treatment effects. A more plausible explanation for the lack of statistical difference among other treatments can be found in the lack of herbaceous control during the growing season following application of chemical site preparation.

If an aggressive broadleaf competitor exists onsite and growing season herbaceous control is not an option, the best alternative might be to not perform any chemical applications. If adequate growing season control cannot be achieved, subsoiling can provide improved results when planting hardwoods on retired agricultural areas. Subsoiling is also beneficial as a site preparation treatment in its own right, with a proven track record in influencing increased survival. The excellent performance of bare root seedlings in this study further substantiates the adequacy of planted properly bare root seedlings in afforestation attempts on retired agriculture areas.

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Table 1—Average height growth by planting stock (all species and site preparation treatments)

Planting Stock	Height Growth (feet)
Bare root	0.34a[1]
Containerized	0.17b
Potted	0.34a

[1]values followed by different letters are significantly different at α = 0.05.

Table 2—Average GLD growth by planting stock (all species and site preparation treatments

Planting Stock	GLD Growth (inches)
Bare root	0.079a[1]
Containerized	0.043c
Potted	0.062b

[1]values followed by different letters are significantly different at α = 0.05.

Table 3—Average GLD growth by site preparation treatment (all species and planting stocks)

Treatment	GLD Growth (inches)
Control	0.053b[1]
Subsoil only	0.051b
Subsoil/Chopper EC®	0.077a
Subsoil/Arsenal AC®	0.058b
Subsoil/OneStep®	0.055b

[1]values followed by different letters are significantly different at α = 0.05.

ESTIMATING THE PROBABILITY OF SURVIVAL OF INDIVIDUAL SHORTLEAF PINE (PINUS ECHINATA MILL.) TREES

Sudip Shrestha, Thomas B. Lynch, Difei Zhang, and James M. Guldin

A survival model is needed in a forest growth system which predicts the survival of trees on individual basis or on a stand basis (Gertner, 1989). An individual-tree modeling approach is one of the better methods available for predicting growth and yield as it provides essential information about particular tree species; tree size, tree quality and tree present status. Individual tree survival models simulate survival and growth of individual trees in a forest stand. They are important in determining the development pattern of stand. A survival model is a major component of the Shortleaf Pine Stand Simulator (SLPSS) (Huebschmann, 1998) which has been developed for even-aged natural shortleaf pine forests. SLPSS includes a prediction equation for probability of tree survival which is based on repeatedly measured plots permanently located in the Ozark and Ouachita National forests which have diverse ages, site qualities and densities.

We developed an individual tree survival model for shortleaf pine (*Pinus echinata* Mill.) trees. Data for this study were from more than 200 permanently established plots on even-aged natural shortleaf pine stands that were located in the Ozark and Ouachita National Forests. Plots were established during the period of 1985-1987. Plots have been remeasured in every 4 to 6 years and individual tree survival or mortality was recorded at each measurement. Logistic regression was used to find the best sets of significant predictor variables to predict periodic survival.

Significant variables found in predicting the survival were mid-period basal area per acre (Mid-BA), inverse of ratio of quadratic mean diameter to DBH (diameter at breast height) (DRINV), their interaction and square of DBH (DBHSQ). These independent variables were found to be very significant in predicting annual probability of survival of a tree (Shrestha 2010). Parameters of the logistic equation were estimated using iteratively re-weighted nonlinear regression. Various independent variables such as square root of DBH, square of DBH / mid-basal area, tree dominant height, site index, and mid-plot age etc. were tested in addition to the variables finally selected for use in the model but they were found nonessential in estimating annual survival of individual shortleaf pine trees.

The final model selected for this study contained the following independent variables: Mid-BA, DRINV, DBHSQ, and Mid-BA × DRINV. Predicted values from the model can be interpreted as probabilities of survival for shortleaf pine trees having the characteristics indicated by the independent variables. Based on the results from the final model, the observed frequencies of individual tree survival have no severe deviation from the expected frequencies indicating that the model for survival fits well. The final model above was evaluated using the Chi-square goodness of fit test and it was found that the model was not rejected at the alpha level of 0.01 significance. The model was rejected by the goodness-of-fit test at the significant level of 0.05 because of these high mortality results in some of the diameter classes. We found that the contribution to chi-square value from mortality is much higher than for survival and there was much more fluctuation in observed and expected number of mortality trees as compared to survival trees suggesting the model did not always behave as well for mortality trees.

The final model is considered as a better alternative than a constant survival rate and could be selected for use in the SLPSS, which is a distance-independent individual tree growth simulator for naturally-regenerated shortleaf pine. This individual tree survival model can be used to predict the annual survival rate of individual trees of even aged shortleaf pine forests located in Ozark and Ouachita National Forests.

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WILL AFFORESTATION IN TEMPERATE ZONES WARM THE EARTH?

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For decades, forest researchers have known that afforestation can lower the surface albedo and that landscapes with low albedo will absorb more solar radiation than more reflective surfaces. As a result, afforestation will typically darken the surface of the Earth (when compared to grasslands or deserts). This darkening of the landscape can be measured and the local warming effect can be quantified.

In spite of this knowledge, many believe that afforestation will have a cooling effect on the Earth's atmosphere since wood is composed of carbon molecules. As a result, there are two schools of thought when it comes to claiming how afforestation will affect the climate. The "CO_2 school" believes that afforestation will have a cooling effect, regardless of the location of the plantation. In contrast, the "holistic school" believes the climate is a complex system that is affected by numerous variables, including clouds and the surface albedo. Many from this school say that afforestation in boreal zones could have a warming effect on the Earth.

Some say that afforestation in temperate zones will cool the Earth (Montenegro and others 2009) while others suggest it might warm the Earth (Feddema and others 2005, Barnes and Roy 2008, South 2008). Others say the effect is not clear (Bonan 2008, South and others 2011) or that the effect is not statistically different from zero (Arora and Montenegro 2010, Fall and others 2010). Some say the result would depend on both growth rate of the plantations and the amount of change in the albedo of the Earth's surface. Afforestation with slow growing conifers in high altitude zones (e.g. the Pyrenees) may not sequester much carbon by 2050 but it would have a relatively large effect on the albedo. In contrast, afforestation with exotic conifers in New Zealand would sequester more carbon and would have less of a change in surface albedo (Kirschbaum and others 2011). In some arid zones, it may take 5 to 8 decades before the "carbon sequestration" effect will equal the warming effect from darkening the Earth's surface (Rotenberg and Yakir 2010).

The climate is not a simple system and therefore, there is no simple answer to the question "will afforestation in temperate zones warm the Earth?" The answer will vary depending on the model used and if the answer is related to "global effects" or just "local effects." Some modelers have suggested that afforestation in the Tropics would cool the Earth while Boreal afforestation would warm the Earth. We claim we do not know if afforestation in temperate zones will have any statistically significant effect on the global temperature. To date, the climate models used in the modeling have not been verified and this makes speculations about "global" effects questionable. We have a low level of confidence that the predictions from these models are accurate down to the second decimal place (ie. 0.01°C). In the absence of data, we doubt that afforestation in temperate zones is an effective practice for the mitigation of climate change.

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Table 1—Estimated temperature effects from afforestation and deforestation. Estimated costs are not associated with deforestation since short-term profits are typically obtained with the sale of wood products

Region	change (ha)	Cost	Temperature effect	Reference
AFFORESTATION				
Arctic	+0.3 billion	$300 billion	Arctic warmed ≈ +1 C	Swann and others 2010
Arctic	+0.1 billion	$100 billion	Globe cooled ≈ -0.015 C	Arora and Montenegro 2011
Temperate	+1 billion*	$1 trillion	?????	House and others 2002
Temperate	+0.1 billion	$100 billion	Globe cooled ≈ -0.017 C	Arora and Montenegro 2011
Tropical	+0.1 billion	$100 billion	Globe cooled ≈ -0.07 C	Arora and Montenegro 2011
DEFORESTATION				
Arctic	-1.37 billion	--	Arctic cooled -3.3 C	Bala and others 2007
Temperate	-1.04 billion	--	Land in NH cooled -0.7 C	Bala and others 2007
Temperate	-1.04 billion	--	Globe cooled -0.04 C	Bala and others 2007
Tropical	-1.76 billion	--	Globe warmed +0.7 C	Bala and others 2007

*Assumes temperate forests can sequester 200 tonnes C/ha

BLUE STORMS DEPRESS GROWTH OF SHORTLEAF PINE IN WESTERN ARKANSAS AND EASTERN OKLAHOMA

Douglas J. Stevenson, Thomas B. Lynch, and James M. Guldin

Climate and weather, especially storms, have major effects on trees. Fast moving "Alberta Clippers," or Blue Storms, that produce extreme cold and little precipitation happen each year on the Great Plains in association with Chinook winds in the Northern and Central Rockies. When these storms occur between February 13th and March 10th when shortleaf pines on the Ouachita National Forest are becoming active, characteristic narrow growth rings are left in the wood. Prior to February 13th, growth is not affected by cold temperatures; after March 10th when trees are fully active, a frost ring is produced. Only between these two dates is growth reduced without the production of a frost ring.

The objective of the study was to identify the cause of a number of narrow, or "marker" rings in shortleaf pine increment cores from the Cold Springs District of the Ouachita National Forest and develop a prediction model for recovery of radial growth.

Forty-six increment cores from thinned and unthinned plots in an ongoing shortleaf pine growth and yield study near Booneville, Arkansas were read and cross-dated. After age and autocorrelation effects were removed from the data, precipitation in all months contributed significantly to ring width at a 95.0% confidence level. Precipitation "explained" 23.9% of the variation. Extreme winter low and summer high temperatures did not correlate with ring width, but temperatures below -12 degrees Celsius in the February 13th - March 10th interval coincided with narrow rings and the occurrence of Blue Storms on the Great Plains. Rings took from 1 to 3 years to recover. A logistic model of precipitation, climate and storm effects "explained" 37.5% of total variation at the 95% level.

Blue storms were identified as the cause of narrow (<0.760mm) growth rings in 1905, 1910, 1920, 1936, 1943, 1963, 1978, 1980, 1993, and 2002. All of these storms produced temperatures below -12 degrees C. at Booneville. Drought was identified as contributing to the narrow ring in 1980 and was the cause of narrow rings in 1933, 1947, 1954, 1956 and 1997. A narrow ring in 2001 was caused by damage from the Christmas Ice Storm of 2000. Ice storms may have contributed to the narrow rings in 1963 and 1993. There were no other years with ring widths less than 0.760 mm. Dates of storms and low temperatures produced were obtained from *Monthly Weather Reports*, available from the National Oceanographic and Atmospheric Administration.

Monthly precipitation and monthly values of the Palmer Drought Severity Index (PDSI) were used to create the following climate model:

$$W = 0.5012 + 0.0166*Oct + 0.04*Nov + 0.0247*Apr + 0.0194*Aug + 0.0228*Sept + 0.0826*OctPDSI + 0.0815*NovPDSI - 0.0716*DecPDSI + 0.0533*JanPDSI - 0.115*FebPDSI + 0.0394*MarPDSI + 0.0428*JunePDSI - 0.0555*JulyPDSI + 0.0421*AugPDSI - 0.0745*SeptPDSI$$

Where,
W = Estimated ring width (mm)
Month abbreviations are monthly precipitation in inches at the Cold Springs Work Center, and
Month abbreviations followed by "PDSI" are monthly values of the Palmer Drought Severity Index for Arkansas Division 4.

Estimated ring width was subtracted from measured ring width and average measured ring width added back in to create the declimatized data set (D). A logistic growth model for each of the five most-recent storms was developed:

$$f(Storm) = Ave5/(1-exp(b*(Year-StormYear)))$$

Where,
f(Storm) = modifier (mm) added to ring width predicted by climate model,
Ave5 = average ring width over all sample trees of five rings immediately preceding the StormYear,
Year = the calendar year of the individual ring,
StormYear = the calendar year of the storm
(Five dummy variables were used to "zero" out growth rings in years prior to the particular storm year.).

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This produced values of:
Ave5(1963) = 1.109
Ave5(1978) = 0.896
Ave5(1980) = 0.758
Ave5(1993) = 1.118
Ave5(2002) = 0.589

Each of the five terms was included in the final model:

D = 1.109/(1-exp(b1*(2007-1963))) +
0.896/(1-exp(b2*(2007-1978))) +
0.758/(1-exp(b3*(2007-1980))) +
1.118/(1-exp(b4*(2007-1993))) +
0.589/(1-exp(b5*(2007-2002)))

This produced the following values of b:

b1 = 1.589 (1963)
b2 = 1.749 (1978)
b3 = 1.326 (1980)
b4 = 2.254 (1993)
b5 = 1.615 (2002)

The resulting correlation coefficient (r^2) was 0.043. The F-value with 5 and 2799 degrees of freedom was 25.13 ($p<0.0001$). The standard error of the ring width was 0.305 mm, high for a shortleaf pine chronology. This is probably due to the sample containing trees from both thinned and unthinned plots and because broken, branch-damaged and undamaged trees from the 2000 ice storm were all included in the data set (When the climate signal was removed from 31 broken trees from the same site, the resulting standard error was 0.262 mm.).

Narrow growth rings (<0.760 mm) in shortleaf pine on the Cold Springs District that were not produced by drought or ice storm damage, resulted from extreme cold events, or Blue Storms, occurring in the latter half of February and first half of March while pine trees are just beginning to become active.

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BEETLE-KILLED STANDS IN THE SOUTH CAROLINA PIEDMONT: FROM FUEL HAZARDS TO REGENERATING OAK FORESTS

Aaron D. Stottlemyer, G. Geoff Wang, and Thomas A. Waldrop

Impacts of spring prescribed fire, mechanical mastication, and no-treatment (control) on fuels and natural hardwood tree regeneration were examined in beetle-killed stands in the South Carolina Piedmont. Mechanical mastication ground the down and standing dead trees and live vegetation into mulch and deposited it onto the forest floor. The masticated debris layer had an average depth of 15 cm and loading of 503 Mg ha^{-1} in the first year (Yr 1) post-treatment.

Prescribed burning reduced fuelbed continuity by significantly ($P < 0.05$) reducing litter (Oi) and duff (Oe + Oa) layer thicknesses by 88 and 84 percent, respectively. There were significant reductions in fine (1- and 10-hr timelag size class) fuels (71 and 73 percent, respectively) and 100-hr fuels (13 percent) with prescribed burning, but not 1000-hr fuels. Total dead and down fuel loading in Yr 1 post-burn (16.3 Mg ha^{-1}) was significantly less than the loading of masticated debris, but not significantly different than total fuel loading in control stands (24.3 Mg ha^{-1}). Both prescribed burning and mastication significantly reduced (by 27 and 52 percent, respectively) dead and down fuelbed depth.

Hardwood tree regeneration re-sprouted after the treatments were implemented. However, there were differences in sprouting between burned and masticated stands. By the second year (Yr 2) post-burn, oak sapling (≥ 1.4 m tall) density was 680 stems ha^{-1} and the ratio of oak saplings to those of other hardwood competitors was 1:3. There were 8417 sprouts (0.5-1.4 m tall) ha^{-1} in Yr 2 post-burn.

There were 47 oak saplings ha^{-1} in Yr 2 post-masticated stands and the ratio of oak to other hardwood saplings was 1:15. There were 66 percent fewer oak sprouts post-mastication (2833 stems ha^{-1}) when compared to post-burn stands. It is likely that because the cutting teeth on the masticating head penetrated the soil surface up to 5 cm in depth, the treatment damaged basal buds and inhibited sprouting. The masticated debris layer may have also been a physical impediment to new sprout growth.

Results of this study suggest that prescribed burning reduces the fuel hazard in beetle-killed stands by reducing the continuity of the fuelbed. Mastication on the other hand increased both the loading of dead and down woody debris and continuity of the fuelbed. However, it is largely unclear how the thick, compacted layer of masticated debris affects fire risk. Finally, advance oak regeneration was abundant in post-burn stands while the sprouting of oak and other hardwoods was inhibited in masticated stands, suggesting that prescribed burning is a superior option when silvicultural objectives include naturally-regenerating hardwoods in beetle-killed pine stands.

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SHORT-TERM CARBON PARTITIONING FERTILIZER RESPONSES VARY AMONG TWO FULL-SIB LOBLOLLY PINE CLONES

Jeremy P. Stovall, John R. Seiler, and Thomas R. Fox

ABSTRACT

We investigated the effects of fertilizer application on the partitioning of gross primary productivity (GPP) between contrasting full-sib clones of *Pinus taeda* (L.). Our objective was to determine if fertilizer growth responses resulted from similar short-term changes to partitioning. A modeling approach incorporating respiratory carbon (C) fluxes, soil CO2 efflux (FS), and biomass was applied to a factorial design with two clones, fertilizer and control treatments, and four sequential monthly harvests of seedlings planted in a greenhouse. Partitioning was integrated over 121 days to above, belowground, and total net primary production (ANPP + BNPP = NPP), total belowground C flux (TBCF), aboveground plant respiration (APR), and FS. While both clones showed similar GPP and responses to fertilizer application, they did so by partitioning GPP in different ways. Fertilizer application increased GPP and resulted in corresponding increases in ANPP, BNPP, and TBCF ($p < 0.01$). When considered as a fraction of GPP partitioned, differences between clones emerged. Clone-by-fertilizer interactions for carbon use efficiency (i.e. NPP / GPP), ANPP / GPP, and APR / GPP were all observed ($p < 0.10$). TBCF was significantly greater in one clone, indicating that plant-soil interactions could be affected by clone-specific partitioning. The other clone had greater growth efficiency (ANPP / GPP) without fertilizer, but with fertilizer application the clones were similar. Our results suggest multiple possible short-term ecophysiological mechanisms are responsible for fertilizer growth response in different yet closely related clones.

INTRODUCTION

Pinus taeda (L.) and less commonly *Pinus elliottii* (Engelm.) plantations are widespread across the Southeast, currently covering more than 13 million hectares, or approximately 75 percent of the 17 million total hectares of plantation forestland in the United States (Wear and Greiss 2002; FAO 2007). High productivity is achieved not only through improved genetics, but also through intensive silvicultural practices including site preparation, competition control, and fertilizer application, which combined are estimated to have increased productivity per land area by approximately 40 percent over natural stands (Fox, Jokela and others 2007). Since the early 1990's millions of hectares of plantations have been fertilized, at an annual rate of 0.5 million hectares as of 2004 (Fox, Allen and others 2007). Fertilizer growth responses vary across sites, but average 25 percent in response to mid-rotation application of nitrogen and phosphorous (Fox, Allen et al. 2007). Tree improvement has also resulted in significant gains in productivity. While open-pollinated seedlings still represent the vast majority of those planted in the Southeast, a number of methods for the production of elite genotypes have been developed in the last two decades (McKeand, Mullin and others 2003). Somatic embryogenesis is utilized to produce millions of genetically identical clonal seedlings from a single seed (Merkle and Dean 2000). More than 20 million clonal *P. taeda* seedlings have been planted as of 2010, and production and planting of clones is only expected to increase as production capabilities of the companies producing clonal seedlings increases (McKeand, Zobel and others 2007; Bettinger, Clutter and others 2009).

Clonal variability in a number of different tree species has been shown for survival (Bitoki 2008), growth and phenology (Paul, Foster and others 1997), soil CO2 efflux (Kasurinen, Kokko-Gonzales and others 2004), light-saturated net-photosynthetic rates (King, Seiler and others 2008), crown structure and radiation interception (Emhart, Martin and others 2007), biomass partitioning (Scarascia-Mugnozza, Ceulemans and others 1997), and partitioning of gross primary production (Bown, Watt and others 2009). As many of these processes affect fertilizer growth response, this suggests the possibility that clone-by-fertilizer interactions may be widespread. However, genotype-by-environment interactions are not problematic in open-pollinated *P. taeda*: high-performing families surpass low-performing families across a range of sites (McKeand, Jokela and others 2006; Roth, Jokela and others 2007). Further, research suggests that across a large number of clones, clone-by-site interactions may not be any more common than G x E interactions in open-pollinated families (McKeand, Jokela et al. 2006). By contrast, some studies among dissimilar sites have observed notable clone-by-site interactions that were more prevalent than interactions observed among half-sib families (Isik, Li and others 2003; McKeand, Jokela et al. 2006). However, it remains uncertain the extent to which clone-by-silviculture interactions may play a role in clonal plantations comprised of a small number of individual genotypes.

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To better understand the ecophysiological mechanisms that may cause different fertilizer growth responses in different clones we examined the C budget of a simplified model system (seedlings in pots). We developed a time-integrated C budget for a four month greenhouse experiment with a factorial design of two full-sibling *P. taeda* clones and two levels of fertilizer application. Quantifying C allocated to biomass and comparing individual fluxes does not accurately assess the full partitioning of gross primary productivity (GPP) to various plant organs and processes (Litton, Raich and others 2007). Modeling of GPP partitioning integrated over time is possible by scaling measurements of biomass, aboveground respiratory C fluxes, and soil CO2 efflux (Ryan 1991; Ryan 1991; Ryan, Hubbard and others 1996; Giardina and Ryan 2002; Giardina, Ryan and others 2003). To develop a more comprehensive representation of the C budget in our model system, we used this modeling approach as adapted to container-based seedlings by Bown et al. (2009).

METHODS

STUDY DESIGN

Clones GE034 and GE769 (ArborGen LLC, Summerville, South Carolina, USA) were planted in this study. These two clones, produced from a single full-sib cross, were among the first selected by ArborGen in 2005 (Bitoki 2008), and have contrasting crown ideotypes. Clone 34 is the faster growing of the two, has a narrower crown than clone 769, and allocates less to branches (Bitoki 2008). Trees were removed from the cooler (4° C) where they had been for two months and were potted on April 30, 2009 in their plugs. Plug media was comprised of a mixture of peat moss and vermiculite and contained an undisclosed quantity of fertilizer. They were left in plugs to minimize reductions in growth rates or survival due to excessive root mortality that would have resulted from removing the trees from the densely rooted plugs. Trees were potted in homogenized A-horizon soil from the USDA Forest Service's Southeastern Tree Research and Education Site (SETRES). The soil is a Wakulla series (siliceous, thermic Psammentic Hapludult), and was selected to minimize native nutrition to allow for as complete nutrient control as is possible in a natural soil. Soil was sieved through a 1-cm mesh to remove any coarse roots, was homogenized, and was placed into 15-by-15-by-38 cm pots (8,550 cm3) that were sufficiently large to limit extensive root binding during this four month experiment.

Trees were in the greenhouse in Blacksburg, Virginia, USA, (37.24°N 80.43°W) from April 30 to October 15, 2009. Watering was conducted daily in an attempt to prevent drought stress while also minimizing leaching from the bottom of the pots. Nighttime minimum temperature was set to 18° C in the greenhouse, and while the vents were set to open during the day at 25° C daytime temperatures did exceed this frequently. Relative humidity was allowed to fluctuate with the ambient air. High-pressure sodium lights were turned on daily for several hours pre-dawn from September 15 to October 15 to augment photoperiod, which averaged 12.9 hours throughout the experiment. Environmental conditions were recorded by a single HOBO datalogger (Onset Computer Corp., Bourne, Massachusetts, USA) placed in the center of the experiment.

The ramets were randomly assigned to fertilizer and control treatments, and fertilizer was applied to the selected ramets on June 16, 2009. This date will be referred to as day 0 throughout the remainder of this chapter. Fertilizer was applied at an operational rate with DAP and ammonium nitrate at 225 kg N per hectare and 56 kg elemental P per hectare. Control trees received no fertilizer. Following fertilizer application, ramets from each treatment combination were harvested monthly on July 16, August 16, September 15, and October 15, 2009 (30, 61, 91, and 121 days after fertilizer application). Thus the experiment was a two-by-two-by-four factorial randomized complete block design replicated eight times (128 trees total), with treatments consisting of clone, fertilizer, and sequential harvest, respectively. Some measurements were only made on the final harvest group (day 121 harvest) throughout the experiment. These variables are described below, and may be considered a two-by-two randomized complete block design with repeated measures. Other variables were measured on each tree at harvest and thus reflect a tree-for-time-substitution assumption.

DATA COLLECTION

At each of the four destructive harvests the entire tree was partitioned into components. Fine roots were considered those < 2 mm diameter, with coarse roots being any root > 2 mm diameter. All biomass components were oven-dried at 65° C for > 10 days, and weighed. Throughout the experiment ground-line diameter and total height were measured weekly on the final harvest group. Prior to each destructive harvest heights and basal diameters of all trees were measured to ensure that no significant growth differences existed between harvest groups, and that tree-for-time-substitution assumptions were valid.

Total soil CO2 efflux (FS) was assessed in the morning between 10:00 and 12:00 EDT using a small dynamic closed (231 cm3 volume, 55 cm2 area) cuvette with no fan. A LI-6200 infrared gas analyzer (IRGA) was used for all respiratory C flux measurements (LiCor Biosciences Inc., Lincoln, Nebraska, USA). The IRGA was zeroed daily immediately prior to the first FS measurement and a blank reading on a sealed cuvette with no soil was taken to ensure the apparatus was operating correctly. Soil temperature (thermocouple) and volumetric moisture content (TDR) were measured concurrently with efflux for use as covariates in statistical analyses. These measurements were made on 22 separate dates. Procedures were based on those described in Gough and Seiler (2004).

Aboveground dark respiration rates were measured at night between 23:00 and 5:00 EDT within two days prior to the day 30 and day 91 harvests. A large inverted trash-can (volume = 120,000 cm3) was used as a cuvette. An incision was made along a radius of the lid, so that it could be sealed with weather-stripping around the base of the stem of the seedling being measured without damaging the seedling. A small fan was installed in the cuvette to mix the air volume inside. Ambient temperature inside the cuvette was measured with a thermocouple during each measurement so that respiration rates could be standardized to 20° C assuming a Q10 of 2.0 (Ryan 1991). Rates were calculated using subsequent harvest data on a plant dry mass basis in order to account for varying tree sizes.

DATA MODELING

The C budget model is shown in equations 1 through 7, and each variable is described in Table 1. Equation 1 partitions GPP into aboveground net primary productivity (ANPP), aboveground plant respiration (APR), and total belowground C flux (TBCF).

$$GPP = ANPP + APR + TBCF \quad \text{[Equation 1]}$$

Partitioning to ANPP is the sum of litter-fall production, mortality, and changes in woody and foliar biomass C storage (Equation 2). Because litter-fall and mortality were not observed in our four month greenhouse study, we set these fluxes equal to zero, yielding Equation 3 for ANPP.

$$ANPP = FA + FW + \Delta CF + \Delta Cw \quad \text{[Equation 2]}$$

$$ANPP = \Delta CF + \Delta Cw \quad \text{[Equation 3]}$$

Partitioning to TBCF is the sum of soil CO2 efflux, C lost through erosion or leaching, changes in soil C, changes in root biomass C, and changes in litter layer C less new litterfall that was previously quantified as part of ANPP (Equation 4). We were again able to eliminate some of these variables, resulting in the Equation 5. We assumed that there was no erosion or leaching, and we observed no litter layer or litter-fall in this study. Analysis of soil data between days 30 and 121 showed no significant changes in soil C, so this flux was also set equal to zero.

$$TBCF = FS + FE + \Delta CS + \Delta CR + \Delta CL - FA \quad \text{[Equation 4]}$$

$$TBCF = FS + \Delta CR \quad \text{[Equation 5]}$$

Two further terms are defined in Equation 6 and Equation 7. Net primary productivity (NPP) is the sum of ANPP and the change in root biomass C, or total aboveground and belowground change in biomass C. Carbon use efficiency (CUE) is defined as the proportion of GPP partitioned to NPP, or biomass.

$$NPP = ANPP + \Delta CR \quad \text{[Equation 6]}$$

$$CUE = NPP / GPP \quad \text{[Equation 7]}$$

In the greenhouse study various C fluxes were quantified with a variety of different cuvettes of different sizes and shapes. As a result, the individual fluxes measured represent an accurate comparison of treatments, but likely did not reflect the magnitude of the absolute fluxes (Norman, Kucharik and others 1997). Further, we did not apply multiple measurement techniques to each flux to determine the accuracy of our methods in assessing the actual rates. Thus, while this modeling approach likely did not reflect the absolute magnitude of GPP partitioned to each component assessed, it remained an accurate treatment index that allowed us to compare the effects of fertilizer application on the C budget of both clones (Bown, Watt et al. 2009).

The model was applied to only the day 121 harvest group of trees and represents data integrated over the duration of the experiment (i.e. days 0 through 121). Thus, all values reflect the change in biomass C pools or the integrated total of respiratory C fluxes from the time of fertilizer application through the final destructive harvest four months later. Data from all trees was utilized in order to estimate parameters for the day 121 harvest group trees.

ANPP was calculated as the change in aboveground biomass from day 0 to day 121, assuming that 50 percent of biomass was carbon. Aboveground biomass was the sum of foliar, branch, and stem mass. Treatment specific non-linear regressions on all trees were applied to determine the relationship between stem dimensions and aboveground biomass. Regressions were of the form shown in Equation 8, and were estimated using PROC NLIN in SAS software version 9.2. (SAS Institute Inc., Cary, North Carolina, USA). Coefficients and statistics for each regression are shown in Table 2. Regressions were then applied to stem dimension measurements taken on each tree from the day 121 harvest group on day 0. Difference between actual aboveground biomass from the day 121 harvest, and estimated aboveground biomass at day 0 was then calculated for each tree.

Aboveground biomass = a (basal diameter)b (height)c [Equation 8]

Modeling efforts found in the literature typically calculate APR by including maintenance respiration rates separately for foliage and wood, and then assume construction respiration as a uniform fraction of biomass (Ryan 1991; Maier, Albaugh and others 2004; Bown, Watt et al. 2009). This was unnecessary in our experiment, as we directly measured APR by placing the entire aboveground portion of the tree in a cuvette. The flux we measured included maintenance respiration of both foliage and wood as well as construction respiration due to elongating shoots and fascicles or secondary woody growth.

APR was measured on days 30 and 91 on those respective harvest groups, and was converted to 20° C using ambient air temperature measured concurrently by assuming a Q10 of 2.0 (Ryan 1991). APR was expressed per plant mass based on harvest data to account for variability in tree size. The average mass-specific APR rates for each treatment group were calculated, and the day 30 rates were applied to days 0 through 59 (inclusive), while the day 91 rates were applied to days 60 through 121. Rates were back-corrected to the temperature measured at the single data logger in the center of the experiment at two minute intervals, again assuming a Q10 of 2.0. Total daily mean mass-specific APR CO2 flux was calculated for each treatment group based on this data. Stem dimension measurements made weekly throughout the trial were linearly interpolated for each tree in the final harvest group between measurement dates at a daily resolution. The regression in Equation 8 was then applied to calculate estimated daily aboveground biomass for each tree in the day 121 harvest group on each day. Mass was then multiplied by the daily mean mass-specific APR CO2 flux for the corresponding treatment group. Daily CO2 yields attributable to APR for each tree were summed from days 0 to 121, and converted from a CO2 basis to a C basis to give APR used in the model.

TBCF was calculated as shown in Equation 5. Change in root biomass C (ΔCR) was calculated in the same manner as ANPP was calculated above. The non-linear regression relating stem dimensions to belowground mass is shown in Equation 9, and coefficients and statistics are shown in Table 2.

Belowground biomass = a (basal diameter)b (height)c [Equation 9]

FS had been measured on all trees from the day 121 harvest group throughout the trial. FS data was scaled to the soil surface area of each pot and was converted to C mass basis. Rates were then scaled up to a daily flux. Daily fluxes were linearly interpolated between measurement dates for each tree, and all daily values were summed for each tree to yield the integrated FS flux over 121 days. Using midmorning rates to reflect daily fluxes required the assumption that midmorning rates represented the average daily rate, which was unlikely. In order to adjust for the close coupling of photosynthetic and respiratory fluxes (i.e. respiration also declines at night) observed in similar sized trees in other studies (Wertin and Teskey 2008), daily fluxes were multiplied by 0.5. This further reflected that rates likely declined at night due to lower temperatures, and likely declined later in the day due to lower soil moisture availability, as watering was done each morning (Fang and Moncrieff 2001; Qi and Xu 2001; Dilustro, Collins and others 2005). The exact magnitude of this adjustment was arbitrary, but it does not alter the validity of modeling efforts as a treatment index.

Various ratios (e.g. CUE) were calculated from the fluxes and biomass pools described above. Data was transformed as necessary to meet statistical assumptions, although all reported values are untransformed. All variables were analyzed in PROC MIXED with block as a random effect, and comparisons were made in PROC GLM with Tukey's HSD test at a significance level of $\alpha = 0.10$.

RESULTS AND DISCUSSION

Fertilizer application increased GPP and resulted in corresponding increases in the absolute magnitudes of NPP, ANPP, and ΔCR (Figure 1; Table 3; $p < 0.01$). A clone-by-fertilizer interaction occurred for APR, whereby both clones showed increases with fertilizer application, but clone 34 increased more ($p < 0.05$). Partitioning to TBCF and FS also showed clone-by-fertilizer interactions ($p < 0.01$). TBCF was not different between fertilizer treatments in clone 34 due to a reduction in FS coupled with an increase in ΔCR as a result of fertilizer application. By contrast clone 769 showed a significant increase in TBCF with fertilizer application that was the result of increased ΔCR but no significant FS response to fertilizer application.

When considered on the basis of percentage of GPP partitioned, rather than on terms of absolute fluxes and pools, similar trends emerged. Fertilizer application resulted in increased CUE in both clones (Table 3; $p < 0.01$). Overall clone 769 had slightly greater CUE ($p < 0.10$). Greater proportional allocation to ANPP was observed in fertilized ramets of both clones ($p < 0.01$), although the clones were not different in this regard ($p > 0.10$). For APR clone 34 showed no effect of fertilizer application, while clone 769 decreased partitioning from 50.9 percent to 41.5 percent of GPP ($p < 0.10$). Conversely, for TBCF clone 769 showed no effect of fertilizer application, while clone 34 decreased partitioning from 36.2 percent to 27.3 percent of GPP ($p < 0.10$). These results contrasted with those based on absolute fluxes, and were driven by both clones reducing partitioning to FS as a portion of TBCF when fertilized, but clone 34 doing so to a greater extent than clone 769 ($p < 0.10$).

Interpretation of these results indicated that while both clones showed remarkably similar absolute values of GPP, and GPP responses to fertilizer application, they did so by partitioning GPP in different ways in response to fertilizer application. Clone 769 partitioned less of GPP belowground in controls but more in the fertilizer treatment, indicating that plant-soil interactions could be affected by clone-specific GPP partitioning patterns in response to fertilizer application. Differences CUE showed that the clones were similar without fertilizer application, but with fertilizer application clone 769 had greater growth efficiency. Thus while the clones may perform similarly on a nutrient deficient site, with fertilizer application clone 769 would likely be the best performer based on this data. This conclusion pertains to total biomass, not only to stem mass or volume, the trait of primary economic concern.

Limited inferences may be drawn from comparisons of our results with ecosystem-level studies in older stands due to differences in processes between tree ages and between single-tree and stand scales. Nonetheless, previous research in older stands has found that fertilizer amendment typically does not result in large changes in CUE, contrary to our results (Lai, Katul and others 2002; Giardina, Ryan et al. 2003; Maier, Albaugh et al. 2004). While we found that even control treatments represented a net C sink (GPP was positive), results from a 12-year-old stand with the same soil indicate control treatments may not be an atmospheric C sink, with GPP values of approximately zero (Maier, Albaugh et al. 2004). The proportion of GPP partitioned to respiration has also been found to vary little across treatments, again conflicting with our results (Litton, Raich et al. 2007). However, in the one study did show an effect on APR / GPP, an increase was observed (Giardina, Ryan et al. 2003), contrary to the reduction observed in our study for clone 769. However, when our results are compared with the only study we are aware of comparing GPP partitioning among clonal seedlings under different levels of fertilizer application (Bown, Watt et al. 2009), our results were surprisingly consistent. Bown et al. observed clone-by-fertilizer interactions for CUE and APR / GPP, fertilizer effects for FS / TBCF and ANPP / GPP, and clonal effects for ANPP / GPP and TBCF / GPP. This further supports that while pot-based seedling studies may produce similar results, these results should not be inferentially scaled to the ecosystem level for older plantations.

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Table 1—Description of all variables utilized in the C budget modeling of the greenhouse clone-by-fertilizer-by-sequential-harvest study. Variables assumed to equal zero in this simplified greenhouse pot study are noted in the description

Acronym		Variable	Description
GPP		Gross Primary Productivity	All C fixed through photosynthesis
ANPP		Aboveground Net Primary Productivity	C stored in aboveground biomass
	F_A	Sum of litterfall C production	Assumed equal to 0 (no litterfall)
	F_W	Sum of mortality C production	Assumed equal to 0 (no mortality)
	ΔC_F	C content change of live foliage	C stored in foliar biomass
	ΔC_w	C content change of aboveground woody tissue	C stored in branch and stem biomass
APR		Aboveground Plant Respiration	Sum of construction and maintenance
TBCF		Total Belowground Carbon Flux	All C allocated belowground
	F_S	Sum of soil respiration	C lost from the soil surface
	F_E	C lost from system through erosion or leaching	Assumed to equal 0 (no leaching)
	ΔC_S	C content change of soil	Assumed equal to 0 (no change)
	ΔC_R	C content change of root biomass	C stored in tap and lateral root biomass
	ΔC_L	C content change of litter layer	Assumed to equal 0 (no litter layer)
NPP		Net Primary Productivity	All C stored in biomass
CUE		Carbon Use Efficiency	Portion of GPP allocated to NPP

Table 2—Non-linear regressions of above and belowground biomass based on stem dimensions at harvest for all 128 trees from the greenhouse clone-by-fertilizer-by-sequential-harvest study. Equations were of the form: biomass = a (basal diameter)^b (height)^c. Regressions were implemented in PROC NLIN in SAS software version 9.2.

Aboveground Biomass								
Treatments		Coefficients			Statistics			
Clone	Fert	a	b	c	F	p-value	R^2	N
34	0	0.2920	1.1369	0.3848	476.51	<0.0001	0.980	32
34	1	0.1231	1.2144	0.5794	622.51	<0.0001	0.985	32
769	0	0.4868	1.2454	0.1919	856.21	<0.0001	0.989	32
769	1	0.0362	1.6936	0.6130	575.99	< 0.0001	0.983	32
Belowground Biomass								
Treatments		Coefficients			Statistics			
Clone	Fert	a	b	c	F	p-value	R^2	N
34	0	0.3013	1.1540	0.1640	307.11	<0.0001	0.969	32
34	1	0.0434	2.1348	0.0833	254.35	<0.0001	0.963	32
769	0	0.0734	1.2373	0.5320	355.50	<0.0001	0.974	32
769	1	0.1332	2.2059	-0.1686	295.06	<0.0001	0.968	32

Table 3—Treatment means and statistics for C allocation in a four month greenhouse experiment with two clones under two fertilizer treatments. Means are shown with standard errors in parentheses. Different letters denote significant differences ($p < 0.10$) based on Tukey's HSD test. P-values are shown in the rightmost three columns. Acronyms are defined in Table 1.

Variable	C34 Control	C34 Fert	C769 Control	C769 Fert	Overall Mean	Clone	Fert	C X F
GPP (g C)	28.7 (1.4) A	39.5 (1.5) B	27.1 (0.9) A	40.1 (2.7) B	33.9 (1.4)	0.60	<0.01	0.51
NPP (g C)	6.7 (0.6) A	14.2 (0.5) B	6.3 (0.4) A	16.2 (1.0) B	10.8 (0.9)	0.48	<0.01	0.19
ANPP (g C)	4.9 (0.5) A	9.4 (0.5) B	3.9 (0.3) A	10.0 (0.9) B	7.0 (0.6)	0.72	<0.01	0.16
APR (g C)	13.4 (0.5) A	19.3 (0.9) B	13.7 (0.3) AB	16.8 (1.6) BC	15.8 (0.6)	0.27	< 0.01	0.05
TBCF (g C)	10.4 (0.6) A	10.8 (0.7) A	9.5 (0.5) A	13.3 (0.5) B	11.0 (0.4)	0.18	<0.01	<0.01
F_S (g C)	8.7 (0.6) A	5.9 (0.5) B	7.1 (0.4) AB	7.1 (0.4) AB	7.2 (0.3)	0.68	<0.01	<0.01
ΔC_R (g C)	1.8 (0.2) A	4.9 (0.4) B	2.4 (0.3) A	6.2 (0.4) C	3.8 (0.4)	< 0.01	< 0.01	0.85
CUE (%)	22.9 (1.4) A	36.2 (1.0) B	23.0 (1.0) A	40.6 (1.4) C	30.7 (1.5)	0.09	<0.01	0.11
ANPP/GPP (%)	16.8 (1.0) A	23.8 (1.1) B	14.2 (1.0) A	24.7 (1.2) B	19.9 (1.0)	0.42	<0.01	0.10
APR / GPP (%)	47.0 (1.5) A	48.9 (0.9) A	50.9 (1.1) A	41.5 (1.3) B	47.1 (0.9)	0.15	<0.01	<0.01
TBCF / GPP (%)	36.2 (0.8) A	27.3 (1.4) B	35.0 (1.1) A	33.7 (1.7) A	33.1 (0.9)	0.02	<0.01	<0.01
F_S / TBCF (%)	83.2 (1.9) A	54.6 (2.5) B	74.9 (1.9) C	53.2 (2.2) B	66.5 (2.5)	0.03	<0.01	0.13

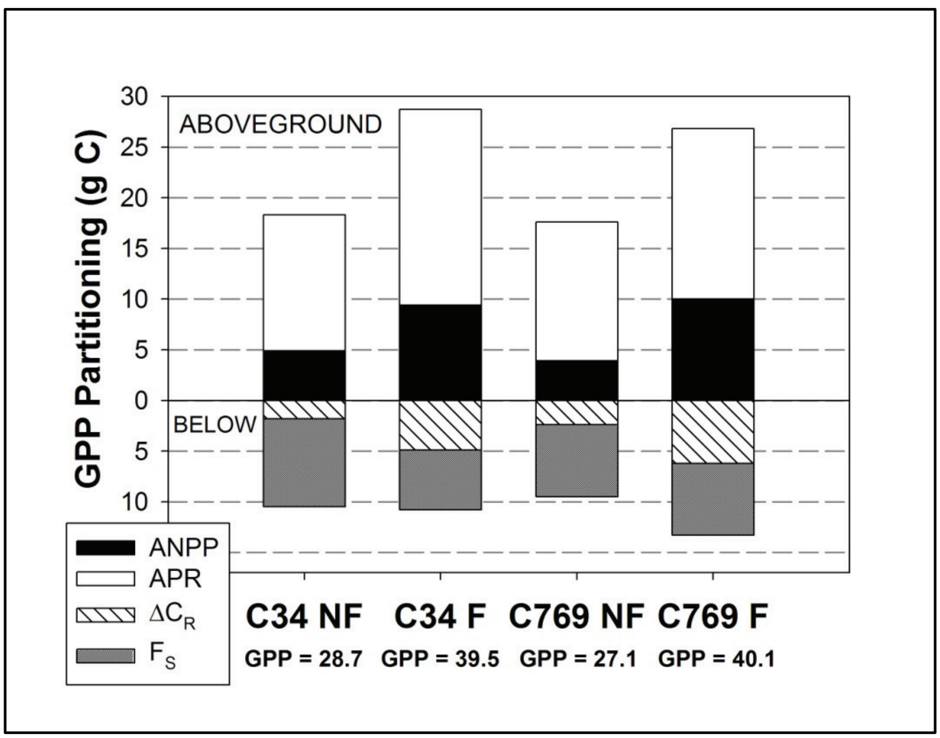

Figure 1—Carbon budget for two clones (C34 and C769) under two fertilizer regimes (F = fertilizer, NF = no fertilizer) over 121 days. GPP = gross primary productivity, ANPP = aboveground net primary productivity, APR = aboveground plant respiration, F_S = soil CO_2 efflux, and ΔC_R = C accumulation in roots, or belowground net primary productivity. Statistics are shown in Table 3.

DIFFERENCES AMONG SHORTLEAF PINE SEED SOURCES ON THE OZARK AND OUACHITA NATIONAL FORESTS AT AGE TEN

Charly Studyvin and David Gwaze

ABSTRACT

Progeny test planting of shortleaf pine (*Pinus echinata* Mill.) was started on the National Forests in Arkansas in 1978, and continued through 1990. A series of progeny tests established on the Ouachita and Ozark National Forests were analyzed to determine if significant differences exist between the three seed sources in Arkansas (the East Ouachita, the West Ouachita and the Ozarks) for height, diameter and survival at age 10. Sixteen tests were from the Ouachita National Forest and fourteen from the Ozark National Forest. Significant differences among seed sources for height and diameter existed, but not for survival. Families within seed sources were highly significant for all traits, indicating that family selection will be effective.

INTRODUCTION

Shortleaf pine has the largest native range of any pine species in the southeastern United States (Fig. 1), is considered a major component of three forest cover types, and a minor component of at least 15 other forest cover types. Adaptability to a great variety of site and soil conditions partly accounts for its wide distribution (Lawson 1990). Shortleaf pine should be at the forefront in efforts to insure genetic diversity and healthy ecosystems able to respond to climate change in the eastern United States.

In the early 1960's the U S Forest Service developed a shortleaf pine tree improvement program that included Arkansas and Oklahoma. The first step in the process was the selection of superior trees. Selection criteria included: growth and form; insect and disease resistance; flowering and cone production; specific gravity; and relative location. Fifty superior trees were chosen in each of three geographic sources—East Ouachita, West Ouachita, and Ozark. Scions were collected from the superior trees, grafted to rootstock, and planted at the Ouachita Seed Orchard. As soon as the young trees began producing cones, the cones were harvested and the seed was used for reforestation--and the breeding program was initiated. Progeny test planting on the Ouachita and Ozark National Forests was started in 1978 and continued through 1990. Data from over sixty valid full-sib progeny tests was collected and analyzed.

For approximately 20 years, from the mid 1970's through the mid 1990's, millions of genetically improved shortleaf pine seedlings were planted throughout the Ouachita and Ozark National Forests. During peak years 12 to 15 million seedlings were planted each season. After the mid 1990's the use of artificial regeneration was curtailed for political reasons, and the number of seedlings planted each year tapered off to the present level of around one million. As a result of the reduced need for seedlings, orchard management became mostly bare bones maintenance. All progeny testing was terminated (Crane, 2005). The Region 8 Regional Geneticist stated that in his opinion, the tree improvement program's objective for quality timber had become obsolete.

Here we are many years after shortleaf pine tree improvement was declared obsolete, challenged with restoring historic vegetation and maintaining or improving genetic diversity. A major epidemic of southern pine beetle damaged forests throughout the southeast in the mid to late 1990's, including thousands of acres on the Ouachita NF. In December of 1999, a significant ice storm damaged or destroyed large acreages of timber in Arkansas. Severe problems with oak decline developed in both Arkansas and Missouri. Thousands of acres were devastated, and thousands more acres of black, red, and scarlet oaks growing on dry, rocky sites are at severe risk of oak decline. These sites were historically populated by shortleaf pine, and forest plans now emphasize the restoration of historic vegetation. In addition, thousands of acres of private forest lands in need of reforestation have recently been acquired by the US Forest Service. Once again there is a need for reforestation using shortleaf pine seedlings. The value of the shortleaf pine tree improvement program has become more evident with the realization that appreciable quantities of high quality, genetically diverse, shortleaf pine seed are available from those efforts. There is also a wealth of data and genetic diversity from the Ouachita and Ozark progeny tests, which could be used to study the genetics of shortleaf pine and give guidance to restoration efforts, and perhaps provide genetic material to improve the health and resiliency of ecosystems threatened by climate change.

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Currently, breeding population 1 of shortleaf pine is divided into three seed sources: (1) East Ouachita shortleaf; (2) West Ouachita shortleaf; and (3) Ozark shortleaf. However, it should be noted that the division of this breeding population into three seed sources is based on no provenance test or other research information. The zone in which Breeding Population 1 occurs, which comprises Arkansas and southeastern Oklahoma, was based on information obtained in the Southwide Pine Seed Source Study (Wells and Wakely 1970), but the division of this population into seed sources was not based on that study, since it did not sample those three sources separately. La Farge (1991) found that the three seed sources were not significantly different for height and survival age 5. Because of the non-significant results, La Farge (1991) recommended that the three breeding populations be maintained as one population. The objective of the study is to determine if significant differences among seed sources for height and diameter existed at age 10.

MATERIALS AND METHODS

Details of materials are in La Farge (1991). Briefly, data from 30 full-sib progeny tests distributed across both the Ouachita and Ozark National Forests was used for the analysis. The study was created for the purpose of testing the genetic worthiness of seed orchard clones and for making second-generation selection, but the purpose of this analysis was to detect differences among seed sources.

The parents came from threes sources: East Ouachita, West Ouachita and Ozark regions. The mating design of these full-sib progeny tests was a six-by-six diallel crossing scheme, such that each partial diallel crossing group consisted of six parents, two from each seed source. Crosses among all parents in a 6-by-6 diallel result in 15 crosses. In each of the diallels in these data, there were three crosses between parents from the same seed source. The other 12 crosses in each diallel were between parents from different seed sources. To maintain the integrity of the seed sources in this study, only crosses between parents of the same seed sources were used. Since all diallel groups comprised unrelated parents, this resulted in one cross per crossing group from each diallel. Hence, all crosses included in the analyses were single-pair matings and were unrelated.

ANALYSIS OF VARIANCE

We used methods similar to those used by La Farge (1991). Seed source and family differences for survival, height and diameter were estimated at 10 years using analysis of variance with Proc GLM and Proc Mixed of SAS (Version 9.1). Plot means were used for the analysis and survival was arcsine transformed before the analyses. Because of the imbalanceness, statistical significance of fixed effects was obtained using Proc GLM. Data imbalance was present across the test sites for different reasons such as: 1) the number of blocks differed, 2) there were unequal number of families; and survival varied. To be conservative, the test random effect was fitted first followed by the fixed effects using the following model:

$$Y_{ijkm} = \mu + T_i + S_j + TS_{ij} + F_{(j)k} + TF_{i(j)k} + e_{ijkm}$$

Where:

Y_{ijkm} = observation of the mth individual of the kth family from the jth seed source in the ith location

μ = overall mean

T_i = random effect of the ith test

S_j = fixed effect of the jth seed source

TS_{ij} = random effect of the interaction between test and seed source

$F_{(j)k}$ = fixed effect of the kth family within the jth seed source

$TF_{i(j)k}$ = random effect of the interaction between test and family

e_{ijkm} = random error term

Error term for testing significance of seed source was the interaction between test and seed source. Error term for testing significance of family within seed source was the interaction between test and family within seed source. The numbers of families for our analysis were: (1) 24 for the East Ouachita, (2) 27 for the West Ouachita, and (3) 29 for the Ozark seed sources.

RESULTS

SURVIVAL

As observed at age 5 (La Farge 1991), differences between seed sources were not significant for survival at age 10 (Table 1). At age 10, shortleaf pine seedling survival was over 72% for all three seed sources (Table 2). At age 5, survival for the three seed sources was above 91% (La Farge 1991). Thus, between ages 5 and 10 survival declined by 21%. The differences among families within seed source were highly significant for survival at age 10 (Table 1).

GROWTH

There were significant differences among seed sources for height and diameter at age 10 (Table 3 and 5). These results differ from those at age 5, where seed sources were found not to be significantly different (La Farge 1991). The East Ouachita seed source exhibited the best growth while the Ozark seed source had the poorest growth performance (Table 4 and 6). East Ouachita seed sources had on average 8% better height growth and 10% better diameter growth compared to the Ozark seed sources. At age 5, height growth averaged 7.7ft across the seed sources (La Farge 1991) and at age 10 it averaged 19.5 ft, an increase of 153%. This shows that with good management shortleaf pine is fast growing.

As pointed out by La Farge (1991), the growth trends are expected because they parallel certain environmental

gradients. The East Ouachita seed source generally grew faster when tested at all locations than did the West Ouachita and Ozark sources because the West Ouachita and the Ozark National Forests generally have more severe summer droughts than does the East Ouachita. Also, seed source studies of forest tree species often show that seed sources from warmer climates tend to grow faster than local sources, if the difference in climate is not great (Schimdtling 2001). According to Schimdtling (2001) seedlings will survive and grow well if they come from any area having a minimum temperature within 5 ^{0}F of planting site's minimum temperature. In loblolly pine, this is at least partly due to the warm-climate sources growing longer in the fall than the sources from colder climates (Jayawickrama et al. 1998). Thus, the two Ouachita seed sources are expected to grow faster than the Ozark seed sources and they do.
The differences between East and West Ouachita were small, and non-significant, indicating that east-west transfers are usually successful as stated by Schimdtling (2001). The differences among families within seed source were highly significant for height and diameter at age 10 (Tables 3 and 5).

CONCLUSION

Trees from the Ouachita National Forest had superior growth than those from the Ozark National Forest, thus confirming the results from past studies which showed that southern sources grow faster than northern sources. Thus, latitudinal differences were evident. Longitudinal differences were not strong, confirming that east-west transfers are usually successful. East Ouachita seed sources had slightly better growth than the west Ouachita seed source. Maintaining a single breeding population across the National Forests in Arkansas is recommended because the large family differences indicate that there were good families from all seed sources. Therefore, tree improvement and orchard establishment programs should concentrate on identifying individuals from the best families regardless of seed source.

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Table 1—ANOVA for survival at age 10

Source of variation	Degrees of freedom	Mea Square	F Value	P-Value
Seed source	2	0.147	2.54	0.088
Family (seed source)	49	0.084	2.75	0.001
Test	29	0.439		
Seed source x test	56	0.058		
Family x test (seed source)	37	0.031		

Table 2—Comparison of survival at age 10 among seed sources

Seed Source	Mean survival (%)*
East Ouachita	72.4a
West Ouachita	74.4a
Ozark	72.6a

*Means with the same letter are not significantly different (P > 0.005)

Table 3—ANOVA for height at age 10

Source of variation	Degrees of freedom	Mea Square	F Value	P-Value
Seed source	2	26.93	3.55	0.035
Family (seed source)	49	10.74	2.65	0.001
Test	29	334.68		
Seed source x test	56	7.59		
Family x test (seed source)	37	4.05		

Table 4—Comparison of height at age 10 among seed sources

Seed Source	Mean height (ft)*
East Ouachita	20.3a
West Ouachita	19.4a
Ozark	18.8b

*Means with the same letter are not significantly different (P > 0.005)

Table 5—ANOVA for diameter at age 10

Source of variation	Degrees of freedom	Mea Square	F Value	P-Value
Seed source	2	1.139	3.37	0.042
Family (seed source)	49	0.601	2.53	0.003
Test	29	23.117		
Seed source x test	56	0.338		
Family x test (seed source)	37	0.238		

Table 6—Comparison of diameter at age 10 among seed sources

Seed Source	Mean diameter (inch.)*
East Ouachita	4.26a
West Ouachita	4.04a
Ozark	3.89b

*Means with the same letter are not significantly different (P > 0.005)

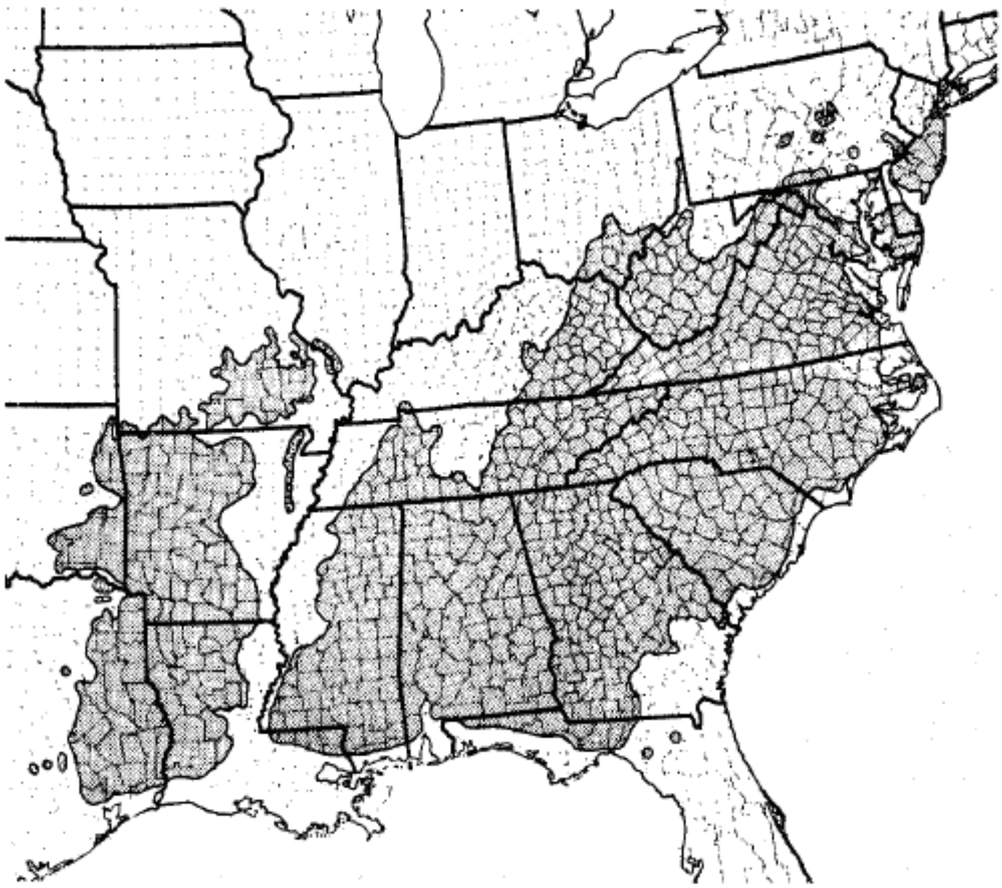

Figure 1—Natural distribution of shortleaf pine (Pinus echinata Mill.) (Lawson 1990).

EFFECT OF CULTURE AND DENSITY ON ABOVEGROUND BIOMASS ALLOCATION OF 12 YEARS OLD LOBLOLLY PINE TREES IN THE UPPER COASTAL PLAIN AND PIEDMONT OF GEORGIA AND ALABAMA

Santosh Subedi, Dr. Michael Kane, Dr. Dehai Zhao, Dr. Bruce Borders, and Dr. Dale Greene

We destructively sampled a total of 192 12-year-old loblolly pine trees from four installations established by the Plantation Management Research Cooperative (PMRC) to analyze the effects of planting density and cultural intensity on tree level biomass allocation in the Piedmont and Upper Coastal Plain of Georgia and Alabama. Each installation had 12 plots, each plot representing a unique cultural intensity (intensive and operational) and planting density (741, 1482, 2223, 2964, 3705 and 4446 trees ha^{-1}) combination. The plots with the operational culture received chemical site preparation, first growing season competition control and fertilization, and fertilization at ages 7 and 11 while the plots with intensive culture received the operational treatments plus complete and sustained competition control and fertilization about every two years. Previous analysis of plot inventory information determined that at age 12, mean tree DBH increased with intensive culture and decreased with increasing planting density. The objectives of the research reported here were to determine effects of planting density and cultural intensity and their interaction on aboveground biomass accumulation and allocation at the tree level. Biomass in stemwood, stembark, dead branches, live branches, and foliage was examined.

The main effect of culture was significant ($p < 0.05$) for stemwood, stembark, dead branch and total aboveground biomass with more biomass on intensively cultured than operationally cultured trees. The effect of planting density on biomass was significant ($p <0.001$) for each component and for total aboveground biomass with greater biomass on trees on lower than higher planting density plots. The interaction between culture and planting density was only significant for dead branch biomass. The amount of dead branch biomass was especially great on trees planted at lower planting densities and grown with intensive culture.

Mean tree-level biomass allocation for each cultural intensity and planting density combination is presented in Figure 1. Culture had a significant effect on dead branch, live branch and foliage biomass allocation. Trees grown under intensive culture had a greater proportion of biomass in dead branches and a smaller proportion of biomass in live branches and foliage than trees grown under operational culture. Planting density had a significant effect on allocation for all the aboveground biomass components. Trees planted at higher planting densities (2223 trees ha^{-1} and above) allocated a greater proportion of biomass to stemwood and stembark than their counterparts at lower densities. Trees planted at lower planting densities (741 and 1442 trees ha^{-1}) allocated a greater proportion of biomass to branches and those planted at the lowest density (741 trees ha^{-1}) allocated a greater proportion of biomass to foliage than trees at greater densities. The culture by density interaction had no significant effect on aboveground biomass allocation.

Both cultural intensity and planting density affected tree-level biomass amount and allocation to aboveground components of 12-year-old loblolly pine. The differences in biomass allocation patterns observed among planting densities from 741 to 2223 ha^{-1} should be considered when estimating plantation yields for components additional to the stem. Biomass amount and allocation among components did not vary significantly for planting densities in the 2223 to 4446 trees ha^{-1} range. Additional analyses of this data is planned to examine if biomass amounts and allocation to components are fully explained by tree size (DBH, height, DBH^2 x Height) alone or if culture, planting density and their interaction affect biomass amount and allocation beyond their effect on tree size. Although, belowground biomass is a very important component of total tree biomass, we only examined aboveground biomass.

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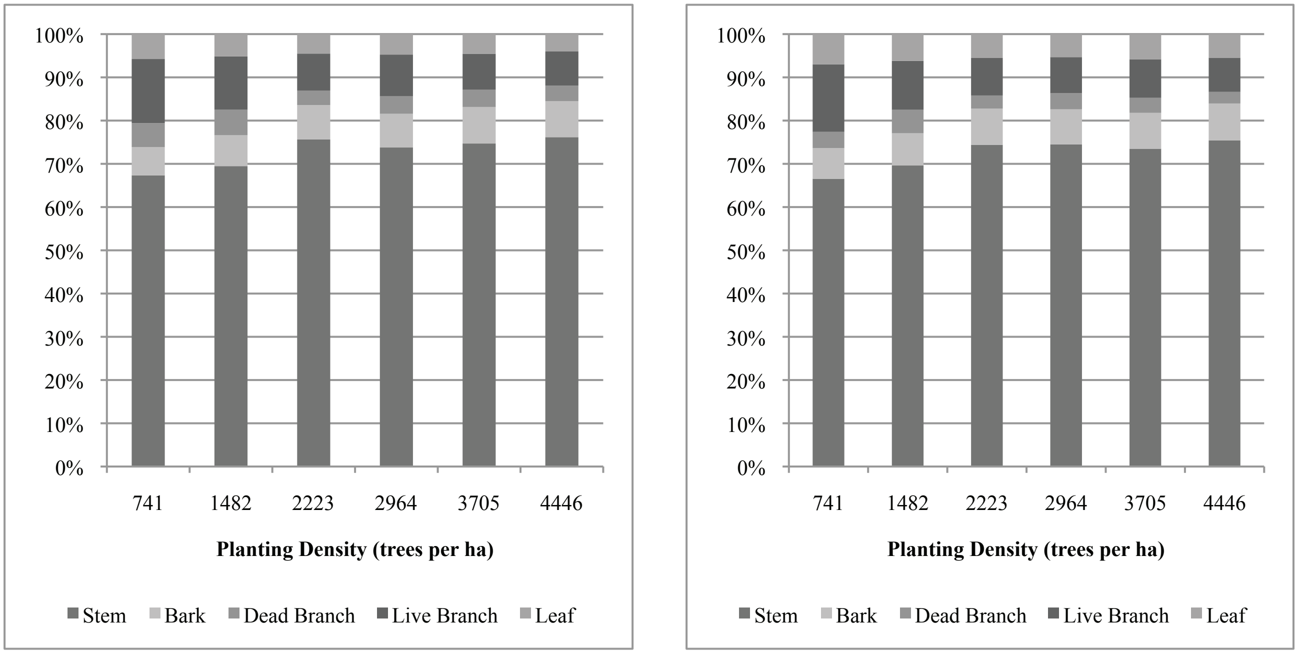

Fig 1—Mean per tree biomass allocation for loblolly pine at age 12 by component and planting densities for intensive (left) and operational (right) culture.

METHODOLOGY AND PRELIMINARY RESULTS OF EVALUATING STEM DISPLACEMENT AND ASSESSING ROOT SYSTEM ARCHITECTURE OF LONGLEAF PINE SAPLINGS

Shi-Jean S. Sung, Daniel J. Leduc, James D. Haywood, Thomas L. Eberhardt, Mary Anne Sword Sayer, and Stanley J. Zarnoch

ABSTRACT

A field experiment of the effects of container cavity size and root pruning type on longleaf pine was established in November, 2004, in central Louisiana. Sapling stems were first observed to be leaning after hurricane Gustav (September, 2008) and again in August, 2009. To examine the relationship between stem displacement and root system architecture, a stem-displaced longleaf pine (sapling was paired with a nearby, non-displaced sapling of comparable size in each of the 24 treatment plots of the original experiment. Saplings were excavated in May, 2010. Here we report the methodology and preliminary results of evaluating stem displacement and assessing root system architecture in three additional longleaf pine saplings in the same experiment. One sapling became toppled in February 2010; the second sapling was toppled by wild horses in August 2009; and the third was a non-displaced sapling which was knocked down during excavation.

INTRODUCTION

Most of the natural longleaf pine (*Pinus palustris* Mill.) forests and ecosystems were decimated by excessive logging between the late 1800s and the early 1900s. Some of these areas were eventually regenerated to fast-growing loblolly pine (*P. taeda* L.) and slash pine (*P. elliottii* Englem.) forests or cleared for cropland or pasture (Landers and others 1995). Much of the original longleaf pine range is within 240 km of the Atlantic or Gulf coasts, a region frequented by strong tropical wind storms including hurricanes (Landers and others 1995). Longleaf pine trees suffered less wind damage than loblolly pine after hurricanes Hugo (September, 1989) in South Carolina (Gresham and others 1991) and Katrina (August, 2005) in Mississippi (Johnsen and others 2009). With increasing occurrence of hurricanes in the Atlantic and Gulf States in recent decades, many forest managers and landowners have decided to restore longleaf pine over these hurricane-prone, historical longleaf pine areas.

More than 70 percent of the longleaf pine seedlings produced by nurseries in the southern United States were container stock for the 2005-2006 planting season (McNabb and Enebak 2008). About 90 percent of the longleaf pine seedlings planted in 2008 were from container stock (Barnard and Mayfield 2009). This trend of preference for longleaf pine container stock continues to date. Container-grown longleaf pine seedlings generally had greater first year field survival than bareroot seedlings (South and others 2005 and references cited therein). However, between the age of 5 and 10 years, juvenile stem instability, such as leaning, bending, and toppling, occurred after high winds mostly in the container stock longleaf pine saplings and not in the bareroot saplings (South and others 2001).

After Hurricane Gustav (September, 2008), sapling leaning was observed in a container stock longleaf pine field experiment established in November, 2004. More sapling stem displacement was sighted in the same study in August, 2009. We hypothesized that root system architecture is the main factor for longleaf pine sapling stem instability. Here we report the methodology and preliminary results of evaluating stem displacement and assessing various parameters pertaining to the root system architecture. The objectives of the study are to 1) compare root system architecture and stem wood quality of stem-displaced (SD) longleaf pine saplings with that of the non-displaced (ND) saplings and 2) assess effects of container size and root pruning type on sapling instability and root system architecture.

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MATERIALS AND METHODS

SEEDLING CULTURE AND FIELD ESTABLISHMENT IN THE ORIGINAL STUDY

Details of seedling culture and field establishment protocols were reported by Sword Sayer and others (2009). Briefly, LLP seeds of mixed seedlots from Florida were sown in containers of three cavity sizes and two cavity coating types in April, 2004. Container cavity volumes for the small, medium, and large cavity sizes were 54, 93, and 170 ml, respectively. Styroblock ® and Copperblock® containers (Beaver Plastics Ltd, Edmonton, Alberta, Canada) of the above mentioned cavity sizes were used for no copper root pruning and copper oxychloride root pruning treatments, respectively. Seedling culture protocols were adapted from those by Barnett and McGilvray (2000) with some modifications (Sword Sayer and others 2009).

The field experiment site is located on the Palustris Experimental Forest within the Kisatchie National Forest in Rapides Parish of central Louisiana (N 31°11', W 92°41'). The soil is a moderately well-drained, gently sloping Beauregard silt loam (fine silty, siliceous, superactive, thermic, Plinthaquic Paludults). Mima mounds of Malbis fine sandy loam (fine loamy, siliceous, subactive, thermic, Plinthic Paleudults) are scattered across the study area. It is a 2 by 3 randomized complete block factorial design with four replications. Twenty-four (3 cavity size x 2 root pruning type x 4 blocks) treatment plots of 0.0576 hectare (24 m x 24 m) each were established. In early November, 2004, 27-week-old container-grown LLP seedlings were lifted and planted on the same day. Seedlings were planted at 2 m x 2 m spacing. Treatment plots are 12 rows of 12 trees. All plots were prescribed burned in February, 2006 (15 months post planting) and again in May, 2009.

SAPLING SELECTION AND ROOT EXCAVATION

In December 2009, all longleaf pine saplings in the original field experiment were assessed visually for stem displacement. In May 2010, a pair of saplings from each of the 24 treatment plots was selected for root excavation. One stem-displaced (SD) sapling was randomly selected from each plot and a non-displaced (ND) sapling of comparable size was selected within a 6-m distance of the selected SD sapling. All fascicles were collected before the north and east sides of the sapling stems were marked with paint starting at the ground level. For the stem displacement evaluation, each sapling was photographed from the side that best illustrated the greatest stem displacement. A vertical height (HT) pole was placed at the ground line of each stem for scaling and alignment. These photographs were used to calculate sinuosity index (SI) and to design a numerical system of ranking stem displacement in the field. Saplings were then cut at ground level. A metal tag was nailed to the north side of the stump. A spade was used to cut along the edge of a 1 m x 1 m square centered on the stump before the root system was excavated with a track hoe. The excavation followed the entire length of the taproot or sinkers. Soil was washed off the root systems before root architecture assessment.

Stem length (tracing along the shape of the stem from the ground line to shoot tip), HT (vertical distance between the ground line and the highest point of the sapling before cutting), diameters at breast height (at 140 cm along the stem length from the ground line, DBH) and at ground line were measured. Three stem segments of 15 cm each were cut with the centers of each of the three segments located at 30, 100, and 140 cm from the ground line up along the length of the stem. These segments were immediately stored in plastic bags on ice. The rest of the stem and branches were also collected. All sapling components were oven dried at 70 C in a forced-air oven except for the stem segments.

DENSITOMETRY

All stem segments were oven dried at 50 C in a forced-air oven for 1 week. From each stem segment, wood specimens for densitometry were obtained by cutting 12 mm x 12 mm sections from bark to bark, and encompassing the pith. Two densitometry specimens were prepared from each tree segment to allow the collection of densitometry data from bark to pith in four compass directions; north, south, east, and west. Specimens were glued (Gorilla Glue, Cincinnati, OH) into yellow-poplar core holders, dried under ambient conditions, and then sawn into 2.3 mm thick strips, from bark to bark, and through the middle of the pith with the radial surface exposed, bordered by strips of yellow-poplar wood. Densitometry was performed using a Quintek Measurement Systems (Knoxville, TN) X-ray densitometer with a resolution of 0.00001. Specific gravity measurements were determined at 0.06 mm intervals. Specific gravity is the ratio of the density of wood (oven dry weight/green volume) to the density of water at 4 C, 1.0 g/cubic cm. A specific gravity value of 0.480 was used to differentiate between earlywood and latewood zones for each core.

ROOT SYSTEM ARCHITECTURE ASSESSMENT

Root system architecture was assessed by placing the stump upside down on the center of a round board with a diameter of 1 m and twelve 30-degree segments. Any portion of the first-order lateral roots (FOLRs) that extended beyond the edge of the board was trimmed off. A FOLR is the primary lateral root originating from the taproot and has at least 0.8 cm diameter measured at 1 cm from the taproot. Parameters on taproots, sinker roots, adventitious roots, and FOLRs were assessed. After the assessment, FOLRs with their branches, sinkers, and adventitious roots were trimmed off the taproot. All root system components were oven dried at 70 C in a forced-air oven.

METHODOLOGY, PRELIMINARY RESULTS, AND DISCUSSION

STEM DISPLACEMENT EVALUATION

Stem displacement was evaluated objectively and subjectively. For the objective evaluation, the SI was measured digitally from the photographs taken in the field according to the procedures by Leduc and others (current Proceedings). The SI is derived from dividing a smallest possible rectangular area encompassing the entire main stem (and not necessarily all the branches) by HT (cm) x DBH (cm). Among various ways of deriving sinuosity indices, this one was recommended by Leduc and others (current Proceedings). Based on the photographs, a qualitative stem displacement (QSD) scale of 0 to 5 (fig 1a) was designed to subjectively evaluate stem displacement in field. A straight or ND stem has a QSD value of 0 and the QSD value for a toppled stem is 5. Figure 1b presented a qualitative scale of ranking the extent of displacement recovery by a SD stem. This scale was based on the study of Cremer (1998) and our field observations. According to Cremer (1998), stem creep (scale = 4.5, fig 1b) occurred when the combined weights of a displaced stem and its branches and fascicles would push previously displaced stem further toward the ground level. Creep reversal (scale = 3 to 4, fig 1b) described the extent of stem recovery from a creep condition. Stems with a curved lean or various degrees of sinuosity are the results of recovery from displacement (fig 1b, Cremer 1998). It should be noted that unless one visits the field often, one may not be able to distinguish between stem displacement and recovery. To solve this issue, QSD scales in figures 1a and 1b should be used simultaneously in a field evaluation. Although objective, a SI system still does not distinguish between stem displacement and recovery.

Table 1 presented some preliminary results of this study. A SD sapling which toppled in February, 2010 (Feb-SD) had a rectangular area based SI of 49.5 and a QSD scale of 3.5. Another SD sapling (Horse-SD), whose displacement was probably the result of wild horses straddling in August, 2009, had an SI of 56.2 and a QSD scale of 3.0 in May, 2010. This sapling had SI of 79.7 and 65.4 and QSD of 4.5 and 4.0 in August, 2009 and January, 2010 respectively. Based on its QSD values over time, this horse-SD sapling was recovering from displacement after August, 2009. Although decreasing over the same period of time, the final SI was still high for this sapling. The ND sapling in table 1 was accidently knocked down by the track hoe during excavation. This sapling had an SI of 4.3 and a QSD scale of 0.0 before the accident.

DENSITOMETRY

We hypothesized that stem wood quality, such as latewood percents and presence of compression wood, as delineated by stem segment densitometry, is the result of stem displacement not the cause. A specific gravity of 0.480 for southern pines was used to distinguish between earlywood and latewood. Presence of higher density compression wood in some of the specimens was unavoidably counted as being latewood. However, because these saplings were cut in May, 2010, the outermost growth ring in each specimen can only be early wood. Both SD saplings in table 1 had greater 2010 early wood densities than the ND sapling. The Feb-SD sapling which was toppled in February, 2010 had similar wood density for the 2009 growth ring to that of the ND and both were lower than that of the horse-SD sapling. No differences in densities existed in the 2008 growth rings for all three saplings which were straight in 2008.

ROOT SYSTEM ARCHITECTURE ASSESSMENT

Rationale and methods of assessing root system architecture in LLP saplings are described below.

Taproots--One advantage that the naturally regenerated LLP seedlings have over the artificially regenerated LLP seedlings is root system architecture. The readily distinguished feature of the former is a long taproot. Taproot length of container LLP, however, is limited by the container cavity depth. Cavities of 10 to 15 cm depth are generally used to grow LLP seedlings in commercial nurseries in the South (Barnett and McGilvray 2000). Taproot is critical to the vertical anchorage of young trees (Burdett and others1986). Because container seedling root plug does not allow pre-outplanting seedling culling based on its root system, some toppled LLP saplings were found to have a much shorter taproot length than the cavity depth (Sung and others 2009). The ND sapling in table 1 was lightly bumped by the track hoe but it toppled immediately. Its taproot extended only 6.5 cm into the soil and had 3.6 percent of total sapling dry weight (DW). Although this sapling was straight before the incident, its lack of vertical anchorage by taproot or sinker roots probably was the cause of toppling by a gentle bump from the track hoe. The horse-SD sapling had similar taproot rooting depth and DW allocation percentage to those of the ND sapling. Compared to the ND or horse-SD saplings, the Feb-SD sapling had much greater taproot rooting depth and DW allocation percentage (table 1). Apparently, the vertical anchorage provided by its deep rooting taproot of substantial mass did not prevent the sapling from toppling. Had it not been sampled, this Feb-SD probably would have eventually recovered because of its deep taproot.

Sinker roots and adventitious roots--After seedlings are outplanted and become in contact with soil moisture, callus tissues will form at the air-pruned end of the container seedling taproot. From these callus tissues, adventitious roots will originate and extend. Sinker roots are adventitious roots which extend vertically (greater than 135 degrees from the taproot) downward into the soil. Some adventitious roots would extend horizontally (about 90 degrees from the taproot) or slightly oblique (less than 135 degrees from the taproot). Depending on the local soil strength or conditions which may be preexisting or caused by planting technique, adventitious roots may or may not extend vertically downward and become a sinker. We hypothesized that sinker roots with large diameters and deep extension into the soil can also offer vertical anchorage to LLP saplings. The horse-SD sapling recovered from a QSD value of 4.5 in August, 2009 to 3.0 in May, 2010. One sinker reached to the depth of 66.5 cm and may have provided the vertical support for stem recovery. Cremer (1998) reported the elongating zone of a displaced P. radiata stem can right itself within a week. But it may take trees of 1.5 to 2 m tall up to 16 months for the stem to become upright and another 2 or 3 years to correct the buttsweep which could compromise wood quality. He did not report on the root systems of these trees.

First-order lateral roots--Number of FOLR was reported to be a highly heritable trait in loblolly pine (Kormanik and others 1990). Copper root pruning treatment affected FOLR egress depth one year after outplanting (Sword Sayer and others 2009). Seedlings grown in copper cavities have similar percents of FOLR egress from each third zone of the original root plug whereas seedlings grown in regular, non-copper cavities had the highest percent of FOLR egress from the bottom third region or the end of root plug (Sword Sayer and others 2009). In this study, FOLR egress depth in soil profile was determined by measuring the vertical distance between the cut stump surface and the beginning portion of a FOLR that was clearly extending away from the taproot circumference. Lengths of the portions of FOLRs extending vertically or horizontally or obliquely close to the circumference of a taproot indicate the extent of FOLR spiraling or strangulation. Number of 30-degree segments a FOLR crosses and number of 30-degree segments that do not have any FOLR crosses may indicate the evenness of FOLR egress around the circumference of taproots. It is obvious that if all FOLR of a LLP sapling egress into one direction (for example, a contiguous three 30-degree segments) or two opposite directions (such as in a plane root system), this LLP may also topple into the leeward direction of high winds. Although FOLR egress evenness was similar among the three saplings in table 1, the Feb-SD sapling which was from non-copper cavities had greater extent of FOLR spiraling than the other two non-copper saplings (6 cm versus less than 3 cm, table 1)

CONCLUSIONS

We designed a detailed assessment scheme for root system architecture evaluation in hoping to be able to correlate sapling stem displacement to one or several root parameters. Our preliminary results showed promising association between sapling stem displacement and taproot and sinker depths in the soil profile. With increasing number of longleaf pine seedlings used for artificial regeneration being container stock, the risk of sapling mechanical instability caused by high winds, ice storm, or animals cannot be overlooked.

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Table 1—Examples of stem displacement, growth, wood density, and root system architecture in two stem-displaced (SD) and one non-displaced (ND) longleaf pine saplings excavated during the sixth growing season. The Feb-SD sapling was toppled in February, 2010; the horse-SD was bent by wild horses in August, 2009; and the ND sapling was straight before it was knocked down by a track hoe during excavation in May, 2010

	Feb-SD	Horse-SD	ND*
Sinuosity Index	49.5	56.2	4.3
Qualitative Stem Displacement Scale	3.5	3.0	0
Height (cm)	122	226	365
Stem Length (cm)	267	379	365
Diameter at Breast Height (cm)	3.63	4.14	4.08
Ground Line Diameter (Dia) (cm)	6.85	7.88	4.60
2010 Earlywood Density (kg/m^3)	397	430	335
2009 Earlywood Density (kg/m^3)	344	310	343
2009 Growth Ring Wood Density (kg/m^3)	401	460	408
2008 Earlywood Density (kg/m^3)	328	338	341
2008 Growth Ring Wood Density (Kg/m^3)	339	366	355
Total Sapling Dry Weight (kg)	3.41	4.78	4.80
Taproot DW Allocation (%)	9.0	3.0	3.6
Sinker Root DW Allocation (%)	0	5.8	0
Adventitious (Adv) Root DW Allocation (%)	0	3.9	9.3
First-Order Lateral Root (FOLR) DW Allocation (%)	10.2	10.2	9.0
Sinker Root (#)	0	2	0
Adv Root (#)	0	2	3
FOLR (#)	9	9	7
Rooting Depth of Taproot (cm)	55.0	6.5	6.5
Taproot Dia @ 5 cm from the Ground Line (cm)	6.60	8.12	7.81
Rooting Depth of Largest Dia Sinker Root (cm)	0	66.5	0
Rooting Depth of Largest Dia Adv Root (cm)	0	2.0	1.5
% FOLR Originating Zone on Taproot			
0 - 5 cm	44	22	57
5.1 - 10 cm	56	78	43
10.1 – root plug end	0	0	0
% FOLR Egress into Soil Profile			
0 - 5 cm	44	22	43
5.1 - 10 cm	44	78	57
10.1 – root plug end	11	0	0
> root plug end	0	0	0
Mean FOLR Dia (cm)	1.40	1.49	2.18
Mean FOLR Spiraling Length (cm)	6.1	2.4	2.9
Mean 30-Degree Segments FOLR Crossing (#)	3.9	2.8	3.0
30-Degree Segments without FOLR Egress (#)	5	7	6

*Values for sinuosity index, qualitative stem displacement scale, and height for this ND sapling wereobtained by propping the sapling up.

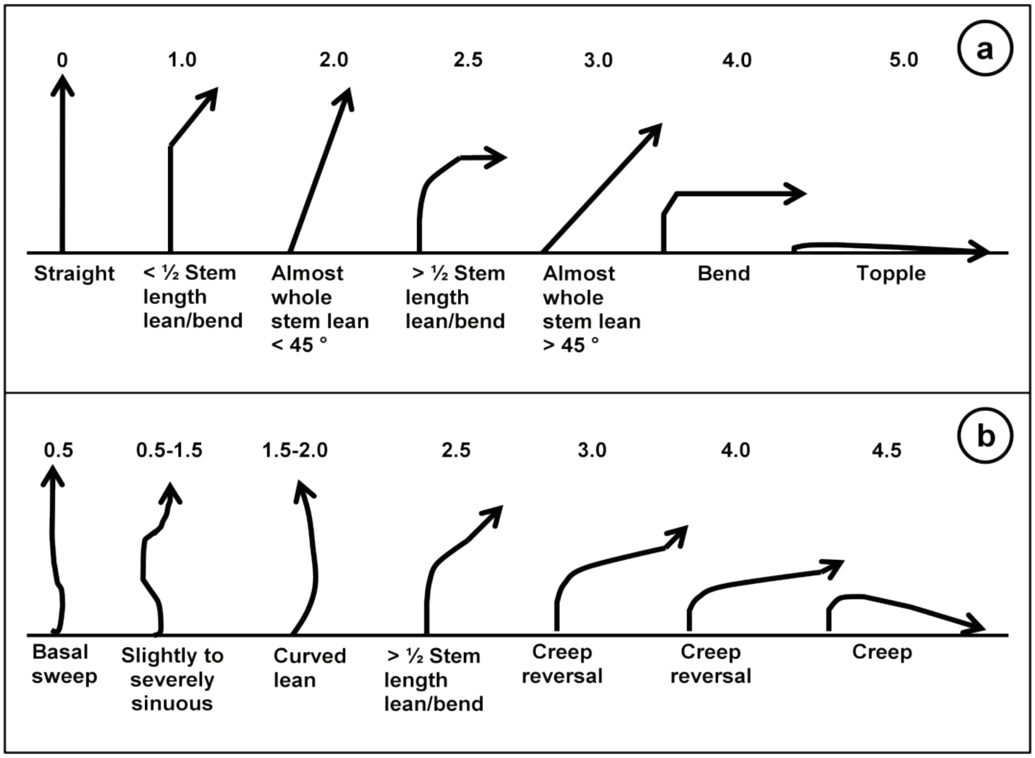

Figure 1—(a) Stem displacement scale of 0, straight to 5, topple; (b) scale of stem recovery from displacement with 0.5 for basal sweep and slightly sinuous and 4 for creep reversal. Creep (4.5) occurs when stem displaces further toward the ground due to its own weight.

SURFACE SOIL ROOT RESPONSE TO SEASON OF REPEATED FIRE IN A YOUNG LONGLEAF PINE PLANTATION

Mary Anne Sword Sayer and James D. Haywood

The potential exists for interaction between naturally high soil bulk density and low soil water content to create root-growth limiting soil strengths. This problem is commonly remedied by soil structural attributes, old root channels and other perturbations, and periods of wetness during which soil strength is favorable for root elongation. Because the application and season of repeated fire affect understory plant structure in southern pine forests (Haywood 2009), they may also affect the quantity and distribution of understory roots. On sites where understory roots play a significant role in alleviating extreme soil strength by perturbing the soil and generating old root channels, awareness of how fire-induced changes in vegetation affect understory rooting and soil strength is warranted. Our objective was to evaluate the relationship between vegetation changes induced by fire and soil strength on a site where the potential exists for pine rooting to be limited by both soil bulk density and soil strength.

In a 14-year-old stand of longleaf pine (*Pinus palustris* Mill.) on the Kisatchie National Forest in Louisiana, an investigation is under way to quantify distributions of pine and understory roots and soil strengths in response to no burning and biennial prescribed burning in March, May, and July. The soil is a complex of Beauregard silt loam and Malbis fine sandy loam. These soil series are characterized by subsoil bulk densities that may exceed 1.4 g/cm^3 (Patterson and others 2004, Scott and others 2007) which is considered root-growth limiting (da Silva and others 1994, Pritchett 1979). As soil water is depleted, bulk densities below this threshold could also contribute to root growth limitations if soil strength exceeds 2 megapascals (MPa) (Bennie 1996, Taylor and other 1991). After four biennial prescribed fires, understory roots were sampled in three replications of four subplots per treatment. Understory root biomass at the 0 to 7.5 cm depth was significantly affected by the application and season of prescribed fire (Figure 1), while that between 7.5 and 20 cm was not significantly affected by burn treatments. Overall, understory root biomass near the surface of the soil was greater on the July- and March-burn plots compared to the May-burn and non-burned plots. Grass and forb cover was greater on the July- and March-burn plots compared to the May-burn plots, and all burned plot had greater grass and forb cover compared to the non-burned plots (Haywood 2009).

Soil strength at 16 percent volumetric soil water content (SS16) which represents field capacity for this soil complex, was estimated in three replications of four subplots per treatment by the method of Sword Sayer (in press). The collection of soil strength and volumetric water content data was delayed by prolonged drought in 2010-2011. Preliminary estimates of SS16 using existing data indicate that at this location, root growth limiting soil strengths are possible at the 5 to 20 cm depth (Table 1). Thus, an understanding of how SS16 responds to fire-induced changes in understory rooting is justified. Once estimates of SS16 are completed, the potential of understory rooting to ameliorate high soil strengths and benefit pine rooting in the 5 to 20 cm depth will be assessed for the March-, May-, July- and non-burned plots.

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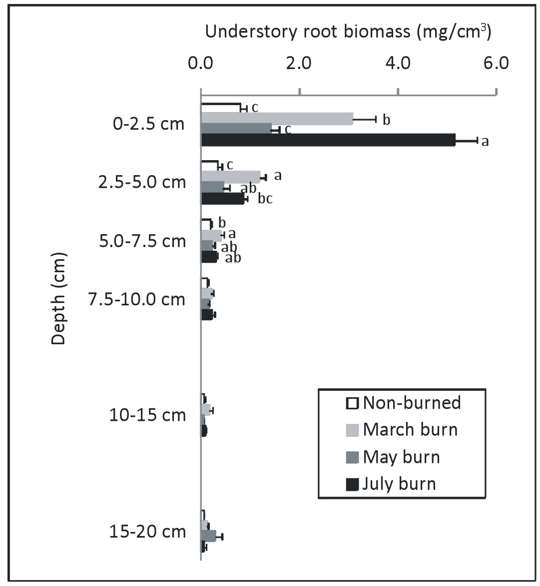

Figure 1—Vertical distribution of understory root biomass in the 0 to 20 cm depth in response to four burn treatments. Means within each depth associated with a different letter are significantly different by the Tukey test at α = 0.05. Error bars are one standard deviation of the mean. Burn treatment did not significantly affect understory root biomass at the 7.5 to 20 cm depths.

Table 1—Mean and standard deviation of SS16 at five depths between 2.5 and 20 cm estimated with data available through December 2010. Values in parentheses represent the percentage of data yet needed before estimates can be finalized. Estimates of SS16 at the 0-2.5 cm depth were not possible by the methods used (NA)

Depth (cm)	Non-burned	March burn	May burn	July burn
	Soil Strength (MPa[1])			
0-2.5	NA	NA	NA	NA
2.5-5.0	1.59 ± 0.37 (17)	1.31 ± 0.26 (33)	1.51 ± 0.35 (25)	1.34 ± 0.19 (50)
5.0-7.5	2.16 ± 0.49 (8)	1.70 ± 0.32 (42)	1.91 ± 0.50 (17)	1.49 ± 0.12 (75)
7.5-10.0	2.26 ± 0.45 (8)	1.80 ± 0.34 (50)	2.08 ± 0.51 (8)	1.47 ± 0.04 (83)
10-15	2.25 ± 0.43 (17)	1.69 ± 0.27 (42)	2.41 ± 0.56 (25)	2.40 ± 0.59 (25)
15-20	1.92 ± 0.33 (25)	1.38 ± 0.21 (42)	1.98 ± 0.46 (42)	2.37 ± 0.54 (42)

[1]MPa: megapascals.

INTEGRATING FOREST STAND PROJECTIONS WITH WILDLIFE OCCUPANCY MODELS TO DEVELOP A DECISION SUPPORT TOOL.

Michelle F. Tacconelli and Edward F. Loewenstein

ABSTRACT

Natural resource managers must often balance multiple objectives on a single property. When these objectives are seemingly conflicting, the manager's job can be extremely difficult and complex. This paper presents a decision support tool, designed to aid land managers in optimizing wildlife habitat needs while accomplishing additional objectives such as ecosystem restoration or timber production. A growth and yield model, the Forest Vegetation Simulator, is used to project future stand structure based on three management scenarios: no management, active manipulation of species composition through harvesting and underplanting, and single tree selection based on the Proportional-B method. At five-year time steps, predicted forest structure is input into species specific wildlife occupancy models to estimate probability of occurrence. This allows quantification of these species response to the silvicultural prescription. By integrating these two models a unique tool is available for land managers to both gauge the efficacy of their management plans before their implementation and to develop a predicted timeline of forest structure that can be used for comparison in adaptive management.

INTRODUCTION

With consumptive trends of wood products on the rise (Bowyer 2007), the need for more comprehensive management grows (Bowyer and others 2007). The Multiple-Use Sustained-Yield Act of 1960 required by law that national forests broaden their focus to include the production of other commodities such as recreation, wildlife and water. However, some argue that the practice has fallen short of the ideal set up by the act (McQuillian 1990 and Shepard 1990). Shands (1988) argued that "multiple use has become a pejorative term that many people believe is synonymous with management that emphasizes timber production to the detriment of other forest resources" (p. 14). In recent years there has been a push for more "Ecosystem Management" (Bengstion 1994), or a process that aims to conserve major ecological services and restore natural resources while meeting the socioeconomic, political and cultural needs of current and future generations (Bengstion 1994, Brussard and others 1998, Grubine 1994, and Szaro and others 1998).

With the greater push for ecosystem management and more efficient natural resource management, the forests that provide timber also need to incorporate other uses, such as wildlife habitats. Therefore, it is increasingly common that natural resource managers are asked to balance multiple objectives on a single property. Management of these multiuse areas can be exceedingly complex, but extremely important for all the parties involved (Keeney and Raiffa 1993). However, bringing multiple fields together, with perceived competing objectives, is never easy.

The fields of wildlife biology and forest management have supposed opposing objectives for the use and management of forests. Wildlife biologists tend to focus on the organism of interest, while forest managers tend to look at the available timber in the forest. The common area is in forests where both wood products and wildlife habitat are provided. From my experience, disagreements on the best way to manage the forests often occur because of differences in the way management is applied and implemented. Although the management perspectives from each field vary, the results are not necessarily mutually exclusive.

Tools exist in both fields to model forest growth and response of wildlife to changes in habitat. However, they are seldom used together. Forest growth and yield models use current forest inventory to predict forest growth and potential outputs in the future by using a set of tree based measures that include tree species, sizes, and densities. Occupancy models provide an estimate of species occurrence based on a variety of factors, including habitat characteristics like tree species and size, density, and available cover. Being that habitat characteristics, or structure is a big predictor of a species occurrence, and growth and yield models are able to produce structure based outputs it may be possible to integrate these tools to determine the effects of forest management on a species before implementation.

METHODS

FIELD METHODS

A forest inventory was designed to quantify vegetative structure, focusing on characteristics that are most important for wildlife habitat suitability (Van Horne and Weins

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1991). Fixed area circular plots, 0.20 hectares (25m radius) were established during July and August 2008. Starting at plot center, a grid of 49 points spread 6.25m apart, was established along the cardinal directions (Figure 1). At each point on the grid the presence or absence of cover was recorded for the canopy, mid-story, reproductive/shrub, and herbaceous/ground cover layers using a "moose horn" densitometer. The canopy layer was defined as the dominant tree cover above the point on the grid. The mid-story layer was defined as trees that were two thirds the height of the dominant canopy, but not extending into the dominant canopy. The reproductive/shrub layer was defined as vegetation not exceeding 3.5 meters in height. The herbaceous/ground layer was defined as any herbaceous ground cover. Within the plot the presence of snags and their DBH was recorded. The height of three of the tallest trees was recorded to establish canopy height. A variable radius plot using a 10-factor angle gauge was established using the center of the grid to determine the basal area of the stand. These trees were tallied by species and DBH.

Point count surveys for birds were conducted at each plot center during the breeding season (May-July) no later than four hours after sunrise. Each survey consisted of three, four minute counts during which each bird that was seen or heard was tallied along with the estimated direction and distance (0-25m, 25-50m, greater than 50m) (Hamel and others 1996). At the beginning of each survey, the temperature was recorded (°C) along with the date and time.

STAND PROJECTIONS

The Southern variant of FVS (SN) was used for stand projection. Three different management scenarios were produced for each stand; (a) No Management, (b) Even-aged, and (c) single-tree selection using Proportional-B Method. All projections with FVS started in 2008 and were for run 100 years at five-year intervals. For the purposes of this project the hardwood sprouting module (SPROUTING) was turned off in the FVS program and all regeneration was simulated manually.

For the No Management simulations no management treatments were simulated in FVS. The stands were allowed to progress for 100 years with no anthropogenic interference, as well as no natural disturbance. In the even aged simulation run for each stand, the current exsisting trees were clearcut in 2008 and replanted with 121 trees per hectare, with 90 percent survival, in 2009. Alternating summer and winter burns were simulated every 5 years starting in 2013. Each stand was grown for a 60-year period, during which time a thin from below was applied when BA exceeded 7.4m^2ha^{-1} or when growth was being impeded, on average 2 times during the rotation . A final harvest took place in 2068. In 2069, the stand was replanted at the same initial planting density. The same management parameters were applied throughout the second rotation until the end of the projection in 2108.

For the single-tree selection using the Proportional-B Method, each stand was prescribed a unique treatment based on the initial stand structure in 2008. The Pro-B method uses three broad size classes as a surrogate for age classes. For this project size classes were always set to 5 to 15cm DBH, 20 to 30 cm DBH, and greater than or equal to 35cm DBH.

If the current structure fit the parameters for an uneven-aged stand Pro-B was implemented immediately. The largest tree existing in the stand was used to set the LDT. Residual basal area (RBA) was set to 5.6m^2, and Q always equaled 1.3. Harvest of trees was applied using a set amount of BA for each size class, with proportionally more in the largest classes. Subsequent harvests were applied when the stand accrued 1.4m^2 to 2.8m^2 BA or roughly 10 or 15 year cutting cycles. Because FVS-sn works in 5-year cycles, cutting cycles for the Pro-B method were simplified to fall on an existing cycle boundary; cutting cycles tend to fall between 7 to 15 years.

If loblolly pine (*Pinus taeda*) was present it was kept as a main component of stand structure. One management objectives is to restore the Longleaf pine ecosystem (open pine woodland); however it is not currently present on the property. Loblolly pine can also form an open pine woodland, therefore if loblolly pine was present it was kept as a main component of the stand to surrogate for longleaf until it can be established. All cuts were made by using the "thin throughout a diameter range" option. The "thin throughout a diameter range" option allows for the user to define diameter classes and cut those classes to a defined amount of BA. All reproduction was simulated manually to adequate levels for structure to be maintained, meaning enough regeneration was simulated to maintain levels of BA needed in the smallest diameter class. Composition of the simulated regeneration was decided by the dominate species within the initial stand structure, and were attempted to be kept proportional to the dominate canopy.

Using the "Compute Stand Variables with SpMcDBH" function canopy cover was calculated for every cycle in the simulation. Midstory cover was calculated with "Compute Stand Variables in Editor". A code that defined our definition of midstory cover was written (Personal communication. Chad Keyser. 2010. FVS Staff, Remote Location: Bent Creek Experimental Forest, 200 W.T. Weaver Blvd. Asheville, NC 28804) and calculated for each cycle. All other structural characteristics needed for calculation of probability of use through the Occupancy models were pulled from the main FVS output.

VEGETATIVE COVER PROJECTIONS

Regression models (R ver. 2.12.0) were created to project the amount of reproductive cover and ground cover at each time step. FVS does not provide an estimate of these two cover layers, both of which are known to influence occupancy by certain wildlife species. A multi-model inference was run on collected inventory data. Multi-model inference is a statistical technique where alternative plausible models are assessed given the data presented and ranked based on relative likelihoods (Burnham and Anderson 2002). A global model was created to include all potentially influential variables for each layer of cover. Model coefficients were averaged and relative variable importance greater than 0.5 was used to determine which variables would be used in the regression model.

OCCUPANCY MODELS

Occupancy models were created by the Alabama Corporative Fish and Wildlife Research Unit using vegetation inventory data of vegetation structure combined with bird point count data. For purposes of this project the top or best model was used to determine probability of use. The best model is the most applicable or has the highest likelihood of being correct from the list of generated models. Other studies use an averaged model where coefficients are averaged; however averaged models were not available for use in this study. Probability of use was calculated for each time step interval using stand projections from FVS and the occupancy models for each species. The Yellow-breasted Chat model included a landscape component, edge, which could not be simulated in FVS. Edge is defined as a border of one area to another, like forest to field or forest to road. The amount of edge is give as a value between -1 and 1. One represents no edge being present, while -1 represents edge being present. Edge was held constant at three levels (-1, 0, 1) to represent various amounts of edge that could be present.

RESULTS

VEGETATIVE COVER PROJECTIONS

FVS does not provide an estimate of reproductive cover or ground cover, which are needed to estimate probability of use of the focal species. The global model parameters for reproductive cover consisted of the variables canopy cover, midstory cover, basal area, and trees per acre. The global model parameters for Ground Cover consisted of canopy cover, midstory cover, reproductive cover, percent basal area hardwood, basal area, and trees per acre. All of the models generated by the multi-model inference were average. The parameters were averaged and relative importance values were obtained for each parameter. The linear regression models generated and used for were:

Reproductive Cover = 36.7 + 0.397Midstory Cover – 0.0945 Basal Area

Ground Cover = 69.3 + 0.171 Reproductive Cover – 0.292 Midstory Cover – 0.0213 Trees per Acre

STAND STRUCTURE

Diameter distributions were similar for all stands in each scenario. In the no management simulation diameters are normally distributed throughout time. Over the projection cycle the average stand diameter increases as the range of diameters increase, but the number of trees in each diameter class decreases, flattening the normal curve over time. In the Pro-B simulations a reverse j-shaped or negative exponential curve was achieved and maintained by 40-years into the simulation. The even-aged scenarios maintain normally distributed diameters throughout the projection.

Basal area increases to a stable point in the no management projections (Figure 2). In the Pro-B projections basal area oscillates with each cut, staying between 5.6m^2ha^{-1} to 7.0 m^2ha^{-1} at the lowest for each Pro-B cut. When even-aged management is implemented stands follow the pattern seen in Figure 2.

Canopy cover follows similar trends seen in basal area for all scenarios (Figure 3). Midstory cover has an initial decrease in the no management projection, then a short period of increase from 2013 to 2048, when it declines to about 6% at the end of the projection (Figure 4). The even-aged projection has no midstory cover after the initial clearcut. In the Pro-B projection the amount of midstory cover varies throughout (Figure 4). It steadily increases from 2038 to 2073, and then oscillates between 30 to 40% as it steadily decreases for the remainder of the projection. Reproductive cover does not change much between the projection scenarios (Figure 5), staying within 10 to 20 percentage points of each other. Ground cover has similar trends between the scenarios (Figure 6); amounts of ground cover stay within 15 to 20 percentage points between scenarios. Ground cover always trended to increase throughout the projection, but only slightly.

PROBABILITY OF USE

The pine warbler is predicted to use stands under both the no management and Pro-B scenarios 100 percent of the time for 100 percent of the projection cycles. Under the even-aged management scenarios pine warbler has a probability of use for the stands between 80 and 100 percent throughout the projection cycle (Figure 7). The yellow-breasted chat's probability of use varies between management scenarios and with what the edge value was held constant at. When there is no edge (edge=1) the yellow-breasted chat is more likely to use even-aged stands over time (Figure 8a). With more edge the difference in probability of use becomes less between management scenarios. The yellow-breasted chat is more likely to use any management scenario, the difference in probability of use becomes significantly less between scenarios (Figure 8b and 8c).

DISSCUSSION

PROBABILITY OF USE MODEL RESPONSES

Each species' occupancy model responds differently to the simulated management scenario. The pine warbler's probability of use is 100 percent for the entire projection cycle for no management and Pro-B scenarios, and 80 to 100 percent for even-aged scenarios. The occupancy model created for pine warbler is responding to a multitude of parameters. It responds positively to canopy height and canopy cover, but negatively to midstory cover, reproductive cover, and ground cover. In many of the simulations canopy height and cover remain high over time, while midstory and reproductive cover decline. In the even-aged scenarios the probability of use for pine warbler decreases to 80 percent because canopy height and cover are not present in sufficient amounts. In most of its range it is associated with a dense canopy layer and a sparse understory or a low density shrub layer (Rodewald and others 1999). While species composition was not taken into account, pine warbler is mostly associated with the North American pine forests. There is anecdotal evidence that it prefers tall dense canopies of pines (Rodewald and others 1999).

The yellow-breasted chat's probability of use varies with the amount of edge represented in the model. The occupancy model for yellow-breasted chat is negatively correlates to edge, there for the more edge available the more yellow-breasted chat is likely to use that stand. When edge is equal to -1, there is no difference between uses of the scenarios. Yellow-breasted chat is often found in low dense vegetation, like power-line corridors, fence rows, and forest edges (Eckerle and Thompson 2001). Its occupancy model also responds negatively to canopy, midstory, and reproductive cover, while it has a positive response to ground cover. When there is no edge present (edge=1) it has preference for the even-aged scenario, especially in its early development. Early stages of plantations are similar to edges or opening. This species is considered a generalist, with preferences to edges (Eckerle and Thompson 2001), which might explain its preference to the even-aged scenario.

Advantages of Integrating FVS with Probability of Use

FVS is a growth and yield model, which uses empirical growth. Therefore, assumptions are held constant for all forest growth simulations, allowing management alternatives to be compared without bias. Using a forest inventory allows the user to update stand information to current conditions after pervious simulations have been made. FVS provides a set of raw outputs tables that need further summarization to obtain the required information for the probability of use estimates. This allows the user to pull what is important from that information, and use it in any model available.

The most important advantage of automating these calculations in FVS is the ability to develop and analyze many alternatives quickly. Stand level simulations can be made to assess and communicate the effects of proposed management regimes. The rapid analysis is especially important when some parties involved in planning have backgrounds other than forestry, and so do not understand standard forestry metrics such as volume, tree sizes and stands structures. Information can be easily explained in terms that any planner can understand. Several alternative silvicultural pathways can be compared to assess their potential benefits. A hypothesis-testing framework can be used before they are applied in a stand or at the whole landscape level.

There are many other analyses available to the user of FVS. Tables which summarize the current and projected future inventories in different ways are available for users. Data created in FVS have been developed to answer questions related to other forestry measures such as inventory tables and stand summary tables. FVS can answer questions about carbon sequestration, as well as stand structures. Visualizations produced by the Stand Visualization System also allow the user to communicate changes in to forest caused by forest management activities.

Limitations of Integrating FVS with Probability of Use

There are several limitations with using this approach. FVS is unable to produce information about reproductive or ground cover. Therefore, regression models were created from inventory data. These models were produced from the best information available. The parameters included within these models (i.e. canopy cover, midstory cover, basal area, trees per acre) were used because they may influence the amount of light that reaches the forest floor. Therefore, changing how much is present or absent within the forest stand. Ellsworth and Reich (1993) found that light attenuation occurs in the upper and middle portions of the canopy; furthermore, light may affect how vegetative structure forms throughout all canopy layers.

However, development of cover layers may relate more to site productivity than to light availability (Liira and others 2007). Liira and others (2007) found a correlation between canopy closure and productivity, and an increase in abundance of shrubs with higher productivity. There has been little study of understory relationships with light in the Southeastern U.S. However, in other regions, like the Pacific Northwest, understory relationships have been studied at length. Studies have focused on developing relationships between overstory and understory structure and composition in a variety of forest types (Halpern and Spies 1995 , VanPelt and Franklin 2000). The vegetation cover models could be improved if these other factors like light availability and productivity are included in future modeling efforts, therefore improving the efficacy of the overall decision model.

Spatial arrangement and size of habitat patches is important for some species. The integration of FVS and occupancy models does not take into account how big and where stands are located on the property. Birds can occupy larger areas with a matrix of suitable and unsuitable habitat because they are capable of flight but other taxa may have size and spatial requirements that cannot be accounted for in this model. Yellow-breasted chat had a landscape scale parameter within its model that was easily modeled. However, edge should also be considered within the matrix of the spatial landscape, and how it could change probability of use over time.

MANAGEMENT IMPLICATIONS

The integration of stand projection models and occupancy models creates a powerful tool for land managers to gauge the efficacy of their management decisions before implementation. Land managers often do not consider the long term effects of the management they are implementing; often short term goals are achieved without any consideration for what the long term challenges might include. This decision support tool will allow for long term planning, not only for wildlife but also for other concerns such as timber or carbon sequestration. Optimistically, it will change the way management is preformed over the long term, and allow for careful planning for future natural resource use.

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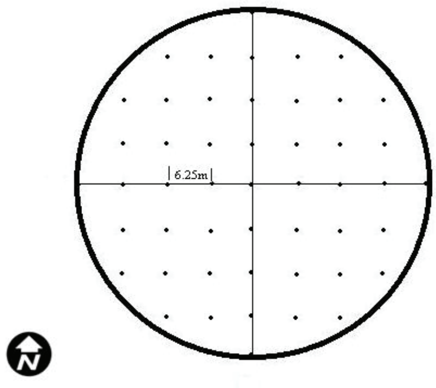

Figure 1—Grid layout used for measuring cover at each of the four layers. At each point on the grid the presence or absence of cover was recorded with a "moose horn" densitometer for the canopy, mid-story, reproductive/shrub, and herbaceous/ground cover layers. The radius is 25m and the distance between points is 6.25m.

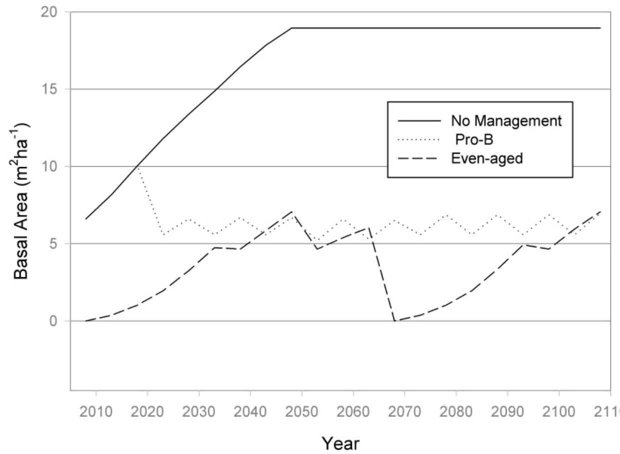

Figure 2—Basal Area in a stand for all three management scenarios after harvesting took place. Basal area increases to a stable point in the no management projections. In the Pro-B projections basal area oscillates with each cut, staying between 5.6m^{2}ha^{-1} to 7.0 m^{2}ha^{-1}. Even-aged management follows the pattern seen below.

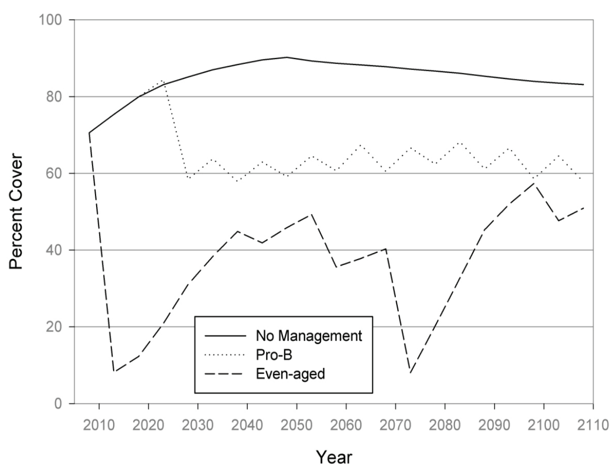

Figure 3—Canopy cover found in a stand for all three management scenarios over the projection cycle. Canopy cover follows similar trends seen in basal area for all scenarios. Canopy cover increases to a stable point in the no management projections. In the Pro-B projections canopy cover oscillates with each cut, staying between 60 to 70% covered. Even-aged management follows the pattern seen below.

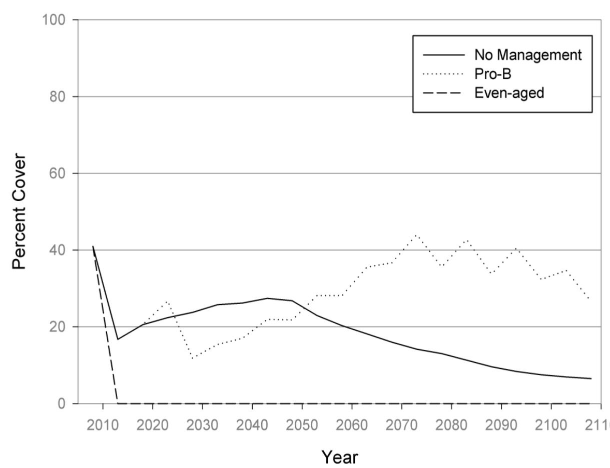

Figure 4—Midstory cover found in all three scenarios for the projection cycle. Midstory cover has an initial decrease in the no management projection, then a short period of increase from 2013 to 2048, when it declines to about 6% at the end of the projection. The even-aged projection has no midstory cover after the initial clearcut. In the Pro-B projection the amount of midstory cover varies throughout but generally steadily increases from 2038 to 2073, and then oscillates between 30 to 40% as it steadily decreases for the remainder of the projection.

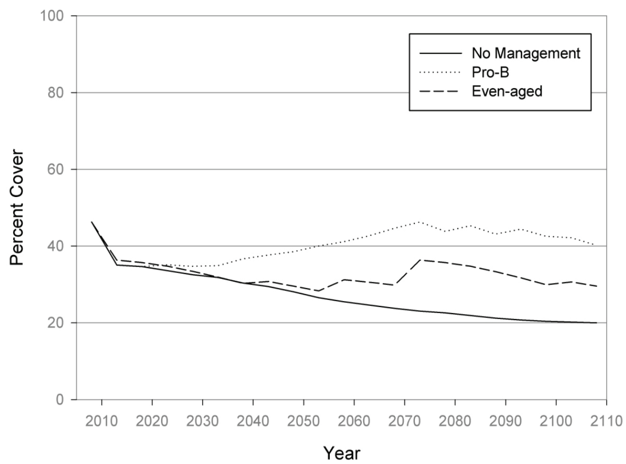

Figure 5—Reproductive cover found in a stand for all three management scenarios over the projection cycle. Little variation can be found in the amount of reproductive cover between scenarios, at the most only a 20 percentage points of difference between the most in the Pro-B scenario and the least in the No Management scenario.

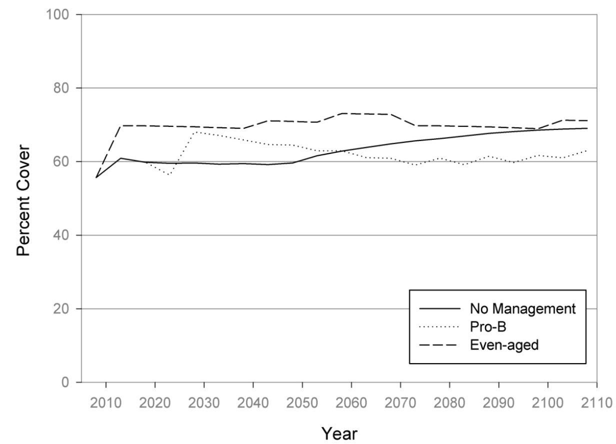

Figure 6—Ground cover found in a stand for all three management scenarios over the projection cycle. Ground cover has similar trends between the scenarios. The amounts of ground cover stay within 15 to 20 percentage points between scenarios.

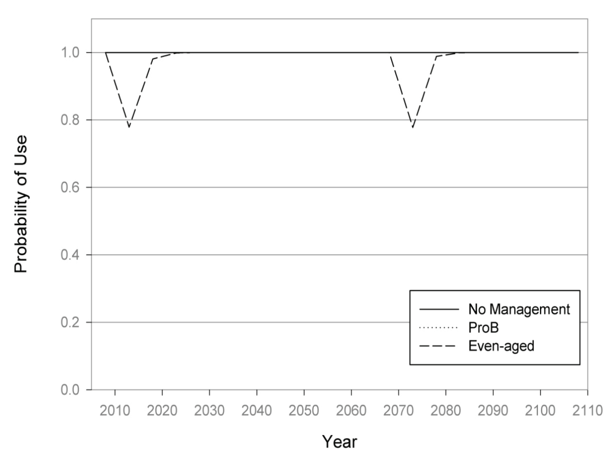

Figure 7—Probability of use of pine warbler over the 100 year projection cycle for all three management scenarios. The pine warbler is predicted to use stands under both the no management and Pro-B scenarios 100% of the time for 100% of the projection cycles. Under the even-aged management scenarios pine warbler has a probability of use for the stands between 80 and 100% throughout the projection cycle.

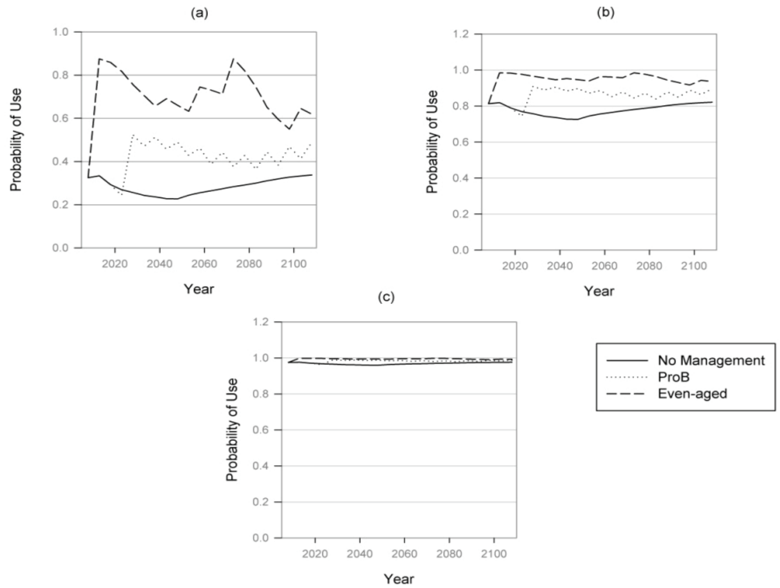

Figure 8—Probability of use of yellow-breasted chat over the 100 year projection cycle for all three management scenarios with (a) edge held constant at 1, (b) edge held constant at 0, and (c) edge held constant at -1. With increased edge there is less of a difference in probability of use between the scenarios.

A MIXED-EFFECTS HEIGHT-DIAMETER MODEL FOR COTTONWOOD IN THE MISSISSIPPI DELTA

Curtis L. VanderSchaaf and H. Christoph Stuhlinger

ABSTRACT

Eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) has been artificially regenerated throughout the Mississippi Delta region because of its fast growth and is being considered for biofuel production.This paper presents a mixed-effects height-diameter model for cottonwood in the Mississippi Delta region. After obtaining height-diameter measurements from the plot/stand of interest, a mixed-effects model can be calibrated often improving height estimates relative to an uncalibrated fixed-effects model. When using an independent validation dataset, the calibrated mixed-effects height-diameter model vastly improved height predictions compared to a completely fixed-effects model. When using only one tree in calibration, bias decreased from -1.1164 m to -0.1334 m while the mean square error (MSE) decreased from 2.3421 to 0.4869 for the fixed-effects and mixed-effects models, respectively. When using three trees in calibration, the bias and MSE were reduced to -0.0495 m and 0.3012. The use of three trees in model calibration will likely provide a reasonable compromise between predictive ability and field sampling times.

INTRODUCTION

Height-diameter models are an integral component of forest inventories and in many cases reduce sampling times. Using diameter (D) to predict height (H) has long been implemented since D is more efficiently measured than H yet the two are strongly correlated. Mixed models are becoming a popular modeling tool to provide more site specific predictions. Many regionwide mixed model equations have been fit that can then be calibrated for local site conditions. When compared to the traditional means of developing local H-D equations, where H and D are measured and then a separate equation is fit for a tree, plot, stand, or tract, a mixed-effects model analysis is efficient because a model can be calibrated without having to statistically fit a model and thus even small sample sizes can be used (since degrees of freedom are not a concern).

Both linear and nonlinear mixed models have been used to model the H-D relationship for many species including loblolly pine (*Pinus taeda* L) in the southeastern US (Trincado and others 2007, VanderSchaaf 2008), cherrybark oak (*Quercus pagoda* Raf.) in the Western Gulf (Lynch and others 2005), and stone pine (*Pinus pinea* L.) in Spain (Calama and Montero 2004). Mixed-effects models provide an efficient means to obtain cluster-specific, or for this particular example, plot-specific, parameters through the prediction of cluster-specific random effects. For example, total tree height (H) can be predicted as a function of diameter at breast height (D):

$$\ln H_{ki} = \beta_0 + \beta_1 \ln D_{ki} + \varepsilon_{ki} \quad [1]$$

Where:
ln--natural logarithm,
H_{ki}--total tree height (m) of tree i for plot k,
D_{ki}--diameter at breast height (cm) of tree i for plot k,
β_0, β_1--parameters to be estimated,
ε_{ki}--random error where it is assumed $\varepsilon \sim N(0, \sigma^2 I)$.

Equation [1] provides what is often termed a population-average estimate of H for a given D. The parameters β_0 and β_1 are assumed to be fixed, or that the parameter estimates apply to every experimental unit (e.g. every tree) in a population. Whether trees are located in North Carolina or Arkansas, the parameter estimates are assumed to be correct. However, plot-specific characteristics such as soil type, nutrient status, elevation, aspect, competition from herbaceous vegetation, genetic stock, etc., may result in the parameters differing across plots. Thus, specific plots may have what are generally termed "random parameters" in mixed-effects model terminology. Equation [1] can be altered by adding plot-specific random effects to the population-average parameters to produce plot-specific parameters:

$$\ln H_{ki} = (\beta_0 + u_{0k}) + (\beta_1 + u_{1k}) \ln D_{ki} + \varepsilon_{ki} \quad [2]$$

Where:
u_{0k}, u_{1k}--are plot-specific random effects, assumed to be $N(0, \sigma^2_0)$ and $N(0, \sigma^2_1)$, respectively,
$(\beta_0 + u_{0k})$--plot-specific intercept,
$(\beta_1 + u_{1k})$-- plot-specific slope,
and all other variables as previously defined.

Additionally, a covariance, σ_{01}, can be assumed to exist between u_{0k} and u_{1k}. Linear mixed-effects models, in this particular case, produce an efficient estimate of plot-specific parameters because only six parameters are estimated using the model fitting algorithm ($\beta_0, \beta_1, \sigma^2_0, \sigma^2_1, \sigma_{01}, \sigma^2$). Based on the variance and covariance estimates, plot-

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specific random effects (u_{0k}, u_{1k}) can be predicted and then added to the population-average intercept and slope (β_0, β_1) estimates to obtain plot-specific parameter estimates. Plot-specific random parameter estimates produce a more localized H-D equation since the random effects account for local site conditions such as soil type, genetic stock, site preparation, mid-rotation silvicultural practices, spatial and time-specific climatic conditions, etc. The prediction of plot-specific random effects is conducted outside the model fitting algorithm and thus degrees of freedom are not lost. A less efficient means of obtaining plot-specific parameter estimates would be to estimate parameters separately for each plot.

Although the parameter estimation efficiency of mixed models is an advantage, often the greatest advantage is the ability to calibrate the model using data independent of those used in model fitting. Hence, for trees obtained from plots not in the model fitting dataset, plot-specific (or stand-specific) H-D relationships can be produced if H and D observations have been collected from trees in that plot (or stand).

Eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) is a fast-growing tree species (Cooper 1990) and has recently been one of the most widely artificially regenerated tree species in the Mississippi Delta region. It has several commercial uses including pulpwood and a strong consideration as a species of choice for biofuel production. The objectives of this paper are to present a mixed-effects individual tree H-D model for cottonwood established in the Mississippi Delta region and to demonstrate how this model improves height predictions for an independent cottonwood validation dataset.

METHODS

DATA USED IN MODEL FITTING

Observed H-D pairs were obtained from a study site occupying about 3 ha located on the University of Arkansas Pine Tree Branch Experiment Station in St. Francis County, AR (Stuhlinger and others 2010). The soil is a Calloway silt loam and the site was previously used as row cropland. See Table 1 for summary information of the data used in model fitting.

STUDY DESIGN AND LAYOUT

The study design was a replicated randomized complete block consisting of six blocks that contained nine plots of randomly assigned cottonwood clones. Each plot contained 56 trees in a seven x eight tree layout. The interior 30 trees (five x six tree layout) were measured, leaving an unmeasured buffer around each measurement plot.

STUDY ESTABLISHMENT

The site was sprayed prior to planting using applications of Goal® (oxyfluorfen) and Roundup® (glyphosate) to control weeds. Each planting row was sprayed with a liquid fertilizer prior to planting at a rate of 112 kg per ha of nitrogen. The site was then bedded (51-cm high beds) to facilitate furrow irrigation.

Cottonwood cuttings were planted by hand at a 3.1 x 3.1 m spacing in March 1996. Disking, herbicide spraying, and hand weeding continued for two years after the initial planting. Irrigation with well water was conducted each year whenever a 5-cm rainfall deficiency was reached. Deficiencies occurred on average five times per year, resulting in about 8 to 10 ha-cms of irrigation water per year.

Nine cottonwood clones were tested, two from Texas (S7C15 and S13C20), five from Stoneville, Mississippi (ST72, ST124, ST148, ST163, and Delta View (mix of the four ST clones)), and two hybrids of eastern cottonwood and black cottonwood (Populus trichocarpa Torr. and Gray) from the northwestern U.S. (49-177 and 1529).

Poor survival forced the complete replanting of five cottonwood clones (S7C15, ST72, ST148, ST163, and Delta View) in Spring 1997. This resulted in two separate groups of clones: replanted clones, which grew 9 years, and non-replanted clones, which grew for 10 years. Measurement data for the two groups were combined when estimating parameters of equations [1] and [2]. Total tree height and DBH (ages 3, 5, 10 for the non-replant cohort and ages 4 and 9 for the replant cohort) were measured for all surviving trees.

MODEL DEVELOPMENT AND PARAMETER ESTIMATION

Prior to model fitting, all trees with broken and leaning stems were removed from the analysis. Observations were also checked to ensure that the H-D relationships were biologically reasonable (Figure 1) and that errors in data recording and translation to a computer file were not made (e.g. the elimination of an H of 4 m and a D of 45 cm).

Parameters of equations [1] and [2] were estimated using SAS Proc MIXED (Littell and others 1996) which assumes random errors are normally distributed and subsequently estimates parameters using maximum likelihood. Rather than simply assuming β_0 and β_1 were random across plots, likelihood ratio tests were conducted and Akaike Information Criterion (AIC) values were examined to determine if assuming β_0 was random, β_1 was random, and if assuming a covariance term existed between u_{0k} and u_{1k} (σ_{01}), produced better model fit statistics. For this analysis, since the reduced models are nested within the full model, a Likelihood ratio test is appropriate (Schabenberger and

Pierce 2002; pgs. 547, 557). Under the null hypothesis, the test statistic is assumed to follow a χ^2_{df} distribution where df is the difference between the number of fixed-effects parameters in the full and reduced models and hence the critical value also differs at an level of 0.05.

In many cases random effects account for nearly all autocorrelation among observations when using longitudinal datasets (Trincado and Burkhart 2006, VanderSchaaf and Burkhart 2007); however, a modeler can also directly model the random error structure. Within-cluster temporal correlation was ignored because it is assumed these models will be calibrated using temporary plot data or at a particular point in time for plots that are repeatedly measured. Hence, for this analysis, each measurement age of a plot is considered a separate plot. When estimating parameters in a mixed-effects model framework it is important to consider that the measurement intervals may not be the same among the model fitting and prediction/validation datasets - this can cause problems because a covariance structure that is appropriate for the model fitting dataset may not be appropriate for the model prediction/calibration dataset. Additionally, no attempt was made to model spatial correlation among trees to reduce complexity when users apply this model. For this particular study, the random error covariance-variance matrix was assumed to be $\sigma^2 I_{nk}$.

DATA USED IN MODEL VALIDATION

To quantify if model calibration of equation [2] produces superior height estimates relative to equation [1], an independent validation dataset was used (Table 1, Figure 1). Heights and Ds were obtained from a cottonwood study adjacent to the study used in model fitting. However, unlike the model fitting dataset, the validation data study site was not irrigated. A previous report demonstrated that irrigation resulted in substantially different growth patterns (Stuhlinger and others 2010), thus observations from the unirrigated study can be considered an independent dataset from that used in model fitting. Besides the lack of irrigation, the only difference in terms of study design, layout, and establishment between the two datasets was that the unirrigated study plots were subsoiled prior to planting and the liquid nitrogen fertilizer was injected 51 cm below the soil surface.

MODEL VALIDATION

Validation of equation [2], firstly, consisted of randomly sampling various numbers of trees from each plot to predict plot-specific random effects for the validation dataset. Secondly, the predicted plot-specific random effects were then added to the population-average parameters (as estimated using the model fitting dataset) to produce predicted plot-specific random parameters of the validation dataset. After obtaining predicted plot-specific parameters, equation [2] and equation [1] (an entirely fixed-effects model) were used to predict height for all trees not used in calibration of equation [2]. To provide a more conservative comparison between equation [1] and equation [2] for various model calibration sample sizes, for those trees used in calibrating equation [2], it is assumed that those heights are also known when calculating model validation statistics for equation [1].

Validation analyses follow those presented in Trincado and others (2007). The difference between the observed (Hobs) and predicted height (Hpred) of all trees whose heights were predicted for each individual plot (k), age (j), and replication (r – as explained below, for each plot, age, and sample size combination 10 random selections were conducted) was calculated for both equations ($e_{kjri} = Hobs_{kjri} - Hpred_{kjri}$). For each plot (k), age (j), and replication (r) combination, the mean residual (emean) and the sample variance (v) of residuals were computed and considered to be estimates of bias and precision; respectively. An estimate of mean square error (MSE) was obtained for each equation by combining the bias and precision measures using the following formula:

$$MSE_{kjr} = [emean_{kjr}]^2 + v_{kjr} \quad [3]$$

Values of MSE were compared between equations [1] and [2] to determine which model produced better estimates of height for this particular cottonwood validation dataset. It is well known that logarithmic transformations in many cases help to linearize data and produce homogeneity of variances; however, a transformation bias occurs since additive errors in log-log models become multiplicative when transformed back to the original scale. To account for the transformation bias, the procedure recommended by Baskerville (1972) was used:

$$\ln H_{ki} = \beta_{0k} + \beta_{1k} \ln D_{ki} + \sigma^2/2 \quad [4]$$

Where:
σ^2 -- mean square error (or residual variance) from the model fit (0.02365 for equation [1] and 0.00429 for equation [2], see Table 2).

For equation [1], $\beta_{0k} = \beta_0$ and $\beta_{1k} = \beta_1$ for all k; respectively. All validation statistics presented in this paper are based on untransformed errors.

The numbers of trees randomly selected from a particular plot for a certain age to be used in calibrating equation [2] were 1, 2, 3, 5, and 10. These sample sizes represent practical numbers of trees to be measured while conducting field inventories. To ensure that bias, variance, and MSE measures between the varying number of randomly selected trees are coherent (for example, if a plot only contains 4 trees, it cannot be used in model calibration for sample sizes of 5 and 10), only those plots that contained at least 20 trees at a specific age were selected. Hence, measuring 10 trees per plot would involve measuring at a minimum half of all trees in a plot. For those plot ages selected, the number of trees per plot varied from 20 to 29.

It should be noted that, in practice, predicted random effects for a particular plot and age are statistics themselves (and thus each predicted plot-specific random effect has a sampling distribution for a particular sample size) and can vary depending on what trees from a particular plot were used in model calibration. Similar to Trincado and others (2007), to capture variability among potential random effects predictions for a particular plot, age, and sample size, for each model calibration sample size trees were randomly selected 10 times. When calculating model validation statistics, all 10 samples for each model calibration sample size from each of the 39 plot observations were averaged (resulting in one MSE, emean, and v observation for each plot and age combination – or 39 observations). The average of these 39 observations was then calculated for each sample size to compare among model equations. To ensure that the specific trees selected for a particular model calibration sample size were coherent, the tree used to calibrate equation [2] for a particular plot and age when using a sample size of one was also used to calibrate the model for a particular plot and age when using a sample size of two, and so forth.

For the case where all tree heights were predicted using equation [1], there was no need to conduct 10 separate replications. The emean, v, and MSE were calculated for each of the 39 plots and then these observations were averaged.

RESULTS AND DISCUSSION

Based on the model fitting results (Table 2), it is best to assume that both β_0 and β_1 are random (or, essentially, that each plot (or stand) has their own intercept and slope) and that a covariance (σ_{01}) exists between u_{0k} and u_{1k}.

VALIDATION RESULTS

As the number of trees used in model calibration increased (Mixed-Effects model – equation [2]) the three validation statistics decreased in magnitude (Table 3). For the fixed-effects model (equation [1]), the most conservative comparison between the mixed- and fixed-effects results are when any tree used in model calibration is also assumed to have been measured when simply using the fixed-effects model. Else, how do you know whether the calibration statistics are better due to model calibration or because some of the trees in the plot had heights actually measured. For all n_c, the mixed-effects model MSE was at least 78 percent less (ranging from 78 percent to 87 percent) than the corresponding fixed-effects model MSE.

In some cases, individuals may predict heights for all trees within a plot (or use equation [1] to predict heights for every tree in a plot). For this case, it is correct to compare the fixed-effects model MSE when using a $n_c = 0$ (MSE = 2.3421) to all mixed-effects model MSEs. For all n_c, the mixed-effects model MSE was at least 79 percent less (ranging from 79 percent to 92 percent) than the fixed-effects model MSE.

In terms of choosing an optimal model calibration sample size, a reasonable trade-off between statistical measures (precision and accuracy) and sampling times appears to be three trees. Calama and Montero (2004) recommended using four trees for stone pine. Sample sizes of 5 and 10 trees do improve statistical measures but will require substantially more sampling time, especially measuring 10 trees. Even the use of only 1 tree in calibration substantially improves height estimates. Similar results were observed by Calama and Montero (2004) and Trincado and others (2007).

CONCLUSIONS

A mixed-effects H-D model for cottonwood in the Mississippi Delta region was presented. By obtaining H-D measurements from plots/stands of interest, Equation [2] can be calibrated to local site conditions. When using an independent validation dataset, the calibrated H-D model (equation [2]) was shown to vastly improve height predictions compared to an entirely fixed-effects H-D model (equation [1]). Large increases in the predictive ability of equation [2] were observed when using only 1 tree in calibration; however, the use of 3 trees in model calibration will likely provide a reasonable compromise between predictive ability and field sampling times.

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Table 1—Tree-level summary statistics of eastern cottonwood plantings at the five ages used in model fitting and the four ages used in model validation. Std. dev. is the standard deviation. For the model fitting dataset, data were obtained from a total of 54 plots (six blocks x nine clones). For the model validation dataset, data were obtained from 39 plot observations (plots had to have at least 20 trees for a particular sampling age – if a plot was included at age 3, it was not necessarily included at age 5). n is the number of trees

Model Fitting Dataset

		D (cm)				H (m)			
Age	*n*	Min	Mean	Max	Std. dev.	Min	Mean	Max	Std. dev.
3	496	2.2	9.1	13.4	1.82	4.1	7.9	15.0	1.34
4	504	1.3	9.5	15.7	2.77	2.0	8.0	12.0	1.79
5	420	2.8	14	19.1	2.14	4.6	11.1	14.0	1.18
9	492	2.5	17.1	28.4	4.1	4.7	15.8	21.1	2.68
10	371	9.9	19	30.5	3.57	8.8	15.9	21.5	2.57

Model Validation Dataset

		D (cm)				H (m)			
Age	*n*	Min	Mean	Max	Std. dev.	Min	Mean	Max	Std. dev.
3	304	2.2	7.5	11.3	1.62	3.4	6.2	9.9	1.03
4	246	2.3	7.4	12.2	1.97	3.5	5.8	7.9	0.98
5	160	4.6	11.9	15.2	1.78	6.2	8.9	11.1	1.12
9	182	4.6	12.1	17.7	2.1	5.5	10.1	12.8	1.27

Table 2—Population-average (β_0 and β_1) and random effects variance (σ^2_0, σ^2_1) and covariance (σ_{01}) parameter estimates. Where: -2LL -- twice the negative log-likelihood (smaller is better), AIC -- Akaike's Information Criterion (smaller is better), σ^2 -- estimated mean square error. Critical values for Full versus Reduced model analyses at an alpha level = 0.05 are: 3 df -- 7.81, 2 df -- 5.99, 1 df -- 3.84, where df is the number of fixed effects in the Full model minus the number of fixed effects in the Reduced model. For instance, when comparing the FULL model to the Fixed-Effects model the df = 6 – 3 = 3, since estimates of σ^2_0, σ^2_1 , and σ_{01} are required for the FULL model. There were a total of 2283 observations used in model fitting and the total number of clusters (plots) was 133

	Fixed-Effects		Random β_0		Random β_1		Random β_0, β_1		FULL	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
β_0	0.3311	0.0199	1.0381	0.0238	0.9723	0.0163	1.1566	0.0276	1.2410	0.0448
β_1	0.8123	0.0078	0.5298	0.0069	0.5483	0.0090	0.4820	0.0101	0.4524	0.0159
σ^2_0	-	-	0.0337	-	-	-	0.0450	-	0.1808	-
σ^2_1	-	-	-	-	0.0050	-	0.0051	-	0.0215	-
σ_{01}	-	-	-	-	-	-	-	-	-0.0541	-
-2LL	-2054.0		-4914.1		-4782.1		-5004.2		-5111.1	
AIC	-2052.0		-4910.1		-4778.1		-4998.2		-5103.1	
σ^2	0.02365		0.00516		0.00551		0.00461		0.00429	

Table 3—Model validation summary statistics when using varying numbers of trees randomly selected from the model validation dataset to calibrate equation [2]. The Fixed-Effects model is equation [1]. A total of 39 plot and age combinations were used. To eliminate the dependence of the model validation statistics on one random sample, for each calibration sample size (n_c) and plot and age combination, trees were randomly selected 10 times

	Fixed-Effects model			Mixed-Effects model		
n_c	Bias (m)	Variance	MSE	Bias (m)	Variance	MSE
0	-1.1164	0.6558	2.3421	-	-	-
1	-1.0693	0.6961	2.2488	-0.1334	0.2565	0.4869
2	-1.0245	0.7290	2.1531	-0.0689	0.2408	0.3602
3	-0.9787	0.7599	2.0591	-0.0495	0.2301	0.3012
5	-0.8862	0.8010	1.8688	-0.0324	0.2084	0.2483
10	-0.6588	0.8069	1.3994	-0.0193	0.1620	0.1804

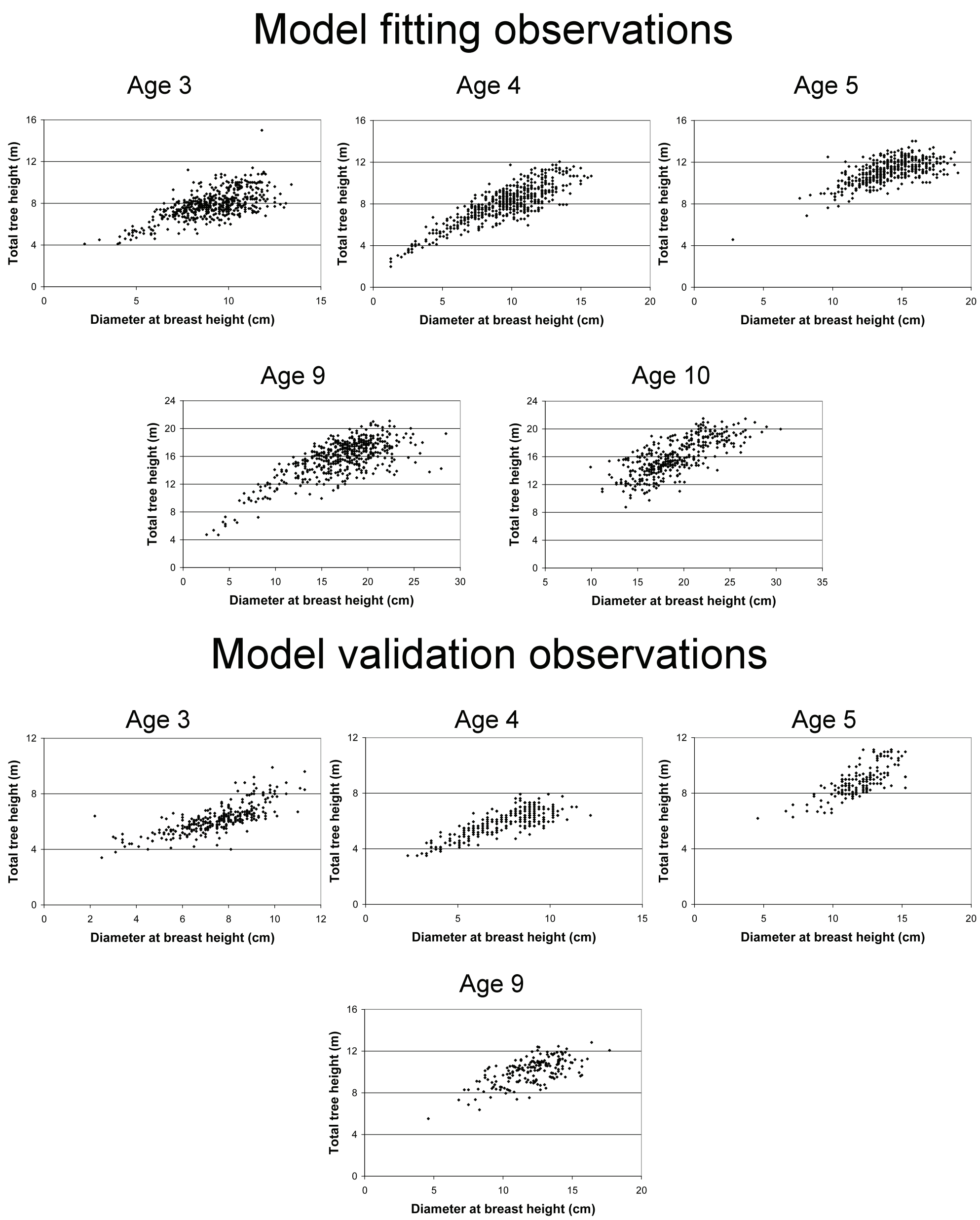

Figure 1—The top figure depicts the height-diameter relationship by measurement age for the model fitting dataset (n = 496 for age 3, n = 504 for age 4, n = 420 for age 5, n = 492 for age 9, n = 371 for age 10). The bottom figure depicts the height-diameter relationship by measurement age for the model validation dataset (n = 304 for age 3, n = 246 for age 4, n = 160 for age 5, n = 182 for age 9).

INCREASED UNIFORMITY BY PLANTING CLONES WILL LIKELY HAVE A MINIMAL EFFECT ON INVENTORY COSTS

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ABSTRACT

When conducting inventories, reducing variability among tree diameters, heights, and ultimately volumes or biomass, can reduce the number of points/plots needed to obtain a desired level of precision. We present a simple analysis examining the potential reduction in discounted inventory costs when stand variability is decreased (via improved genetics and intensive management on a uniform soil). Sampling time might be reduced if the coefficient of variation in point volume/biomass estimates is reduced to 10% (versus 25% for genetically diverse stands). However, if this level of variability could be achieved (and depending on the desired probability and allowable percent error) discounted costs might be only reduced by $0.50 per acre for a single inventory (when a 15% error is used). When four inventories are made across a rotation (at ages 10 to 25 years) with a goal of 5% error, total discounted savings might be $20 to $30 per acre. On some very uniform sites, stands with low variability may only need one inventory plot per 25 acres. Although clones (in theory) might reduce variability, microsite conditions within a plantation will always produce variability among plots/points.

INTRODUCTION

In the early 1960's, southeastern foresters recognized that genetic modification of trees could increase yields. After years of breeding selected trees based on morphological traits, we are now able to plant third generation genetically-improved pine seedlings (Wright and Dougherty 2006) as well as mass control pollinated (MCP) seedlings. Recent technologies have been developed that eliminate variability in genotype among trees in a stand (e.g. somatic embryogenesis and varietal forestry). It is generally thought that stand uniformity can be increased by eliminating genetic variability especially when reducing variation in competing weeds (by using intensive site preparation, herbaceous weed control and perhaps release treatments). Uniformity might also be maintained by fertilization, control of pests such as Nantucket pine tip moth, *Rhyacionia frustrana* (Comstrock), and regular thinnings. When stands are uniform, fewer inventory plots will be required.

The cost of forest inventories is justified because the data help managers make decisions about future management practices. Data from inventories are used by foresters to make management prescriptions, develop silvicultural systems, and to write management plans. Rather than using rules-of-thumb to determine the number of plots to measure, foresters will often vary the sample size or number of plots to achieve a desired level of precision for a specified degree of confidence. This approach is used to better ensure that not too much time is wasted taking more plots than is required to achieve the inventory objectives. The objective of this paper is to provide a simple example of how much inventory costs of loblolly pine plantations might be reduced if stand uniformity could be greatly increased.

METHODS

When sampling stands using horizontal-angle points, the population can be assumed infinite (Shiver and Borders 1996, pg. 106) and thus the following equation can be used to estimate a required sample size:

$$n = (zCV / E)**2 \qquad [1]$$

Where:
n -- sample size required to obtain a desired level of precision for a specified degree of confidence,
z -- z-value corresponding to a desired degree of confidence,
CV-- percent coefficient of variation, or estimate of the amount of inherent variability among points within the population, and
E -- percent allowable error.

The CV must be estimated using either a pilot study (a reduced number of points to estimate the population CV prior to conducting the inventory) or the CV can be obtained from previous inventories of similar populations. For sample size estimation purposes, since the sample CV is assumed to equal the true CV (or the population CV), a z-value is used rather than a t-value.

To evaluate the economics, the following factors were assumed:

1. It costs $11.00 per point to obtain an estimate of tons per acre using a 10 BAF at ages 10 and 15, while at ages 20 and 25 it costs $14.00 per point. Heights and diameters will be measured on all sample trees.

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2. Cruises are conducted at ages 10, 15, 20, and 25 years.

3. Two CVs were used, a CV of 25% which is associated with open pollinated genotypes and a lower intensity of management and a CV of 10% which is assumed to be associated with a mono-clonal plantation on a uniform site with a higher intensity of management. Based on preliminary analyses, intensive management can reduce point sampling CVs to near 10%.

4. The allowable percent error was varied; (5%, 15%, 25%) and probability level was varied from 90% to 95%. A 6% interest rate was assumed.

RESULTS AND DISCUSSION

There has been much debate about the economic feasibility of establishing “clonal” or “varietal” plantations because of increased costs associated with the planting stock and the need for conducting intensive silviculture to achieve additive economic gains (Stanturf 2003). As of January 2010, the cost per thousand of 1.5 generation stock bareroot loblolly and slash pine seedlings was around $50 while those of bareroot mass control pollinated seedlings were around $140 and container grown clones were around $320 to $450. With rising fuel costs, fertilizer costs have increased, and intensive site preparation and conducting several herbaceous or woody vegetation control treatments can be expensive (Barlow et al. 2009). Thus, a large amount of money is invested at the beginning of the rotation that must be carried around 10 to 30 years depending on site characteristics, management preferences, and local markets.

A cost reduction that may not be generally recognized is the reduction in inventory costs resulting from stands with greater tree uniformity. When using either plots or points to sample stands, the sampling unit is the plot or point and thus the CV corresponds to the amount of variability among plots or point estimates of attributes (e.g. volume or tons), not the amount of variability among an attribute of individual trees. If greater tree uniformity is obtained from planting superior genetic stock and conducting intensive forest management, then the CV in equation [1] will be smaller resulting in a reduction of the number of required plots or points.

As the percent error decreases but the level of probability increases establishing uniform plantations will increasingly reduce the relative sampling costs across a rotation (Table 1). Assuming a 5 percent error is considered allowable at a 90% probability level, a savings of $1,046 per 50 acres might be obtained ($1248-$202; or roughly a $21 per acre savings). In contrast, a $30 per acre savings ([$1781-$294]/50 acres) might result when a 95% probability level is desired.

Of course the sample size equations are merely guidelines. For instance, for the more variable stand with a 5 percent error at a 95% probability level, the estimated sample size is 97 points (about 2 plots per acre). In a 50 acre stand, some foresters might only use one inventory plot per acre. Some prefer general rules of thumb (such as one point per acre) to taking the time to calculate an estimate of plots required. However, in cases where stands and sites are uniform, the one-per-acre rule would likely require a greater amount of time sampling than needed. Foresters need to realize their ability to reduce sample sizes because of greater uniformity, thus decreasing inventory costs. In some small sites, the coefficient of uniformity for tree diameters in a mono-clonal stand might be less than 13% (Sharma et al. 2008).

In this paper, we are not necessarily promoting the goal of increasing stand uniformity. In fact, in cases where the price-size curve (Caufield et al 1992) for logs has a positive slope, increasing uniformity might decrease stand value (Nance and Bey 1979). Although stand value would be increased when seven diameter classes (5” to 11”) were reduced to one DBH class (“8”), it would be decreased if seven diameter classes (7” to 13”) were reduced to one “10” class – assuming 11” and greater are sawtimber trees, trees from 8” to 11” are chip-n-saw trees, and trees smaller than 8” are pulpwood trees. The lower production of sawlogs might reduce total stand value by $100 per acre or more. This could outweigh any reduction in inventory costs.

Assuming the planting of clonal stock and intensive management would reduce the amount of variability in a stand (Sharma et al. 2008), the related reductions in inventory costs appear to be minimal. It seems likely that any savings in inventory costs might not be passed on to the landowner (except for when the landowner is conducting their own inventory). Although clonal stock will likely reduce variability among points/plots, microsite conditions within plantations will always produce some amount of variability among plots/points.

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Table 1—Required sample size (i.e. number of plots/points required - calculated using equation [1]), inventory costs for 50 uniform acres ($ per 50 acres), and net present value (NPV) per 50 acres estimates when the coefficient of variation (CV) is reduced from 25% to 10% (due to practices that increase stand uniformity). Each sampling point at ages 10 and 15 years is assumed to cost $11 while at ages 20 and 25 years each sampling point is assumed to cost $14. A 6% interest rate was used in calculating NPV. The numbers 5, 15, and 25 correspond to the allowable percent errors

90% probability

Age	Management Intensity	Sample Size 5%	15%	25%	Inventory cost 5%	15%	25%	NPV per 50 acres 5%	15%	25%
10	Less (CV = 25%)	68	8	3	$748	$88	$33	$417.68	$49.14	$18.43
15		68	8	3	$748	$88	$33	$312.11	$36.72	$13.77
20		68	8	3	$952	$112	$42	$296.84	$34.92	$13.10
25		68	8	3	$952	$112	$42	$221.81	$26.10	$9.79
Total								$1248.45	$146.88	$55.08

Age	Management Intensity	Sample Size 5%	15%	25%	Inventory cost 5%	15%	25%	NPV per 50 acres 5%	15%	25%
10	More (CV = 10%)	11	2	1	$121	$22	$11	$67.57	$12.28	$6.14
15		11	2	1	$121	$22	$11	$50.49	$9.18	$4.59
20		11	2	1	$154	$28	$14	$48.02	$8.73	$4.37
25		11	2	1	$154	$28	$14	$35.88	$6.52	$3.26
Total								$201.95	$36.72	$18.36

95% probability

Age	Management Intensity	Sample Size 5%	15%	25%	Inventory cost 5%	15%	25%	NPV per 50 acres 5%	15%	25%
10	Less (CV = 25%)	97	11	4	$1067	$121	$44	$595.81	$67.57	$24.57
15		97	11	4	$1067	$121	$44	$445.22	$50.49	$18.36
20		97	11	4	$1358	$154	$56	$423.43	$48.02	$17.46
25		97	11	4	$1358	$154	$56	$316.41	$35.88	$13.05
Total								$1780.87	$201.95	$73.44

Age	Management Intensity	Sample Size 5%	15%	25%	Inventory cost 5%	15%	25%	NPV per 50 acres 5%	15%	25%
10	More (CV = 10%)	16	2	1	$176	$22	$11	$98.28	$12.28	$6.14
15		16	2	1	$176	$22	$11	$73.44	$9.18	$4.59
20		16	2	1	$224	$28	$14	$69.84	$8.73	$4.37
25		16	2	1	$224	$28	$14	$52.19	$6.52	$3.26
Total								$293.75	$36.72	$18.36

SILVICULTURE OF VARIETAL LOBLOLLY PINE PLANTATIONS: SECOND YEAR IMPACTS OF SPACING AND SILVICULTURAL TREATMENTS ON VARIETIES WITH DIFFERING CROWN IDEOTYPES

Lance A. Vickers, Thomas R. Fox, Jose L. Stape, and Timothy J. Albaugh

ABSTRACT

A long-term study has been established to address the following objectives: 1) Evaluate the crown ideotype approach to clonal testing in loblolly pine; 2) Determine impacts of increasing genetic uniformity on growth and uniformity of loblolly pine plantations; 3) Compare growth response, carbon allocation patterns (above and below ground), and ecophysiological processes of loblolly pine clones under different management intensities and planting densities; and 4) Compare the effects of different climatic and edaphic conditions and silvicultural regimes on growth and ecophysiology of loblolly pine varieties. This study has two North American installations in the southeastern United States (Virginia Piedmont, North Carolina Coastal Plain) and one South American installation in Brazil (Santa Catarina State). A split-split plot design was used in this study with two levels of silviculture (operational, intense), as the main plot treatment, six genotype entries (1 open pollinated, 1 control pollinated, 4 clonal) as the split-plot treatment, and three planting densities (250, 500, and 750 trees per acre) as the split-split plot treatment. The clones were a range of crown ideotypes, with two moderately wide crown ideoptypes and two broad crown ideotypes. Second year growth responses are presented.

INTRODUCTION

Despite the large gains in productivity resulting from previous forestry research, growth rates in many loblolly pine (*Pinus taeda* L.) plantations in the United States remain well below what is possible (Amateis et al. 2000, Borders and Bailey 2001, Jokela et al. 2000). As silvicultural inputs become more intensive and tree improvement efforts continue to produce more intensively selected and less genetically heterogeneous full-sib families or clones, there is a greater need to understand how elite genotypes respond to silvicultural manipulations (Li et al. 1991). For this reason a long-term study has been established to address the following objectives: 1) Evaluate the crown ideotype approach to clonal testing in loblolly pine; 2) Determine impacts of increasing genetic uniformity on growth and uniformity of loblolly pine plantations; 3) Compare growth response, carbon allocation patterns (above and below ground), and ecophysiological processes of loblolly pine clones under different management intensities and planting densities; and 4) Compare the effects of different climatic and edaphic conditions and silvicultural regimes on growth and ecophysiology of loblolly pine varieties.

METHODS

STUDY ESTABLISHMENT AND LOCATION

This study has two North American installations that were established within the United States (Virginia Piedmont, North Carolina Coastal Plain) in 2009 and one South American installation was established within Brazil (Santa Catarina State) in 2011. These three locations were selected to form a gradient of productivity within the planted range of loblolly pine. The Virginia Piedmont site was chosen to represent the lower end of loblolly pine productivity due to the increased intensity and duration of winter. The soil at this installation is mapped as a well drained Fairview series (Fine, kaolinitic, mesic Typic Kanhapludults). The North Carolina Coastal Plain site was selected to be representative of more typical conditions for loblolly pine planted in the southern United States. The soil series at this installation is mapped as a somewhat poorly to poorly drained Rains series (Fine-loamy, siliceous, semiactive, thermic Typic Paleaquults). The Brazil site was selected to represent the upper end of productivity for loblolly pine in the world (Cubbage et al. 2007). Since the Brazil site has not yet completed a growing season, the remainder of this report is restricted to the two North American installations.

STUDY DESIGN

A split-split plot designed was used in this study (Fig. 1). The main plot treatment was two levels of silviculture (operational, intense), the split-plot treatment was six different genotype entries (1 open pollinated, 1 control pollinated, 4 clonal), and the split-split plot treatments was three different planting densities (250, 500, 750 trees

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per acre). Operational silviculture consisted of practices commonly used by many landowners over a typical rotation for loblolly pine including strategic weed control and nutrient amendments. Intensive silviculture consisted of practices intended to approach the maximum growth rate of loblolly pine for existing soil and climate conditions at each installation. These intense practices included attempts at complete and sustained weed control as well as the avoidance of nutrient limitations.

Six genetic entries (varieties) provided by Arborgen were used as the split-plot treatments. These included one open-pollinated family (op), one control-pollinated family (mcp), and 4 different clones (c1, c2, c3, c4). Each entry is from Atlantic coastal plain sources. The clones included a range of crown ideotypes: c1 and c2 were moderately wide crown ideotypes; c3 and c4 were broad crowns ideotypes. The open-pollinated and control-pollinated seedlings were bare-root stock. All clonal material was containerized.

Three different initial planting densities served as the split-split plot treatments (250, 500, and 750 trees per acre). The 250 trees per acre planting density was designed as a sawtimber regime where diameter growth is maximized. The 500 trees per acre planting density was designed as a mixed product regime including both pulp and sawtimber production. The 750 trees per acre planting density was designed as a pulpwood or biomass regime. The spacing between planting rows in all three densities was 12 feet. To achieve the desired densities, the tree spacing on each planting row was 14.5 feet for the 250 trees per acre planting density, 7.26 feet for the 500 trees per acre planting density, and 4.84 feet for the 750 trees per acre planting density. Planting spaces were measured and marked with pin prior to planting. Seedlings were hand-planted at both North American installations during February-March 2009. Following planting, the location of all trees at each installation was georeferenced to sub-meter accuracy.

The study was replicated four times at the Virginia Piedmont installation, and three times at the North Carolina Coastal Plain installation. Each split-split plot (planting density) was intended to include 81 trees in a 9 row by 9 planting space configuration, permitting a 5 by 5 (25 tree) internal measurement plot with two rows available for destructive sampling and an additional two rows serving as a buffer from adjacent treatments. Due to area constraints this was not possible for all replications at each installation. When plot size was restricted by area, each split-split plot included 63 trees in a 7 row by 9 planting space configuration. At the Virginia Piedmont installation three replications were established using the 81 tree design, and one replication established using the 63 tree design. All replications at the North Carolina Coastal Plain installation were established using the 63 tree design. Large buffers of several planting rows were established between the main plots (silviculture intensity).

FIRST YEAR TREATMENTS

The silviculture applied within each treatment level (operational and intense) was similar, but due to varying site conditions, particularly drainage, there were some differences. The Virginia Piedmont installation was chemically site prepared using an aerial application of 4 quarts of Accord XRT II + 4 quarts of Milestone VM Plus + 20 ounces of Chopper with 20 ounces of DLZ oil per acre. A broadcast burn was completed following the chemical site preparation. Banded herbaceous weed control was applied following planting in the operational silviculture treatment; broadcast weed control was applied in the intense silviculture treatment. The North Carolina Coastal Plain installation was chemically site prepared with a ground application of 32 ounces of Chopper + 5 quarts of Krenite + 21 ounces of Garlon XRT with 32 ounces of methylated seed oil per acre. The site was V-blade bedded with 12 feet between bed centers using a Savannah bedder. Banded herbaceous weed control was applied following planting in the operational silviculture treatment; broadcast weed control was applied in the intense silviculture treatment.

SECOND YEAR TREATMENTS

There was considerable mortality on many plots at the Virginia Piedmont installation following the first growing season. Given that initial density is a treatment in this study, mortality within the future internal measurement plots was replanted. Greenhouse reserves of extra seedlings from the initial establishment planting were planted as available, but were limited in number. Virginia state nursery bareroot seedlings were used to replant remaining mortality.

Following the first growing season a second broadcast herbaceous weed control was applied on the intense silviculture plots at both locations using 4 ounces of Arsenal AC + 2 ounces of Oust XP in 10 gallons of water per acre. At the Virginia Piedmont location 0.25 ounces per acre of Escort was added to control blackberry. A fertilization treatment of 100 pounds nitrogen + 10 pounds of phosphorous per acre in the form of Arborite coated urea fertilizer (39-9-0) was applied by hand to the intense silviculture plots following the first growing season. This was applied to individual living trees at a rate of 0.5 pounds per tree due to the varying planting densities.

MEASUREMENTS

Measurements were taken in January following the first and second growing season at each location. Following the first growing season the total height of each tree was measured. Evidence of disease and damage was recorded for each tree. At both locations the area immediately surrounding each tree was given a categorical evaluation of site prep quality, soil drainage, and weed control efficacy. At the coastal plain location bed height was measured at each tree. Following the second growing season measurements of each tree included total height and height to live crown. Each tree was again inspected for disease and damage. The diameter at breast height and crown width was measured on a subset of 25 trees in each split-split plot following the second growing season. Foliage samples were collected at the time of measurement each year.

RESULTS AND DISCUSSION

CROWN WIDTH

Crown width was measured on a subset of 25 trees within each measurement plot following the second growing season. At the North Carolina Coastal Plain installation most varieties had an average crown width near 3.5 feet in the intensive plots and around 2.5 feet in the operational plots (Table 1.). At the time of measurement there was not a significant silviculture effect on crown width, but there were differences between varieties. All of the clones were significantly different from the open pollinated variety, but only clone 4 was different from the control pollinated variety. There was a significant difference in crown width between clone 3 and clone 4, both broad crown ideotypes. That difference is most notable in the operational plots. There were differences by density but no discernable trend at the time of measurement. There was no significant difference in crown width between the North Carolina Coastal Plain and Virginia Piedmont installations. However, there was a significant silviculture effect at the Virginia Piedmont installation. Crown widths in the intense plots at the Virginia Piedmont averaged at least 3.5 feet for all varieties, but only clone 2 and clone 4 approached that width in the operational plots. There were significant varietal differences: clone 4 was significantly wider than all other varieties except clone 2. All of the clones except clone 1 were significantly wider than the control and open pollinated varieties. The two moderate crown ideotypes, clone 1 and clone 2, were significantly different in crown width. There was no significant density effect overall, but there was an individual difference for clone 2.

STEM VOLUME

After 2 growing seasons about 40 percent of the trees at the North Carolina Coastal Plain installation had a measurable diameter at a height of 4.5 feet (Table 2.). From those measurements stem volume was calculated using the square of diameter at breast height multiplied by the total height (d^2h). The stem volume in the intense plots at the North Carolina Coastal Plain installation averaged 0.4 cubic inches for most varieties except for the open pollinated trees. In the operational plots, stem volume averaged half that of the intense plots, but there was no significant silviculture effect found. This can be likely be attributed, in part, to considerable variation in this metric following only two growing seasons. However, such a degree of variation, even found within the intense plots underscores the early importance of microsite conditions on growth in somewhat poorly to poorly drained soils. There were significant differences by variety in stem volume: clone 2 had significantly more volume than all others except clone 1 and clone 3. The open pollinated variety had significantly less volume than all other varieties except clone 4. There were overall density differences as well, but no discernable trends.

At the Virginia Piedmont installation over 80% of the trees had a measurable diameter at a height of 4.5 feet, but there was no location effect between the Virginia Piedmont and North Carolina Coastal Plain for stem volume. There was a significant silviculture effect on stem volume at the Virginia Piedmont installation. In the intense plots, stem volume averaged about 0.5 cubic inches for the clonal varieties compared to only about 0.3 cubic inches in the operational plots. There were no significant differences amongst the 4 clones in the piedmont, but the 4 clones did have significantly more stem volume than the control pollinated variety which, in turn, had significantly more stem volume than the open pollinated variety. There were significant differences in stem volume attributed to density, but again no clear trends for those density effects at the time of measurement. At both the Virginia Piedmont and North Carolina Coastal Plain installations there were no significant differences in stem volume amongst clones of the same ideotype. As at the North Carolina Coastal Plain installation, there was considerable variation in stem volume at the Virginia Piedmont installation.

CONCLUSIONS

Although two growing seasons is far from an adequate length of time to draw meaningful conclusions from a study designed to address questions that may take a full rotation to fully explore, there are some interesting trends evident early in the life of this study. The impact of increasing genetic uniformity has highlighted the considerable amount of variation in growth that can be expressed early in the life of a stand. This variation is likely largely due to microsite effects. Interestingly, through two growing seasons the performance of the seedlings at Virginia Piedmont installation has exceeded that of the North Carolina Coastal Plain installation. As this study matures this condition is expected to reverse. Subsequent fertilization treatments will likely remedy any innate phosphorous deficiencies, and improved soil aeration from a lowering water table will likely allow the North Carolina Coastal Plain installation to express the greater expected potential growth rates compared to the Virginia Piedmont installation. Following two growing seasons, among clones of the same ideotype performance has been largely consistent. There were no significant differences for tree height, height growth, live crown length, diameter at breast height, or stem volume found amongst clones of the same ideotype; however, there were some significant differences in crown volume and crown width.

This report does not attempt to address the results following two growing seasons in relation to each previously stated study objective. However, it is expected that subsequent work by a team of international collaborators as this study matures will yield meaningful results that address not only longstanding, unanswered biological questions, but also timely issues concerning the future of intensive plantation management.

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Table 1—Mean crown width measured following the second growing season of the study for each variety, initial planting density, silviculture level, and installation location. Crown widths are reported to the nearest tenth of a foot

Variety	North Carolina Coastal Plain						Virginia Piedmont					
	Intense silviculture			Operational silviculture			Intense silviculture			Operational silviculture		
	250 tpa	500 tpa	750 tpa	250 tpa	500 tpa	750 tpa	250 tpa	500 tpa	750 tpa	250 tpa	500 tpa	750 tpa
	feet (std. err.)											
c1	3.6 (0.7)	3.5 (0.8)	3.7 (0.7)	2.7 (0.6)	2.4 (0.5)	2.1 (0.5)	3.4 (0.5)	3.6 (0.5)	3.4 (0.4)	2.9 (0.4)	2.6 (0.4)	2.9 (0.4)
c2	4.0 (0.8)	3.7 (0.9)	3.8 (1.0)	2.5 (0.6)	2.3 (0.7)	2.3 (0.6)	4.3 (0.6)	3.8 (0.7)	3.6 (0.6)	3.3 (0.4)	3.3 (0.4)	3.3 (0.5)
c3	3.3 (0.8)	3.1 (0.8)	3.1 (0.7)	2.2 (0.5)	2.6 (0.6)	2.6 (0.5)	3.6 (0.4)	3.6 (0.5)	3.5 (0.5)	2.8 (0.4)	3.0 (0.4)	3.1 (0.4)
c4	3.3 (0.7)	3.5 (0.7)	3.5 (0.7)	2.6 (0.6)	3.5 (0.7)	3.2 (0.8)	4.3 (0.4)	4.3 (0.3)	4.1 (0.5)	3.6 (0.4)	3.3 (0.3)	3.5 (0.4)
mcp	3.4 (0.8)	3.3 (0.8)	3.3 (0.9)	2.2 (0.5)	2.3 (0.6)	1.9 (0.5)	3.2 (0.5)	2.9 (0.5)	3.1 (0.5)	2.4 (0.4)	2.7 (0.3)	2.6 (0.3)
op	2.4 (0.6)	3.3 (0.7)	2.4 (0.6)	1.9 (0.6)	2.3 (0.5)	1.9 (0.5)	3.2 (0.6)	3.2 (0.6)	3.0 (0.6)	2.6 (0.4)	2.6 (0.4)	2.7 (0.4)

Table 2—Mean stem volume calculated using the d^2h method following the second growing season of the study for each variety, initial planting density, silviculture level, and installation location. Stem volumes are reported to the nearest tenth of a cubic inch

Variety	North Carolina Coastal Plain						Virginia Piedmont					
	Intense silviculture			Operational silviculture			Intense silviculture			Operational silviculture		
	250 tpa	500 tpa	750 tpa	250 tpa	500 tpa	750 tpa	250 tpa	500 tpa	750 tpa	250 tpa	500 tpa	750 tpa
	$inches^3$ (std. err.)											
c1	0.5 (0.3)	0.4 (0.2)	0.4 (0.2)	0.2 (0.1)	0.2 (0.1)	0.1 (0.1)	0.5 (0.2)	0.5 (0.2)	0.5 (0.2)	0.3 (0.1)	0.3 (0.1)	0.3 (0.1)
c2	0.5 (0.3)	0.6 (0.3)	0.6 (0.4)	0.2 (0.2)	0.3 (0.2)	0.2 (0.1)	0.6 (0.3)	0.5 (0.2)	0.5 (0.2)	0.3 (0.1)	0.3 (0.1)	0.3 (0.1)
c3	0.4 (0.2)	0.5 (0.3)	0.3 (0.2)	0.2 (0.1)	0.3 (0.2)	0.3 (0.2)	0.6 (0.2)	0.5 (0.2)	0.6 (0.2)	0.3 (0.1)	0.3 (0.1)	0.3 (0.1)
c4	0.3 (0.1)	0.3 (0.2)	0.3 (0.2)	0.1 (0.1)	0.3 (0.2)	0.2 (0.1)	0.5 (0.2)	0.6 (0.2)	0.5 (0.2)	0.3 (0.1)	0.2 (0.1)	0.2 (0.1)
mcp	0.4 (0.3)	0.4 (0.3)	0.4 (0.3)	0.2 (0.1)	0.2 (0.1)	0.1 (0.0)	0.3 (0.2)	0.3 (0.1)	0.3 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.0)
op	0.1 (0.1)	0.2 (0.1)	0.1 (0.0)	0.2 (0.1)	0.1 (0.1)	0.1 (0.1)	0.2 (0.1)	0.2 (0.1)	0.3 (0.1)	0.1 (0.0)	0.1 (0.1)	0.1 (0.0)

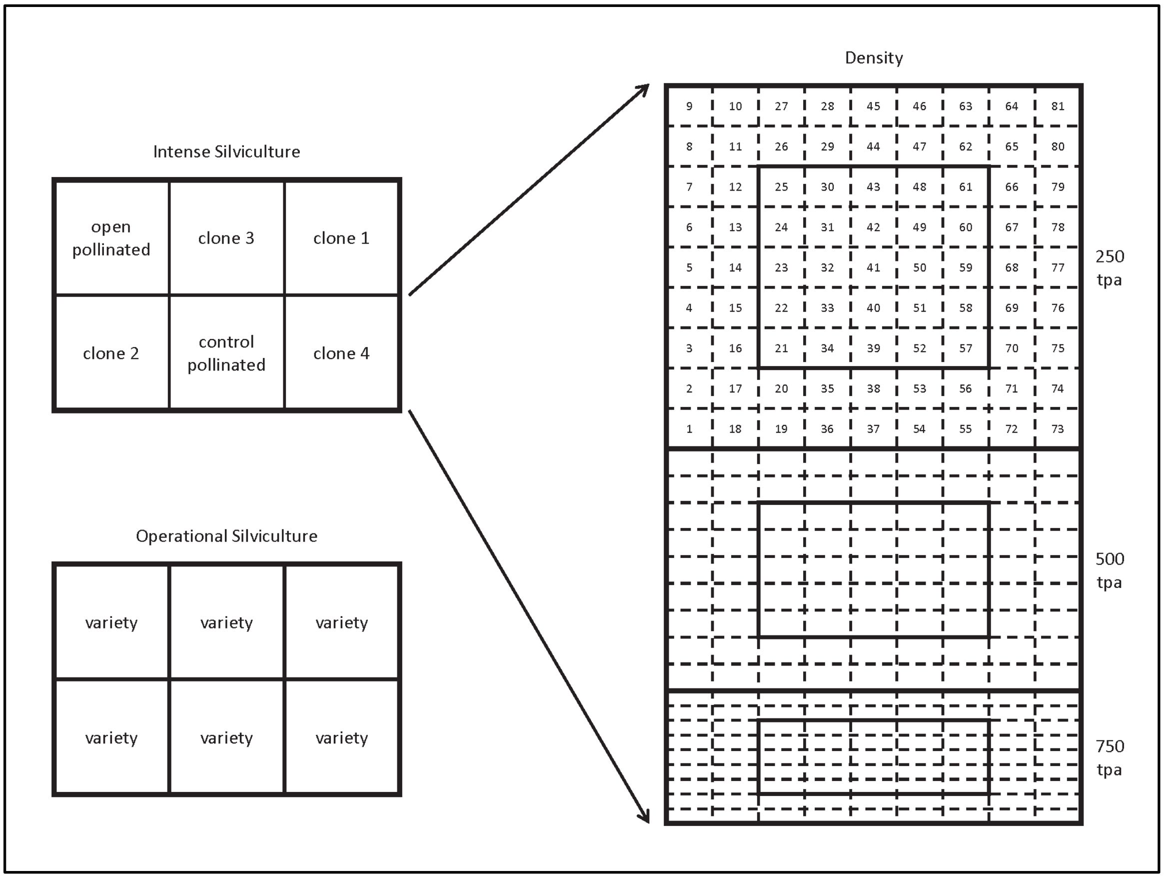

Figure 1—Hypothetical layout of a full replication of the split-split plot study design including two levels of silviculture as the main plot treatments, six different varieties as the split plot treatment, and three initial planting densities as the split-split plot treatment

BEST MANAGEMENT PRACTICES FOR EROSION CONTROL FROM BLADED SKID TRAILS

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ABSTRACT

Sediment from forest operations is primarily associated with roads and skid trails. We evaluated five skid trail closure treatments applied to bladed skid trails in the Virginia Piedmont. Closure treatments were Waterbars, Seed, Mulch, Pine slash, and Hardwood slash. Sediment traps were used to collect monthly sediment samples for one year. The Mulch, Pine slash, and Hardwood slash treatments produced erosion of less than 4 tons/acre/year while the Waterbar only treatment produced over 60 tons/acre/year. Seed was better than Waterbar only, but was not as effective as the other treatments. Other factors that contributed to sediment production included time since installation, frost heaving, and precipitation quantity and intensity. These data indicate that best management practices which favor ground cover by slash, vegetation, or similar treatments should provide adequate erosion control.

INTRODUCTION

Numerous research projects have concluded that forest roads and skid trails produce a disproportionate quantity of sediment as compared to other forest operations (e.g. Reid and Dunne 1984, Swift 1985, Megahan and others 2001, Litschert and MacDonald 2009). Bladed skid trails are commonly used on steep terrain in order to facilitate ground based skidding (Garland 1997). Kochenderfer (1977) found that bladed skid trails can comprise 2-10% of the harvest area, but Jackson and others (2002) found that even greater areas are found in harvests with poor preharvest planning. Due to difficult terrain and the typically minimal standards used to construct such trails, erosion is often a concern (Croke and others 1999, Ziegler and others 2007). Garland (1997) outlined the environmental and economic advantages of preharvest planning of skid trails. Worrell and others (2011) found that bladed skid trails in the Allegheny Plateau region of Virginia produced erosion rates greater than 25 tons/acre/year. These erosion rates are of concern to landowners due to potential losses in productivity and to society because of potential stream sedimentation problems (Aust and Blinn 2004, Anderson and Lockaby 2011). Forestry Best Management Practices (BMPs) used to stabilize bladed skid trails include water control structures, revegetation, and addition of soil cover (Grace and others 1998, Grace 2002, Shepard 2006). The objective of this project was to evaluate the erosion control efficacy of five different bladed skid trail closure BMPs.

METHODS

STUDY SITE AND TREATMENTS

The study was conducted at the Virginia Tech Reynolds Homestead Forestry Research Center near Critz, VA. The site is located in the upper Piedmont Physiographic Province (Fenneman 1938). A 25 acre site was selected and had been clearcut harvested, prescribed burned, and was scheduled for replanting. Soils were Fairview sandy clay loams and sideslopes ranged from 20-30%. We located the centerline for six bladed skid trails of approximately 250 feet in length on 10-15% grades. Each skid trail was constructed with a John Deere 450 bulldozer and waterbars were installed approximately every 50 feet. The water bars provided separation between each 50 foot segment, which provided the experimental unit area. PVC gutters were installed at the base of each skid trail segment and were attached to geotextile sediment traps.

The six trails each had five skid trail closure treatments randomly assigned to the trail, creating 30 experimental units. Treatments were 1) Waterbar with bare soil (Waterbar), 2) Waterbar with fertilizer, lime, and grass seed (Seed), 3) Waterbar with seed and mulch (Mulch), 4) Waterbar and hardwood slash (Hardwood), and 5) Waterbar and pine slash (Pine). For the Seed and Mulch treatments we applied lime (one ton/acre), 10-10-10 fertilizer (200 lbs/acre), and a blend of winter rye, timothy, orchard grass, perennial rye, medium red clover, and annual rye at 50 lbs/acre. Reseeding was conducted until all Seed plots had at least 40% cover.

FIELD METHODS

Geotextile sediment traps (Robichaud and Brown 2002) were weighed monthly with a crane scale mounted on a bulldozer blade. Soil moisture was obtained for each sediment trap so that weights could be corrected for soil moisture. Soil weights were also corrected for bag weights. A subproject evaluated the sediment trapping efficiency of the sediment traps and found that the traps collected 70% of the sediment so final weights were adjusted to reflect total sediment.

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STATISTICAL ANALYSIS

Data were analyzed as a Randomized Complete Block Design with repeated measures (Schabenberger and Pierce 2002). The six skid trails provided the blocks, the trail closure BMPs provided five treatments, and the monthly erosion measurements during a 13 month period served as the repeated measures. Data were analyzed with SAS version 9.2 statistical software (SAS Institute 2008). Treatments were judged to be statistically different at an alpha level of 0.05 and Tukey mean separation tests were used to separate treatment effects.

RESULTS AND DISCUSSION

The five skid trail closure treatments had significantly different rates of erosion (p=0.02) (Table 1). Overall, the Waterbar treatment was the least effective for controlling erosion (61.3 tons/acre/year) and produced erosion rates similar to active construction (Yoho 1980). The Seed treatment, even with relatively low establishment (40-60% cover) reduced erosion by 77.1% as compared to the Waterbar treatment. The two slash treatments (Hardwood and Pine) and the Mulch treatment all had erosion rates that would be considered sustainable for agricultural operations and that reduced erosion by over 93% as compared to the Waterbar treatment. Our results are typically supported by literature from a variety of areas and situations. McGreer (1981) evaluated slash as an erosion control treatment on skid trails in Idaho and had similar results. Grusheky and others (2009) evaluated the use of fiber mats for erosion control in West Virginia and concluded that they provided more immediate and effective erosion control than seed only.

Examination of the treatment effects during each monthly measurement period revealed that the significantly different erosion rates were typically associated with one of three situations (Table 2). Periods having precipitation greater than 2.2 inches resulted in higher erosion rates, particularly during intense precipitation events. For example, May, June, October, and January had precipitation greater than five inches/month and only October did not have significantly greater erosion for at least one of the treatments. October had several events of low intensity, thus it did not have significantly different erosion rates for any treatment. Treatments that did not provide cover immediately after application (both Waterbar and Seed) had higher erosion rates (Table 2). For example, the Waterbar and Seed treatments had the highest rates of erosion during the first two months following treatment because they did not immediately provide cover. Periods of frost heaving during January and February were also associated with higher erosion on the bare soil of the Waterbar treatments. The data indicate that the Waterbar treatment was still eroding significantly faster than the other treatments even at the end of the collection period.

CONCLUSIONS

These data indicate the importance of cover for minimizing erosion from bladed skid trails. Additional considerations are logistics, costs, and additional benefits of the treatments. The Mulch, Pine, and Hardwood treatments all provide effective and immediate erosion control. Both slash treatments potentially have the added benefits of reducing off road vehicle traffic and providing erosion control for several years after application. The Mulch treatment requires less equipment for application, but requires purchase of straw bales. The Mulch treatment could also potentially become less effective if unfavorable condition such as drought killed seeded vegetation after mulch decomposition. The Hardwood and Pine slash treatments could be conducted as part of the harvesting operation with minimal costs. However, the slash would not be available for chipping if this were a whole tree harvest operation. A typical harvest operation of 50 acres could have five acres of bladed skid trails (10% of area). If we assume that we would track slash onto the skid trails to a depth of at least one foot, this would require over 4,000 tons of wood. This slash would have environmental benefits, but the costs of leaving this much slash may become of more concern if additional biomass markets emerge.

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Table 1—Average soil erosion rate (tons/acre/year) for the five skid trail closure methods. Treatments with different letters are statistically different (alpha = 0.05). Each average is based on 78 measurements (6 blocks x 13 months)

Erosion Control Treatment	n	Erosion	Standard Deviation	Erosion Reduction Relative to Waterbar
		(tons/acre/year)		(%)
Waterbar	78	61.3 a	8.1	na
Seed	78	14.0 b	4.1	77.1
Hardwood	78	4.0 bc	0.7	93.5
Pine	78	2.6 cd	0.5	95.8
Mulch	78	1.3 d	0.2	97.9

Table 2—P-values, erosion, and precipitation by closure treatment and collection period. Within a month, treatments with different letters are statistically different (alpha = 0.05). Each treatment x period combination represents the average of six bladed skid trails (blocks)

	Month												
Treatment	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
P-value 0.001	0.001	ns	ns	0.03	ns	ns	ns	0.001	0.001	ns	0.001	0.001	
	(Erosion (tons/acre))												
Waterbar	11.6 a	11.0 a	1.2 a	0.3 a	2.5 a	1.8 a	0.7 a	1.7 a	6.9 a	8.5 a	1.8 a	9.0 a	9.6 a
Seed	4.3 b	4.9 b	0.1 a	0.0 a	0.6 a	1.8 a	0.1 a	0.2 a	1.2 b	0.7 b	0.9 a	1.0 b	1.0 b
Hardwood	1.1 c	0.8 c	0.1 a	0.0 a	0.1 b	0.1 a	0.1 a	0.1 a	1.0 b	1.3 b	0.2 a	0.4 b	0.2 b
Pine	0.7 c	0.4 c	0.0 a	0.0 a	0.1 b	0.1 a	0.1 a	0.1 a	0.5 b	0.5 b	0.1 a	0.2 b	0.1 b
Mulch	0.4 c	0.2 c	0.0 a	0.0 a	0.1 b	0.1 a	0.1 a	0.0 a	0.4 b	0.2 b	0.1 a	0.1 b	0.1 b
	(inches/month)												
Precipitation	6.9	5.3	1.5	1.0	3.4	8.3	4.9	1.9	8.9	3.9	2.2	4.4	3.7

LOW-COST REGENERATION TECHNIQUES FOR MIXED-SPECIES MANAGEMENT – 20 YEARS LATER

Thomas A. Waldrop and Helen H. Mohr

ABSTRACT

Four variations of the fell-and-burn technique, a low-cost regeneration system developed for pine-hardwood mixtures in the Southern Appalachian Mountains, were tested in the Piedmont of South Carolina. All variations successfully improved the commercial value of low-quality hardwood stands by introducing a pine component. After 20 years, pines were almost as numerous as hardwoods and more than twice their height. Summer site preparation burning reduced hardwood size and increased the number of pine volunteers but did not affect pine diameter, height, or volume. This study represents the first definitive measurement of volume resulting from low-cost regeneration techniques in the Southeastern Piedmont. Nonindustrial private forest landowners may find these techniques useful as a means of increasing stand value from a low initial investment.

INTRODUCTION

Improving productivity on nonindustrial private forest (NIPF) lands for both hardwood and softwood timber has been a goal for decades. NIPF landowners control the majority of commercial forest land in the Piedmont region of the Southeast, and much of their land is poorly stocked or unmanaged (Bechtold and Ruark 1988). Conversion of these stands to pine plantations is expensive so many choose to leave their forests unmanaged. Low-cost alternatives for regeneration may attract NIPF landowners to management if these alternatives are cost effective and meet multiple goals.

In the late 1980s and early 1990s, research on low-cost regeneration alternatives focused on pine-hardwood regeneration. The goal was to introduce planted pines among hardwood sprouts to improve stand productivity and value. A number of papers discussed hardwood competition control (McGee 1986, 1989), herbicide application (Zedaker and others 1987, Zedaker and others 1989), mechanical release (Lloyd and others 1991), season of harvest (McMinn 1989), and fire effects (Robichaud and Waldrop 1994, Waldrop 1997). Most of this research concentrated on a low-cost system called the fell-and-burn technique (Abercrombie and Sims 1986) which was developed for the Southern Appalachian Mountains. This technique regenerated hardwood stands to mixtures of pine seedlings and hardwood sprouts at less than half the price of conversion to pine plantations (Phillips and Abercrombie 1987). Briefly, the system involved clearcutting a hardwood stand, felling residual stems in spring when leaves are almost fully developed, summer broadcast burning, and planting pine seedlings at a wide spacing. Each step is designed to control hardwood sprout growth enough to allow pine seedlings to become established and grow. Full descriptions of the system were given by Abercrombie and Sims (1986) and Phillips and Abercrombie (1987).

Results of the first attempt to use the fell-and-burn technique in the Southeastern Piedmont were described by Waldrop and others (1989) 1 year after regeneration and by Waldrop (1997) 6 years after regeneration. That study included four variations of the fell-and-burn technique and compared winter and spring felling and burning with no burning. Results indicated that season of felling had no impact on pine survival or hardwood height after six growing seasons. Burning had no impact on pine survival but did reduce hardwood height. Planted pines overtopped hardwoods in burned plots within 6 years but remained shorter than hardwoods in unburned plots. The fell-and-burn technique was never fully adopted by NIPF landowners in the Piedmont, partially because there were no reliable projections of growth and yield. This paper compares pine and hardwood growth among the four variations of the fell-and-burn technique (Waldrop 1997) after 11 and 20 growing seasons.

METHODS

Study sites are on the Clemson University Experimental Forest in Pickens and Anderson Counties of South Carolina. These sites are similar in aspect, soil, and vegetation. All sites are classified as subxeric to xeric (Jones 1989), occur on south-facing slopes, and soils are Typic Hapludults. Site index at 50 years is 60 feet for pines and 40 feet for oaks. Before harvesting in December 1987 and March 1988, common overstory tree species included white oak (*Quercus alba* L.), southern red oak (*Q. falcata* Michaux.), post oak (*Q. stellata* Wangenh.), black oak (*Q. velutina*

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Lam.), scarlet oak (*Q. coccinea* Muenchh.), chestnut oak (*Q. prinus* L.), hickory (*Carya* sp.), and shortleaf pine (*Pinus echinata* Mill.). Stand basal area included 18.0 square feet per acre of pines and 57.3 ft^2/ac of hardwoods. A total of 87 sample plots was established in 3 replications of 4 treatment combinations in a 2 by 2 factorial arrangement. One treatment factor was season of felling residual stems (winter vs. spring) and the other was burning (burned vs. unburned). Treatment combinations included: spring felling of residuals over 5 feet tall followed by summer broadcast burning (the fell-and-burn technique), winter felling with burning, spring felling with no burning, and winter felling with no burning. Each treatment combination was randomly assigned to one of four treatment areas within each replication. Treatment areas were approximately 2 acres and included 5 to 8 sample plots. Each sample plot was 1 chain x 1 chain square (1/10 acre).

Phillips and Abercrombie (1987) suggested that sprout vigor would be reduced by felling residual hardwood stems in late spring when carbohydrate reserves in root systems are typically low. Winter felling and spring felling were used in this study to test this hypothesis. Chainsaw crews felled all residual stems over 5 ft tall. Winter felling was done during the first week of March 1988; spring felling was done during the third week of June 1988.

Burning occurred on July 7, 1988, 2 days after a rainfall of 0.5 in. Humidity at the time of burning was 5060 percent; wind speed was approximately 5 mph. Moisture content of 10hr timelag fuels (0.251 in. in diameter) was 12% at 10:00 A.M. and 9% to 10% after noon. Backing fires were started along the edges of the units, followed by striphead fires to ignite the interior fuels. Disturbance by skidding and the presence of tree tops affected fuel loading which ranged from none to very heavy. Fuels consisted of large logs, old down material, freshly felled residuals, logging slash, and leaf litter.

Improved loblolly pine seedlings were hand planted by contract crews in all treatment areas during March 1989. Observations on fell-and-burn areas on the Sumter National Forest in South Carolina indicated that pines outcompete and overtop hardwoods by age 7 to 10 (Waldrop and others 1989). Therefore, in this study, loblolly pines (*P. taeda* L.) were planted at a spacing of 15 x 15 feet (194 per acre) instead of 10 x 10 feet (454 per acre), which was used in the mountains, to reduce costs and to allow favorable conditions for hardwood development.

For this paper, all plots were measured after the 11th (1998) and 20th (2007) growing seasons except those in one replicate which had been lost to southern pine beetles (*Dendroctonus frontalis*) before the 20th year. Measurements included species, height, and diameter at breast height (dbh) of all pines and hardwoods in sample plots. Cubic foot volume was estimated from tables provided by Clark and Souter (1996) for pines and Clark and Schroeder (1985) for hardwoods. Treatment differences were compared by analysis of variance with each variable for all pine and all hardwood species groups. Mean separation was by linear contrast ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Tests of the season of felling residual stems showed no significant differences for all variables including number, dbh, height, and volume of pines and hardwoods after both growing seasons (11 and 20). This pattern was emerging after the 6th growing season (Waldrop 1997) and remained consistent through the next 14 years. Therefore, winter and spring felled plots were combined for additional analyses. Season effects will not be discussed, and comparisons will be made between the burning and no burning treatments only.

The number of pines counted in burned plots was significantly higher than in unburned plots at both measurement years (Table 1). In both treatments and in both measurement years, the number of pines was much higher than the 194 per acre that were planted. Volunteers of loblolly and a few shortleaf pines were noted in earlier years, and many of those trees persisted through the 20th year. Site preparation burning probably helped prepare the seedbed thus allowing higher germination and survival of volunteer pines. By year 11, pines had grown enough that field crews were no longer able to distinguish between volunteer and planted pines, so estimates of survival were not possible. The dbh of pines was significantly higher in burned plots than in unburned plots after year 11, but there was no significant difference in year 20. Mean dbh in burned plots was lower after year 20 than it had been 9 years earlier suggesting that small trees had grown tall enough to measure dbh during that period, thus lowering mean dbh. Pines were too small to estimate volume after the 11th growing season. After the 20th growing season pine volume was 1,408 cubic feet per acre in burned plots and 1,212 cubic feet per acre in unburned plots but the difference was not significant. Managers of the Clemson Experimental Forest estimate that a loblolly pine plantation on those sites would yield 2,000 cubic feet per acre after 20 years.

The number of hardwood stems (all species) was significantly lower in burned plots (1,731 per acre) than in unburned plots (2,586 per acre) in year 11 (Table 2). However, that difference did not persist through year 20. By then, hardwood numbers had thinned to 531 and 601per acre in burned and unburned plots, respectively. Between years 11 and 20, hardwood numbers (Table 2) reduced much more than did pine numbers (Table 1), suggesting that pines may eventually outnumber hardwoods. Hardwoods remained small through the 20-year study period; most were too short to measure dbh after year 11 (Table 2). After 20 growing seasons, hardwood dbh and volume were significantly smaller in burned plots (1.7 in and 99 cubic feet per acre) than in unburned plots (2.2 inches and 176 cubic feet per acre). Waldrop (1997) saw a similar pattern in height growth after 6 growing seasons and suggested that the difference was caused by a shorter growing season after burning in year 1. Sprouts in unburned plots grew for the entire growing season while those in burned plots emerged after site preparation burning in July.

Site preparation burning showed a significant impact on hardwood height throughout the 20-year study (Figure 1). At every sampling period, hardwoods were significantly taller in unburned plots than in burned plots. By the end of the 11th growing season, hardwoods were 11.7 feet tall in burned plots and 16.4 feet tall in unburned plots. After the 20th growing season, the difference in height remained about 5 feet with hardwood mean height in burned plots of 15.1 feet and 20.3 feet in unburned plots. Hardwood height growth between year 11 and year 20 was only about 4 feet, emphasizing the dry conditions of these sites and the dominance of pines during this period. Height growth was almost identical in burned and unburned plots suggesting no long-term site damage from burning.

Pine heights were not significantly different between burned and unburned plots at any time during the study. Previous to the measurements made for this study, pines in burned plots had grown taller than hardwoods but were about the same height as hardwoods in unburned plots (Waldrop 1997). Measurements made after the 11th growing season showed that all pines (planted and volunteer, all species) were significantly taller than hardwoods for the first time during the study. Pines had a mean height of 20.5 feet and were approximately 4 feet taller than hardwoods in unburned plots. As these pines became taller than hardwoods, they began rapid height growth. During the next 9 years, pines more than doubled in height reaching a mean of 48.3 feet tall.

A shift in species dominance occurred during the 20 years of this study. During the first 6 years, sample plots would have been described as hardwood or hardwood-pine because hardwoods were taller than pines and outnumbered pines by a wide margin. Today, these plots would be described as pine or pine-hardwood. Pines are more than twice the height of hardwoods and are almost as numerous, particularly in burned plots. This study shows that loblolly pine is a strong competitor with all hardwood species on xeric and subxeric sites. Even though pines were planted at a low density, the hardwoods grew very slowly and did not become a component of the overstory. A higher planting density of pines may have proven to be a better choice if volume production was a goal.

CONCLUSIONS

This study confirms a previous suggestion from this study that the fell-and-burn technique would be successful on dry Piedmont sites. Pine regeneration was successful among hardwood sprouts regardless of treatment combination. The precise timing of felling residual stems during spring after clearcutting is not necessary because growth of pine and hardwood regeneration was the same after felling during winter or spring. Site preparation burning had a lasting effect on hardwood regeneration with fewer trees and smaller dbh and height. However, these reductions did not affect pine development as pines became the dominant canopy species by year 11 and were more than twice the height of hardwoods by year 20. One advantage of site preparation burning was to increase the number of pine volunteers, although this difference had no impact on pine dbh, height, or volume. This study also confirms an earlier suggestion that little or no site preparation is needed on dry Piedmont sites to establish pine seedlings among hardwood sprouts. The heavy dominance of pines also suggests that the fell-and-burn technique may be successful on sites with better fertility and more moisture where hardwoods would be stronger competitors. This study represents the first definitive measurement of volume resulting from low-cost regeneration techniques in the Southeastern Piedmont. NIPF landowners may find these results to be attractive because the value of these stands was increased after a low initial investment.

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Table 1—Pine (all species) characteristics, 11 and 20 growing seasons after site preparation burning

Variable	Treatment	Year 11	Year 20
Number per ac	Burned	425 b[1]	392 b
	Unburned	336a	293a
DBH (in)	Burned	7.0 b	6.8a
	Unburned	5.5a	7.0a
Volume (ft^3/ac)	Burned	-	1,408a
	Unburned	-	1,212a

[1]Means for each variable followed by the same letter within a column are not significantly different at α=0.05.

Table 2—Hardwood (all species) characteristics, 11 and 20 growing seasons after site preparation burning

Variable	Treatment	Year 11	Year 20
Number per ac	Burned	1,731a[1]	531a
	Unburned	2,586 b	601a
DBH (in)	Burned	-	1.7a
	Unburned	-	2.2 b
Volume (ft^3/ac)	Burned	-	99a
	Unburned	-	176 b

[1]Means for each variable followed by the same letter withina column are not significantly different at α=0.05.

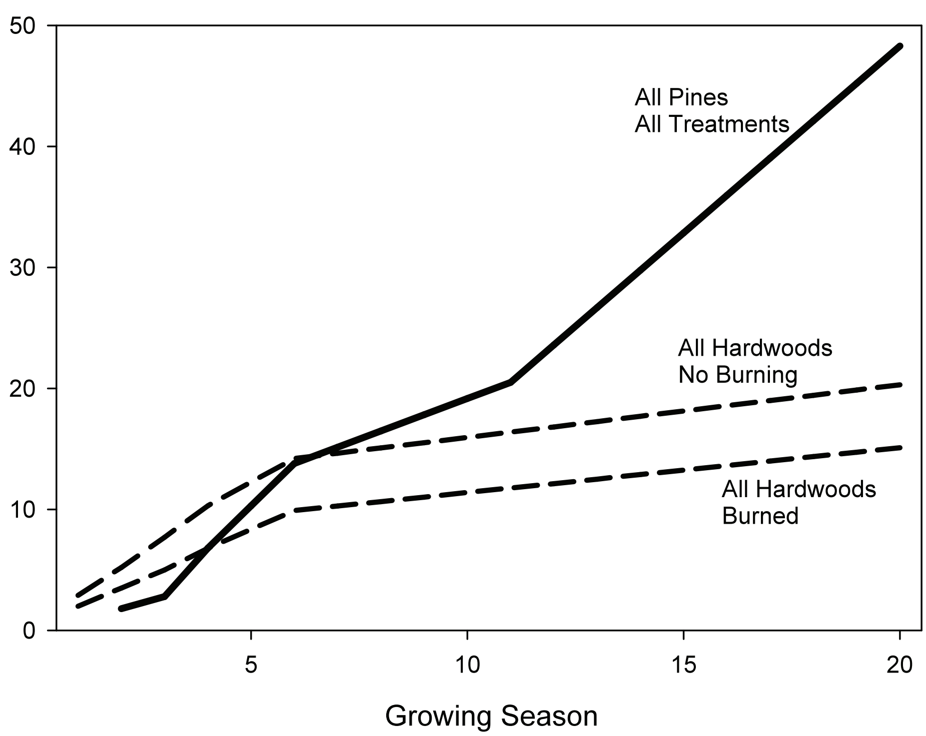

Figure 1—Height of pines (all species, all treatments) and hardwoods (all species) in burned and unburned plots through 20 growing seasons.

SCIENCE DELIVERY IS A TWO-WAY STREET – DEVELOPMENT OF THE CONSORTIUM OF APPALACHIAN FIRE MANAGERS AND SCIENTISTS (CAFMS)

Thomas A. Waldrop, Helen H. Mohr, and Zoe Hoyle

BACKGROUND

The Appalachian region stretches along the Blue Ridge Mountains from Pennsylvania south into Georgia and Alabama. The region's lands shelter some of the greatest biological diversity in the United States. The heavily forested public lands are in great need of science-based fire management after decades of fire suppression. Fire-related research is relatively new to the region; fire managers often have to rely on knowledge and techniques developed for other, less biologically diverse regions. Though two fire learning networks (FLNs) have developed in the region over the last few years and fire research has been established, a disconnect remains between managers and scientists. Outside of the FLNs, there are few if any ways for managers to convey to researchers the questions they have about the conditions they encounter on the ground.

OBJECTIVES

The primary objective of CAFMS is to form a widening network of fire managers and scientists to facilitate knowledge exchange and interaction among managers and scientists. This includes communicating what is known about natural fire and managing with prescribed burning in the Appalachian region, demonstrating techniques and results, and identifying remaining and emerging research questions.

CAFMS DEVELOPMENT AND RESULTS

With funding from the Joint Fire Science Program, a series of three independent meetings of fire managers and scientists was held throughout the Appalachian region in the autumn of 2009. At each meeting, participants were divided into breakout groups and asked how they received information about fire research and what the most effective means of science delivery are. Comments and suggestions were informative but not always predictable. Most participants noted that many fire resources existed, but they were disconnected and difficult to find. Managers across the region were largely unaware of science delivery tools such as Compass, the Fire Science Encyclopedia, and the Tall Timbers Fire Ecology database. They did not like to read scientific articles and particularly disliked metric measurements. Many liked to attend local or regional conferences and used proceedings as a major source of information. Large national or international conferences were perceived as being for researchers only and were not attended by managers. Intimidation of researchers is a problem that can be reduced by face-to-face contact. Lack of rewards for researchers to become involved in science delivery is a problem that needs to be addressed.

The Fire Learning Network is strong in the Eastern United States, especially in the Southern Appalachians. Individual efforts of scientists in the Northern Research Station have greatly improved scientist/manager communications, but there is no structure (i.e., events or organizations) to ensure continued success. One-on-one interaction is the best means of science delivery but the most costly. There is no single best method to provide science delivery because each individual receives and digests information differently.

Dozens of suggestions were given at each meeting for improving science delivery, but some were common among all meetings and breakout groups. Common suggestions are listed below in order of preference. Some of these resources are already available and the others will be provided by CAFMS within the next few years.

"One-stop shopping" Web site, including:

- CAFMS newsletter
- List of fire publications
- Links to Fire Science Encyclopedia and other resources
- Fact sheets

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List-serve for management questions with scientist input

Maps to management or research burns with podcasts and/or geo-caching of information

Summary of management burns in a database with standardized protocols

Widgets

Synthesis of research results for the Appalachian region – possible titles:

Impacts of fire on flora in the Appalachian region

Impacts of fire on fauna in the Appalachian region

Impacts of fire on atmospheric quality in the Appalachian region

Impacts of fire on soil and water in the Appalachian region

Face-to-face networking, including:

Field trips with managers and researchers

Small group meetings

Week-long road trip

MEMBERSHIP

CAFMS is for all land managers and researchers in the region who deal with any aspect of fire. The backbone of the consortium is a partnership among the fire managers involved in the two Appalachian region FLNs and scientists from the U.S. Forest Service Southern and Northern Research Stations and partner universities in the region. Other partners include additional Federal agencies (National Park Service, U.S. Fish and Wildlife Service), nongovernmental organizations (The Nature Conservancy, the National Wild Turkey Federation, and others), and State natural resource and other departments. Becoming a member is as simple as signing up. Visit our website at cafms.org or email Helen Mohr (helen@cafms.org) or Tom Waldrop (tom@cafms.org).

THE 3 Ps OF OAK REGENERATION: PLANNING, PERSISTENCE, AND PATIENCE

Dale R. Weigel, Daniel C. Dey, and John Kabrick

Oak regeneration research in the United States has been ongoing in earnest since the late 1950s. Most research has focused on specific silvicultural practices, regeneration processes, site characteristics, and local limiting factors such as deer browsing or interfering species. Research has evaluated the effects of thinning on regeneration development, methods for oak planting, post-harvest treatments to control competing vegetation, and many other aspects of oak silviculture. All of these have provided solutions to individual problems in oak regeneration for local to regional areas.

However, with all this research we still have difficulty regenerating oak forests. One question remains "How do we insure that oaks are present at desired levels in the next stand following harvest?" We believe the answer is more a managerial problem than biological. The long-term and more universal solution is based on the 3Ps of oak regeneration: planning, persistence, and patience. Because these three steps are not consistently followed nor their importance recognized, oak regeneration often fails.

Research and operational silviculture have been focused on the application of one or several treatments over a short period of years. Oak regeneration is a long-term ecological process requiring long-term planning. Two important questions that must be answered in the planning process are: when do you want to regenerate, and where or which stands do you want to regenerate to oak? It is necessary for oak advanced regeneration (OAR) to be present before harvest for oaks to have a chance of developing in the next stand (Sander and others 1976). OAR is increased through acorn germination. Unfortunately acorn crops are sporadic and unpredictable (Beck 1977, Dey 1995, Godman and Mattson 1976). Planting can supplement OAR in order to decrease the time necessary to develop sufficient regeneration. Planting research has been completed across the entire eastern hardwood region (Dey and Parker 1997, Johnson and others 1986, Spetich and others 2009, Weigel and Johnson 2000).

Persistence in treatments is required both pre-harvest to enable oak regeneration to develop and post-harvest to keep oak regeneration competitive (Carvell and Tryon 1961). Repeated treatments may be required to maintain increased light levels in the lower canopy and shrub layer. These treatments can include herbicide, mechanical, and prescribed fire. Fire has been present on the landscape dating back to at least the 1600s (Guyette and Dey 2006). The use of prescribed fire has been shown to benefit oak regeneration (Brose and others 2006). Post-harvest thinning and crop tree release are necessary to keep oak competitive (Perky and Wilkins 1993, Schuler and Miller 1999).

Because oak is a species physiologically adapted to repeated disturbances over decades, patience in the regeneration process is necessary. Oak's growth habit of favoring early root growth over shoot growth helps oaks persist through repeated disturbances better than competitors (Johnson and others 2009, fig. 10.1). But the limited shoot elongation puts it at a competitive disadvantage with other species in the absence of disturbances such as fire and drought.

By completing these three steps; planning, persistence, and patience, oak regeneration can be accomplished.

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EFFECT OF SIMULATED ICE STORM DAMAGE ON LOBLOLLY PINE TREE AND STAND GROWTH

Rodney E. Will, Thomas Hennessey, Thomas Lynch, Robert Heinemann, Randal Holeman, and Dennis Wilson

Ice damage to loblolly pine plantations is a recurrent problem in eastern Oklahoma and western Arkansas with significant ice events occurring recently in 1995, twice in 2000, and in 2007. Following ice damage, forest owners need to decide to clear-cut and replant, thin or partial cut to rehabilitate, or take no action. A quantitative assessment of tree and stand growth in response to varying levels of ice induced crown damage is currently lacking that would allow informed decisions regarding stand termination or continuance.

In March 2008, six previously undamaged, mid-rotation stands (average age 16) were located that included two each that were unthinned, thinned, and thinned and pruned (pre and post thinning target densities of 450 and 115 trees per acre). Thinning (combination row thinning and thinning from below) and pruning (to approximately 20 feet) were completed less than a year before imposing simulated ice damage. Stands were divided into sub-stands that were randomly assigned to have 0, 25, 50, 75, or 100% percent of trees in the stand damaged. Ice damage for individual trees was simulated by shooting out up to 50% of the top portion of the live crown length. Both before treatment and two growing seasons post-treatment, height, dbh, and crown height were measured (Table 1). Live crown loss due to simulated ice damage was measured for each damaged tree at time of treatment.

To account for differences in initial tree size, data analyses focused on the relative basal area growth of individual trees [(BA 2010 – BA 2008)/BA 2008] and fraction loss of live crown ratio due to treatment [(LCR pre treatment – LCR post treatment) / LCR pre treatment]. We plan to conduct final measurements after six years that will include taper so that we can calculate changes in stem form and volume.

Tree growth decreased with fraction of live crown ratio removed (average R^2 for relationship between relative basal area growth and fraction of live crown ratio removed was 0.17) (Figure 1). Relative basal area growth was greater for thinned stands than for nonthinned stands, but the slope of the relationship between relative basal area and fraction of live crown ratio lost did not differ among stands (Figure 1). The regression relationships predicted a 57, 43, and 31% decrease in relative basal area growth with a 40% reduction in live crown ratio for the nonthinned, thinned, and thinned and pruned stands respectively.

Stand-level relative basal area growth decreased as percentage of trees receiving damage within stands increased. Average relative basal area growth was 0.288, 0.291, 0.272, 0.264, and 0.265 for the 0, 25, 50, 75, and 100% of damage within sub-stands. However, these reductions were less than predicted from the regression equations. Growth of undamaged trees did not increase as the percent of trees damaged within sub-stands increased.

Results indicate that even though basal area growth is reduced by crown damage, the stand-level reduction is not as large as might otherwise be anticipated from moderate and variable damage (ranging from 0 to 50% loss of live crown).

We thank Weyerhaeuser Co. and the personnel at the Kiamichi Tree Farm for providing the stands to work in and their willingness to postpone normal silvicultural operations and to allow us to damage trees. We thank Keith Anderson, and Greg Campbell for assistance with data collection and treatment installation.

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Table 1—Mean diameter at breast height (DBH), height (HT), and live crown ratio (LCR) for the no thin/no prune (NT/NP), thinned (Thin), and thinned and pruned (Thin-Prune) stands for damaged and undamaged trees measured in 2008 and 2010. PreT and PostT refer to the pre- and post-treatment measurements for trees that were damaged. Each mean represents two stands.

		DBH (in)		Ht (ft)			LCR		
		2008	2010	2008	2008	2010	2008	2008	2010
	Tree condition			PreT	PostT		PreT	PostT	
NT/NP	Undamaged	7.28	7.83	42.2	NA	49.4	0.497	NA	0.467
	Damaged	7.26	7.70	42.3	34.4	44.7	0.521	0.410	0.446
Thin	Undamaged	7.65	9.03	38.3	NA	42.5	0.563	NA	0.529
	Damaged	7.44	8.55	38.2	29.8	38.5	0.553	0.427	0.491
Thin-Prune	Undamaged	7.89	9.15	40.5	NA	44.4	0.523	NA	0.512
	Damaged	7.97	9.14	40.7	33.5	41.5	0.522	0.417	0.485

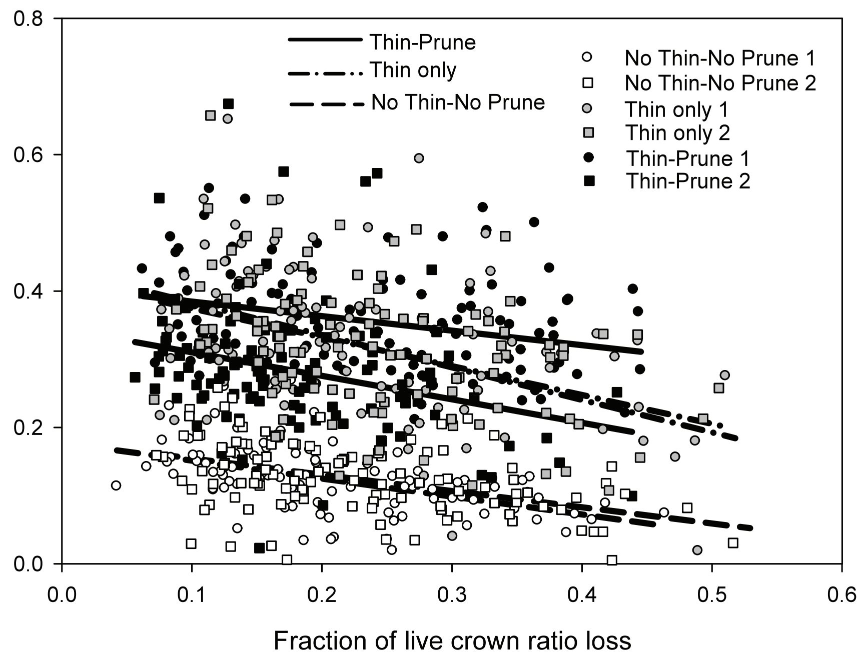

Figure 1—Relationship between relative basal area growth and fraction of live crown ratio removed for damaged trees in nonthinned, thinned, and thinned and pruned stands.

CONTROLLING ROADSIDE NONCROP PINE IN SE OKLAHOMA USING SELECTED GLYPHOSATE FORMULATIONS WITH AND WITHOUT LI 700 AND MILESTONE VM PLUS

J.L. Yeiser, M. Finke, and J. Grogan

ABSTRACT

Noncrop pine control is a major issue confronting managers of openings along roadsides and in clearcuts.Herbicides containing glyphosate are commonly used for pine control. Traditionally, managers have applied 4 quarts product/acre with inconsistent results. LI 700 is a penetrating non-ionic surfactant that contains lecithin. Selected treatments of Makaze, Accord Concentrate and Accord XRT II, some with and without LI 700 or Milestone VM Plus, were tested for control of loblolly (*Pinus taeda* L) and shortleaf (*P. echinata* Mill) pines in southeastern OK. Herbicides were applied at 15 GPA on 10-Jun-08. Plots were evaluated for control on 14-Jun-09. Three glyphosate formulations at 4 quarts product/acre produced dramatically different results exemplifying the state of operations today. All 6-quart and 8-quart formulations provided ≥89 percent control. Treatments with LI 700 exhibited more control than comparable treatments without LI 700. Adding 4 quarts product/acre of Milestone VM Plus to 4 quarts product/acre of Accord XRT II increased control numerically over Accord XRT II alone. Managers seeking to control unwanted pines while using less product, should consider Makaze (6 quarts product/acre). This treatment required less active ingredient to provide statistically similar pine control as higher rates of glyphosate.

INTRODUCTION

Roadsides, like harvested timberlands, provide openings readily colonized by unwanted pines. Reproductively mature pines can seed openings with an excess of 500,000 sound seeds/acre (Cain and Shelton 2001) resulting in significant wilding pine encroachment that reduces access, elevates fire hazards and increases land management costs (George 1900).

While application volume and method are important factors in pine control (Cain 1988), most research has focused on pine species, herbicide timing and rate, and pine size and density. For example, susceptibility to glyphosate varies by species: slash pine (*Pinus elliottii* Englem) >loblolly pine (*P. taeda* L)>shortleaf pine (*P. echinata* Mill) (Voth 1987, Voth 1989, Yeiser 1999). But even with the species variable addressed, pine control with glyphosate remains inconsistent.

Screening trials have focused on three size classes of pines: seed, seedling and sapling. Yet, inconsistency in control exists within these size classes. For example, Yeiser (1999) controlled germinating seeds in a nursery bed with several herbicide treatments. Follow-up field tests of R6447 (Milestone-azafenidin) provided inadequate pine seed control (Yeiser 2001). In rate trials for seedlings <2 feet tall, herbicide tolerance was sufficient in newly planted loblolly pine receiving a herbaceous release treatment of glyphosate (44oz or 1.374 quarts product/acre) to produce little damage. Released seedlings continued to exhibit enhanced survival and growth with growth gains over checks increasing through age four (Voth 1987, 1989). Cain (1988) applied 1.5 quarts product/acre (Roundup) for pine seedling release and experienced significant damage that varied with the application method. Timing of application did not influence the amount of damage. In a site preparation trial for pine control, small (<6", 500,000 per acre) and large (>1 foot, 800 per acre) natural loblolly pine seedlings were readily controlled with 64oz (2 quarts product/acre) of glyphosate (Razor Pro) in Mississippi and Texas (Ezell and Yeiser 2010). Yeiser (1999) targeted the setting of the first flush (Burkhalter 1996) in an April screening trial of 37 products for control of nursery-grown shortleaf pine seedlings. April control of shortleaf seedlings with Accord Concentrate+Timberland 90 (3, 4, 5 quarts+.25% volume/volume) was inadequate with only 28 percent, 6 percent, and 10 percent mortality, respectively. Other stand-alone treatments of Krenite S (4 quarts product/acre) with 41 percent control and Vanquish (4 quarts product/acre) at 85 percent control appeared more promising than Accord Concentrate. In rate trials of sapling pines, three young pine plantations received a woody release treatment of 1.5 or 2 quarts product/acre of glyphosate (Roundup) applied in September and April or May and both rates reduced crop pine height growth (Minogue and Creighton 1987). In Arkansas and Mississippi, site preparation trials of pines 4-8 feet tall achieved similar and intermediate August control from Vanquish+Accord Concentrate+Timberland

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90 (2+4, 2+3 quarts product/ac+.25% Timberland 90 v/v), as compared to alternative herbicide treatments (Yeiser et al. 1999). These results suggest ≤3 quarts product/acre of glyphosate (Roundup and Razor Pro) may damage pines but are inadequate for reliable pine control.

Use of an appropriate surfactant is very important. Gnegy (1987) added surfactant to a September woody-release, loblolly pine trial of 1-quart product/acre or 2 quarts product/acre of glyphosate (Roundup) resulting in nearly total year-2 pine mortality. Voth (1989), in a report of large-plot (5-30acres) helicopter trials, applied 5 quarts of Accord+surfactant and concluded that (1) Cide-Kick II was antagonistic to glyphosate activity, (2) glyphosate+Ortho X-77 (1-3.5% test rates) provided excellent hardwood control (95-95%) that was independent of surfactant rate. Loblolly pine control ranged from 95-100 percent as the Ortho X-77 rate increased from 1-3.5% and (3) MON-0818 provided superior control (95 percent) to Cide-Kick II (80 percent). Cobb (1987) reported that the concentration and type of surfactant used with glyphosate in his large-scale operational trials in Alabama and Tennessee affected long-term control of brush species and the speed at which treated brush browns out following application. Thus, be sure to only use a surfactant that is labeled and recommended for your specific application (over-the-top release, site preparation, etc.). Use of glyphosate without the appropriate surfactant will result in reduced herbicide performance on weeds or damage to crop trees. Always read and follow the precautionary statements and applicable use directions on the label of the surfactant product.

The mixed results from trials of different timings, products, surfactants, and rates may be best illustrated in the single study by Cargill et al. (1987). In a roadside shortleaf pine control study in Oklahoma, Cargill et al. (1987) compared June applied Garlon 4+Tordon K (1+1 gallon product/acre in 50 GPA), Tordon 101 Mixture (3 gallons product/acre in 50 GPA), Graslan 40% P at 4 pounds active ingredient/acre against September-applied Krenite S (3 gallons product/acre in 40 GPA), Roundup (1% and 2% solutions) and Rodeo (.75% and 1.5% + X-77 .5% volume/volume). Pine control with Roundup (1%, 2% solutions) was less than 48 percent, with Rodeo (.75%+.5% X-77) 77 percent and with Rodeo (1.5%+.5% X-77) over 96 percent. All of the alternative, non-glyphosate test treatments in this trial also yielded over 96 percent pine control.

In an effort to understand glyphosate activity as related to plant and weather parameters, D'Anieri (1987) related independent variables such as water stress, phenology, and weather variables to the dependent variable, relative crown volume growth. Linear relationships were not strong (D'Anieri 1987), indicating the complex and unobvious parameter relationships. Furthermore, D'Anieri (1987) showed the absorption of glyphosate in sweetgum (*Liquidambar styraciflua* L), loblolly pine and red maple (*Acer rubrum* L) to be similar, but translocation from the leaf was greater for sweetgum>loblolly pine>red maple. This translocation pattern explains the injury patterns often seen in field applications of glyphosate, that is, sweetgum is killed, loblolly pine has terminal dieback, and red maple is suppressed but seldom killed.

Currently, multiple formulations of glyphosate are available for managers to consider. Some products are fully loaded with surfactant while others are not. Fully loaded means the manufacturer does not recommend the addition of more surfactant to the mixture. Furthermore, formulations also vary by concentration and the parent acid from which the formulation acquires its particular properties. In short, this means that all formulations of glyphosate are not the same. Thus, users should not take a given product (glyphosate) rate, and use it across products and expect the same results.

The results reported above are based on studies of different formulations of glyphosate all from the isopropylamine salt. Glyphosate products commonly in use today are:
(1) Accord Concentrate (53.8% glyphosate, containing 5.4lbs per gallon isopropylamine salt)--needs additional surfactant.
(2) Accord XRT II (50.28% glyphosate, containing 5.4lbs per gallon dimethylamine salt)--no additional surfactant recommended.
(3) Accord XRT (53.6% glyphosate, containing 5.4lbs per gallon isopropylamine salt)--fully loaded with surfactant.
(4) Razor Pro (41% glyphosate, containing 4.0lbs per gallon isopropylamine salt)--no additional surfactant recommended
(5) Makaze (41% glyphosate, containing 4.0lbs per gallon isopropylamine salt)--fully loaded with surfactant and contains lecithin.

Leci-Tech/LI 700--Lecithin occurs naturally in the cell membrane of all cellular organisms. It is a surfactant that contains phospholipids with a natural affinity for water and oil (Shurtleff and Aoyagi 2011). Lecithin can be totally metabolized by humans, so it is well tolerated by humans and non-toxic when ingested (Shurtleff and Aoyagi 2011). Leci-Tech/LI 700 contains lecithin and is a non-ionic penetrating surfactant, which reduces off-target spray drift, and reduces spray water pH (Loveland Products Inc. 2011). It enhances drift management (improves droplet size) and improves droplet deposition (less bounce), adhesion, spreading and penetration.

Milestone VM Plus is a herbicide by Dow AgroSciences containing the active ingredients, aminopyralid and triclopyr (Dow AgroSciences 2010). It is labeled for control of herbaceous broadleaf weeds and woody plants in rangeland, permanent grass pastures, Conservation Reserve Program (CRP), forests, and on non-cropland areas including industrial sites, rights-of-way, (such as roadsides, etc), fencerows, non-irrigation ditch banks, natural areas and grazed areas in and around these sites. Use within sites listed above may include applications to seasonably dry wetlands and around standing water on sites such as deltas and riparian areas. Milestone VM Plus is labeled for pine control.

PROBLEM

Research results from surfactant, rate, product concentration, and timing trials for pine control with glyphosate from the isopropylamine salt are mixed and sometimes conflicting. More confusion will likely occur with the more recent introduction into the market of Accord XRT II and Makaze. An appropriate pine-control treatment will likely not result from an intuitive, linear approach to biological processes using current technology. New adjuvants that: (1) improve the penetration of glyphosate into needles and (2) facilitate glyphosate movement to binding sites in cells are needed. A desirable outcome from future research would be increased pine control with decreased levels of active ingredient.

OBJECTIVE

The objective of this study was to compare selected glyphosate treatments with and without the addition of LI 700 or Milestone VM Plus for the control of unwanted, noncrop pines.

METHODS

The study site was near Broken Bow, OK. Unwanted, noncrop loblolly and shortleaf pines 3-feet to 8-feet tall on roadsides and ditches received a herbicide treatment for control. Test treatments (quarts product/acre) were: (1) Razor Pro-10, (2) Accord XRT II+LI 700-8+1/2%, (3) Accord XRT II-8, (4) Makaze-8, (5) Accord Concentrate+LI 700-6+1/2%, (6) Accord XRT II+LI 700- 6+1/2%, (7) Accord XRT II-6, (8) Makaze-6, (9) Accord Concenrate+LI 700-4.5+1/2%, (10) Accord XRT II+LI 700-4+1/2%, (11) Accord XRT II-4, (12) Accord XRT II+Milestone VM Plus+LI 700-4+4+1/2%, (13) Accord XT II+Milestone VM Plus-4+4, (14) Accord Concentrate+LI 700-3+1/2%, (15) Makaze-4, and (16) a untreated check. These test treatments represent the glyphosate issues before managers today. That is, formulations of glyphosate originate from different salts, come in different concentrations, and are packaged with and without surfactant and other adjuvants such as lecithin.

Treatment plots were 30-feet x 120-feet. The evaluation plot was 10-feet x 100-feet and internal to the treatment plot leaving 10-feet on each end as buffer. Pines more than 8-feet tall were cut and removed from plots. Thirty pines within each plot were systematically and randomly selected for evaluation and tagged for measurement.

Pre-treatment pine total height was recorded 4-Jun-08, herbicide was applied June 10, 2008. All herbicide treatments were applied at 15 gallons/acre using a CO_2 backpack aerial simulator with a single, KLC-9 nozzle. Total pine heights were recorded again, 14-Jun-09 (one year after treatment).

percent control was computed as: ((initial height - evaluation day height)/initial height) x 100. This means that trees taller at the end of the study (check) than when the study initiated have a negative value. Control, the purpose of the study, has a positive value (herbicide treatments). Percent data were transformed with an arcsine square root transformation. Real values are reported here.

Treatments were assigned to plots in a randomized complete block design with block being different locations along the timber access road. Pine height and density (trees/acre) averaged: block 1=4.5-feet, mean=4,356 (range=2,178-7,296) trees/ac, block 2=4.8-feet, average=3,049 (range=1,220-4,574) trees/acre and block 3=5.2-feet, mean=3,477 (range=1,684-5,227) trees/acre.

Data were analyzed using PROC GLM and means separated according to Duncan's New Multiple Range test (SAS Publishing 2008). Three analyses were performed. One analysis was conducted on all treatments in the study. For the second analysis, glyphosates were grouped according to similar amounts of active ingredient. These groups are: 2.0-2.5, 3.0-3.3 and 4.0 quarts product/ac. Percent control was averaged for these groups with mean active ingredient becoming 1.6, 2.2, 3.1, and 4.0 quarts glyphosate/ac. A third analysis was performed on pairs of treatments, each with a level of glyphosate with and without LI 700.

RESULTS

COMPARISONS BASED ON PRODUCT VOLUME

When all treatments were compared, herbicides reduced pine height from 37 percent to 99 percent while check pines increased in height almost 60 percent (Table 1). The high rate of Razor Pros (10 quarts) provided intermediate control of pines. Results indicated 12 treatments with and without LI 700 provided statistically similar and best pine control ranging from 76 percent to 99 percent. Glyphosate rates ranged from a low of 4 quarts product/acre to a high of 8 quarts product/acre with higher rates providing more control than lower rates. All treatments containing LI 700 provided more numeric control than the comparable treatment without LI 700.

When we examine control based on product volume, the 4 and 4.5 quarts product/acre treatments containing only glyphosate, Accord Concentrate+LI 700, Accord XRT II+LI 700, Accord XRT II and Makaze, provided 60 percent, 89 percent, 81 percent and 37 percent pine control, respectively. This is widest range and the most variable control of the four glyphosate-groups (Table 1). Accord Concentrate (4.5 quarts/acre product) and Makaze (4 quarts/acre product) provided some of the lowest pine control. The dimethylamine salt in Accord Concentrate II (4 quarts product/acre with and without LI 700) produced 81 percent and 89 percent control, respectively, and increased pine control over the other 4 and 4.5 quarts product/acre treatments. Adding Milestone VM Plus to 4 quarts product/acre glyphosate also numerically increased pine control over the addition of LI 700.

COMPARISONS BASED ON LEVEL OF GLYPHOSATE

The comparison of glyphosate rates and treatments with and without LI 700 is more appropriate when separated into groups based on the amount of active ingredient, glyphosate, and the presence and absence of LI 700 (Table 1). Glyphosate groups averaged 94.2 percent, 92.3 percent, 80.3 percent and 39.4 percent pine control for 4.0, 3.1, 2.2 and 1.6 quarts glyphosate/ac, respectively. Significantly less control resulted from 1.6 quarts glyphosate/acre than other treatments with all other treatments being statistically similar. No differences were detected among treatments within each of the four glyphosate-groups.

DISCUSSION

The high rate of Razor Pro (10 quarts product/acre) is a research treatment (exceeds the maximum labeled rate) (Table 1) and is neither recommended nor available for forest operations. Like that of other high rates of Razor Pro (12, 14 quarts/acre) tested and not reported here, all provided intermediate control with lower glyphosate rates achieving higher control. These results suggest: 10-14 quarts product/acre of glyphosate may exceed the biological limit of pine, screening trials are currently testing near the biological limit, and a new technology is needed that facilitates glyphosate cuticle penetration and cellular movement to binding sites for glyphosate inhibition of amino acids.

Managers prefer a low rate that provides comparable control as a high rate. But, glyphosates vary in concentration, thus a quart of one product may contain more or less glyphosate than a quart of a competitor’s product. Therefore, it is important for managers to compare glyphosate formulations based on the amount of active ingredient and not the volume of the container. For example, 4 quarts of Makaze and 3 quarts of Accord Concentrated contain 1.64 and 1.61 quarts of glyphosate, respectively. This illustrates the differences in glyphosate based on a comparison of volume and active ingredient. This is important because, as the rate of glyphosate increases, pine control increases, that is, 39.4 percent, 80.3 percent, 91.6 percent, and 96.7 percent, pine control resulted from 1.6, 2.2, 3.1, and 4 quarts/acre of glyphosate, respectively. Based on concentration, Makaze (8 quarts product/acre), Accord Concentrate (6 quarts product/acre), and Accord XRT II (6 quarts product/acre), have approximately the same amount of glyphosate and provided comparable pine control. Likewise, Makaze (6 quarts product/acre), Accord Concentrate (4.5 quarts product/acre), and Accord XRT II (4 quarts product/acre) have similar amounts of glyphosate and provided similar pine control with the exception of Accord Concentrate (4.5 quarts product/acre) that provided less control than comparable glyphosate treatments. The average pine control for 2.2, 3.1, and 4 quarts glyphosate/acre were similar. However, years of experience have demonstrated the inconsistent performance of 2.2 quarts of glyphosate, thus favoring the selection of 3.1 quarts (commonly 6 quarts of product for many formulations). The next level higher than 2.2 quarts is 3.1 quarts glyphosate/acre with Makaze 6 quarts product/acre being the best glyphosate (numeric) performer of the 2.2 group. This is an opportunity for users of 6 quarts product/acre to achieve the same control as the users of 8 quarts product/acre but with less active ingredient.

Adding LI 700 to glyphosate mixtures consistently increased numerical pine control for comparisons with the fully loaded Accord XRT II (4, 6, 8 quarts/acre). Selecting 4 quarts product as the base level, then adding Milestone VM Plus (4 quarts product/acre) to Accord XRT II (4 quarts product/acre) numerically increased control from 80.8 percent to 93.0 percent and introduced 0.65-quart aminopyralid/acre and 0.09 quarts triclopyr/acre into the environment. Adding LI 700 to the Accord XRT II+Milestone VM Plus mixture further increased control to 94.8 percent. Alternatively, selecting 6 quarts product/acre of Makaze, increased control to 92 percent and introduced an additional 0.5-quart glyphosate/acre into the environment. Thus, to achieve more control with the addition of Milestone VM Plus to the base 4-quart product/acre rate requires the use of more active ingredients than selecting Makaze (6 quarts product/acre). Selecting Makaze (6 quarts product/acre) rather than Accord XRT II+Milestone VM Plus may reduce pine control by 3 percent. It appears that Milestone VM Plus substitutes for Accord XRT II for pine control at a 2-quart product/acre to 1quart product/acre replacement level.

CONCLUSIONS

When selecting a formulation of glyphosate for pine control, managers should select an application rate based on the amount of active ingredient (glyphosate) and not the quarts of product. Although not statistically significant, the addition of LI 700 surfactant improved the performance of Accord XRT II at all test rates. Managers should consider 6 quarts product/acre of Makaze for pine control. This product and rate achieved pine control comparable to higher rates while introducing fewer active ingredients into the environment than Accord XRT II+Milestone VM Plus.

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Table 1—Herbicides, application rates, amount of active ingredient and percent control of noncrop pine along a timber access road in southeastern Oklahoma. Product was applied 10-Jun-08 and control determined 14-Jun-09. Duncan's New Multiple Range Tests (DNMRT) was used to separate means for all treatments, groups of treatments selected for comparable amounts of glyphosate, and treatments with and without LI 700

Herbicide	Product Rate/ac (qts.+%)	Glyphosate (qts a.i.)	percent Control	All Treatments[1]	Glyphosate Groups	With vs Without LI 700
Razor Pro	10	4.1	75.8	ab		
Accord XRT II+LI 700	8+1/2	4.0	99.0	a	a[1,2]	a[1,3]
Accord XRT II	8	4.0	94.3	a	a	a
Makaze	8	3.3	89.2	a	b[1,2]	
Accord Concenentrate+LI 700	6+1/2	3.2	90.9	a	b	
Accord XRT II+LI 700	6+1/2	3.0	95.2	a	b	b[1,3]
Accord XRT II	6	3.0	90.9	a	b	b
Makaze	6	2.5	92.1	a	c[1,2]	
Accord Concentrate+LI 700	4.5+1/2	2.4	59.6	bc	d	
Accord XRT II+LI 700	4+1/2	2.0	88.6	a	c	c[1,3]
Accord XRT II	4	2.0	80.8	ab	c	c
Accord XRT II+Milestone VM Plus+LI 700	4+4+1/2	2.0	94.8	a	c	d[1,3]
Accord XRT II+Milestone VM Plus	4+4	2.0	93.0	a	c	d
Accord Concentrate+LI 700	3+1/2	1.6	41.7	c	e[1,2]	
Makaze	4	1.6	37.1	c	e	
Check	---	0	-59.0	d		

[1] Means within a column sharing the same letter are not significantly different (DNMRT, a=0.05).
[2] a=1st of 4 DNMRT; b=2nd of 4 DNMRT; c and d=3rd of 4 DNMRT; e=4th of 4 DNMRT.
[3] Each pair of letters represents a different DNMRT.

SCREENING CUT-STUMP CONTROL OF CHINESE TALLOWTREE, SWEETGUM AND YAUPON WITH AMINOCYCLOPYRACHLOR

J. L. Yeiser, M. Link, and J. Grogan

ABSTRACT

Aminocyclopyrachlor (MAT28) was investigated for the potential control of unwanted woody rootstocks of Chinese tallowtree (Triadica sebifera), sweetgum (Liquidambar styraciflua), and yaupon (Ilex vomitoria). A cut-stump application of MAT28+Brush and Basal Oil by Helena was tested against standard treatments: (1) MAT28 2.5%, (2) MAT28 5%, (3) MAT28 10%, (4) MAT28 15%, (5) Garlon 4 Ultra 30%, (6) Garlon 4 Ultra+Stalker 20+1%, (7) MAT28+Stalker 10+1% and (8) untreated check. Herbicides were applied on February 4, 2009. Stems were severed with a chainsaw and herbicide applied immediately and sufficiently to thoroughly wet the surface, edges and top 2 inches of the stump. All rootstocks were free of sprouts 30 and 60 days after treatment (DAT). The total height of Chinese tallowtree checks averaged 8.8-feet initially and 7.5-feet 540 DAT. MAT28 (10%), MAT28+Stalker and Garlon Ultra mixtures all provided 100 percent control 540 DAT. For sweetgum, total height for check rootstocks averaged 11.8-feet initially and 5.9-feet 540 DAT. Least sprouting and best control occurred on rootstocks treated with Garlon Ultra alone. Sprouts averaged 2.4-feet 540 DAT. For yaupon, total height of checks averaged 11.1-feet initially and 4.8-feet 540 DAT. No sprouts (100 percent control) were detected 540 DAT on rootstocks treated with Garlon Ultra, Garlon Ultra+Stalker, or MAT28+Stalker. Cut-stump treatments of MAT28 show potential for reducing unwanted rootstocks of Chinese tallowtree, sweetgum and yaupon.

INTRODUCTION

Chinese tallowtree (*Triadica sebifera*), sweetgum (*Liquidambar styraciflua*), and yaupon (*Ilex vomitoria*) are unwanted competitors on many nonagricultural areas, non-crop producing areas, industrial sites, and natural areas in the South. Traditionally, herbicides containing triclopyr and imazapyr have been used for control of these unwanted woody plants (Tu and others 2001, Wilson and others 2006).

Society demands the introduction of less herbicide (both product and active ingredient) into the environment. Forest managers seek socially responsible and cost effective weed control. Recent advances in herbicide chemistry have yielded products requiring lower use rates while delivering greater human, environmental and wildlife safety as well as weed efficacy (DuPont 2009). Aminocyclopyrachlor, formulated as MAT28, is a new research herbicide that could potentially control Chinese tallowtree, sweetgum, and yaupon with less herbicide than currently required.

Broadcast foliar applications are commonly used during large-scale operations to control dense unwanted plants. Individual stem foliar sprays are more common where unwanted rootstocks are sparse, making an area treatment less practical. Enhanced selectivity and environmental protection are achieved with a herbicidal application directly to cut stumps. In research, results from foliar and cut-stump treatments may be assessed for a better understanding of herbicidal leaf penetration and movement down the stem or lack thereof.

DuPont's new herbicide, MAT28, has highly desirable human, environmental and wildlife safety properties (DuPont 2009) while potentially controlling unwanted woody plants at lower than standard use rates. In this study, a cut-stump treatment of MAT28 alone, tank mixtures of MAT28 plus leading competitor products, and industry checks were tested for the control of Chinese tallowtree, sweetgum and yaupon rootstocks on an unmanaged site supporting a natural stand of mixed pine-hardwood. This site is currently retired from production.

MATERIALS AND METHODS

SITE

The study site is in the hilly upper coastal plain near Timpson (Shelby County), TX. Soils are a sandy loam. The site was recently clearcut with substantial sprouting of Chinese tallowtree, sweetgum and yaupon, with numerous other woody species present. No planned regeneration followed timber harvest.

METHODS

Seven herbicide treatments and an untreated check were tested. Test treatments were: (1) MAT28 at 2.5%, (2) MAT28 at 5%, (3) MAT28 at 10%, (4) MAT28 at 15%, (5) Garlon 4 Ultra at 30%, (6) Garlon 4 Ultra+Stalker at 20%+1%, (7) MAT28+Stalker at 10%+1% and (8) untreated check (severed rootstock with no herbicide treatment). In each treatment plot, rootstocks of 7 Chinese tallowtrees, 10 sweetgums and 10 yaupons spaced at least 10-feet

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apart were equally assigned to 1-, 2- and 3-inch ground line diameter classes and balanced for all treatment-plot replicates. Each rootstock was treated with herbicide mixed with Brush and Basal Oil by Helena on February 4, 2009 in the following manor: 1) all stems within 1-feet radius of the dominate stem were severed with a chainsaw leaving a 4-inch stump and 2) a herbicide and basal oil mixture was immediately applied to the cut surface and top 2 inches of all the severed stems of the rootstock, using a CO_2-backpack sprayer with 5500 Adjustable Conejet Orifice 10 at 11PSI. The dominant stem of all rootstocks was measured for total height (feet) and ground line diameter (in) at the onset of the project. Dominant stems were assessed for sprouting and sprout total height at 30, 60, 90, 180, 360 and 540 days after treatment (DAT). Efficacy was determined by monitoring the number of sprouts, as well as the percent control of the dominant stem. Percent control was defined as initial height minus height at post-treatment evaluation, divided by the initial height times 100.

RESULTS

No sprouts occurred in any of the treatments 30 and 60 DAT. Sprouting were present in many of the treatments by 90 DAT, however sprout frequency, and thus herbicide efficacy varied greatly between treatments, therefore results will be discussed by species.

CHINESE TALLOWTREE

In the untreated check, virtually all rootstocks had sprouted (20 out of 21) by 90 DAT. The earliest sprouts in herbicide treatments were detected at 90 DAT with a few additional sprouts observed 180 DAT. Sprout number stabilized at 360 DAT and thereafter. Only the 2.5% MAT28 treatment exhibited new sprouts from 360-540 DAT. The maximum number of sprouts for any treatment was 7 out of 21. This occurred 360 DAT in the lowest MAT28 test rate (2.5%). No further sprouting was observed in any of the treatments after 360 days. No sprouting occurred at all for the following treatments: MAT28 10%, Garlon 4 Ultra and Garlon 4 Ultra +Stalker. A single sprout was recorded in the MAT28+Stalker treatment at 30 DAT, however this sprout subsequently died, effectively resulting in no sprouting for this treatment as well (Table 1).

The heights of the dominant stem in the untreated check rootstocks averaged 8.8 feet initially and 7.5 feet 540 DAT. Sprouts regrew 86 percent of their initial height. The heights of the dominant stem in the MAT28 treated rootstocks averaged 8.5 feet initially and 3.0 feet 540 DAT. Sprouts regrew 35 percent of their initial height. The height of the dominant stem in the Garlon treated rootstocks were 9.6 feet initially and without sprouts 540 DAT. Only the MAT (10%) and MAT28+Stalker treatments matched this performance (Table 2).

Rootstock control at 90 DAT and thereafter was similar and significantly greater on all herbicide treatments than checks. At 180, 360 and 540 DAT only the low rate of MAT28 (2.5%) had significantly less control than the other herbicide treatments and significantly greater control than the check.

SWEETGUM

All check rootstocks supported sprouts by 90 DAT. By this same time, sprouts were observed in all herbicide treatments except Garlon 4 Ultra (30%), for which there were no sprouts. In both Garlon 4 Ultra treatments sprouting stabilized 360 DAT resulting in only 3 total sprouts recorded at 540 DAT. Sprouting increased for all MAT28 rates and mixtures throughout all evaluations (Table 1).

The heights of the dominant stem in the untreated check rootstocks averaged 11.8 feet initially and 5.9 feet 540 DAT. Sprouts regrew 50 percent of their initial height. The heights of the dominant stem in the MAT28 treated rootstocks averaged 12.7 feet initially and 3.4 feet 540 DAT. Sprouts regrew 27 percent of their initial height. The height of the dominant stem in the Garlon treated rootstocks was 12.3 feet initially and 3.8 feet 540 DAT. Sprouts regrew 31 percent of their initial height (Table 2).

No significant differences in herbicidal control were noted until 180 DAT. Treatment ranks did not change for the evaluations 180, 365 and 540 DAT. At 540 DAT, treatments seemed to move towards groups. For example, Garlon 4 Ultra (30%) provided significantly best control. Stalker treatments were significantly better than the low rate of MAT28 (2.5%). Treatments of MAT28 (5%, 10%, 15%) alone and mixtures of Stalker were statistically similar as were MAT28 (2.5%, 5%, 10%, 15%) treatments.

YAUPON

By 90 DAT, all check rootstocks had sprouted. Only one sprout was recorded in all of the herbicide treatments (MAT28 10%). Virtually all sprouts had occurred by 180 DAT and by 540 DAT the greatest number of sprouts in any treatment was 3 (MAT28 2.5%). A total of 4 sprouts occurred for the MAT28 5%, 10% and 15% treatments collectively. No sprouts were found in either of the Garlon 4 treatments or the MAT28+Stalker treatment (Table 1).

The heights of the dominant stem in the untreated check rootstocks were 11.1 feet initially and 4.8 feet 540 DAT. Sprouts regrew 43 percent of their initial height. The height of the dominant stem in the MAT28 treated rootstocks was 13.1 feet initially and 3.5 feet 540 DAT. Sprouts regrew 27 percent of their initial height. The height of the dominant stem in the Garlon treated rootstocks was 13.4 feet initially and without sprouts 540 DAT. Only the MAT28+Stalker (10+1) mixture equaled the Garlon performance (Table 2).

For all evaluations, all herbicide treatments exhibited control that was statistically similar and greater than observed for checks.

DISCUSSION

MAT28 control of Chinese tallowtree, sweetgum and yaupon rootstocks varied by species. Results will be discussed for individual species.

CHINESE TALLOWTREE

Treatment-related sprouting was observed 90 and 180 DAT (Table 1). No new sprouts occurred on any treatment 360 DAT and thereafter. No sprouts were detected at any evaluation for treatments: MAT28 10%, Garlon 4 (30%), Garlon 4+Stalker and MAT28+Stalker.

Percent control was excellent at all evaluations for six treatments: three MAT28 (5%, 10%, 15%), two Stalker mixtures, and Garlon (30%) (Table 2). MAT28 (10%) and Garlon and Stalker treatments all exhibited no sprouting and therefore, 100 percent control 365 DAT and thereafter. It is hypothesized that over time the lack of sprouting and increased control of MAT28 10% and its mixtures will statistically separate from the other MAT28 treatments. Good MAT28 cut-stump control of Chinese tallowtree is consistent with results from foliar treatments (Ezell and Yeiser 2009). This product provides stand-alone control of Chinese tallowtree.

Sprouting frequency decreased as rate increased from 21 sprouts in the check, to 7 sprouts in the MAT28 2.5% treatment to 2 sprouts in the MAT28 5% and 15% treatments (no sprouts in the 10% treatment). Sprout average total height decreased significantly as rate increased up to a 5% MAT28 rate, then no significant decreases were noted at the higher rates.

MAT28 (15%) had more sprouts than the lower concentrations of MAT28. This result is counter-intuitive and may be explained. At the high concentration (15%), MAT28 was difficult to keep in solution and required significant agitation, something unnecessary for all other herbicidal treatments. Although frequent agitation was used, it is possible that some separation of product still occurred resulting in applicator error.

SWEETGUM

For sweetgum, sprout frequency 90 to 540 DAT varied by treatment (Table 1). Sprouting occurred in all treatments at 360 and 540 DAT. Garlon 4 treatments had the fewest sprouts.

Differences in percent control at 90 DAT were between treated and untreated (Table 2). Treatment differences increased with time. At 540 DAT, Garlon 4 (30%) was the best treatment with 99.4 percent control. The best performing MAT28 treatments were the 5%, 10% and 15% rates and the MAT28+Stalker (10%+1%). Test treatments of MAT28 (5%, 10%, 15%) provided less control than Garlon or MAT28 mixtures. Poor control of sweetgum with cut-stump applications parallels results from foliar application tests of MAT28.MAT28 does not provide stand-alone control of sweetgum.

YAUPON

There were no new yaupon sprouts 360 DAT and thereafter. No sprouting occurred in either of the Garlon 4 treatments. No statistical differences in sprout frequency or percent control were observed between any of the herbicide treatments. Although there were a few sprouts in the MAT28 treatments, for percent control, MAT28 performed as well as the Garlon treatments. It should be noted that control with the low rate of MAT28 (2.5%) was statistically and numerically similar with higher rates for yaupon control only (not Chinese tallowtree or sweetgum). Yaupon cut-stump control with MAT28 is good while foliar control is poor (Ezell and Yeiser 2009). This inconsistency suggests a different surfactant may be needed to better move MAT28 into the leaves or down the stem.

Additional research is currently underway that examines different formulations and rates of MAT28 for control of various other tree species using cut-stump and basal-bark applications. Preliminary results indicate MAT28 provides excellent control of winged elm (*Ulmus alata*), green ash (*Fraxinus pennsylvanica*) and sugarberry (*Celtis laevigata*) using both cut-stump and basal bark application methods. Collectively, these data suggest MAT28 provides broader-spectrum control than is evidenced in this one trial. More work is planned for trifoliate orange (*Poncirus trifoliate*) and honeylocust (*Gleditsia triacanthos*).

CONCLUSIONS

MAT28 control of unwanted woody plants varies with the species treated. MAT28 provided stand alone control of Chinese tallowtree and yaupon but will need a higher rate than tested here or a tank partner for sweetgum control. Yaupon susceptibility to MAT28 warrants further investigation into formulations and adjuvents to enhance foliar control. MAT28 can potentially provide effective control of numerous species occupying many nonagricultural areas, non-crop producing areas, industrial sites and natural areas in the South.

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Table 1—Sprouting frequencies of Chinese tallowtree (CT), sweetgum (SG) and yaupon (Y) rootstocks 90, 180, 360 and 540 days after treatment (DAT) following a February 4, 2009 cut-stump application of herbicide

	DAT	90			180			360			540		
TREATMENT	SPECIES	CT	SG	Y	CT	SG	Y	CT	SG	Y	CT	SG	Y
PRODUCT+BASAL OIL	N	21	30	30	21	30	30	21	30	30	21	30	30
MAT28 2.5%		1	6	0	2	23	4	7	24	3	7	26	3
MAT28 5.0%		0	2	0	2	14	1	2	15	2	2	18	2
MAT28 10.0%		0	2	1	0	9	2	0	14	1	0	16	1
MAT28 15.0%		1	2	0	2	17	1	2	20	1	2	22	1
Garlon 4 Ultra 30%		0	0	0	0	0	0	0	1	0	0	1	0
Garlon 4 Ultra+Stalker 20%+1%		0	2	0	0	5	0	0	2	0	0	2	0
MAT28+Stalker 10%+1%		1	2	0	0	14	0	0	15	1	0	18	0
Untreated Check (Chainsaw only)		20	30	30	21	30	30	21	29	30	21	29	30

Table 2—Mean rootstock initial height (feet) and percent control (%) at 90, 180, 360 and 540 days after treatment (DAT) with a cut-stump application of herbicide, applied Feb 4, 2009

SPECIES	TREATMENT (Product+(Basal Oil))	MEAN HT INITIAL	% 90DAT	% 180DAT	% 360DAT	% 540DAT
Chinese tallowtree						
	MAT28 2.5%	8.3	99.2a[1]	87.5b[1]	86.0b[1]	77.5b[1]
	MAT28 5.0%	8.1	100.0a	96.9a	95.0a	93.0a
	MAT28 10.0%	8.1	100.0a	100.0a	100.0a	100.0a
	MAT28 15.0%	9.9	99.7a	97.6a	96.6a	94.8a
	Garlon 4 Ultra 30%	9.1	100.0a	100.0a	100.0a	100.0a
	Garlon 4 Ultra+Stalker 20%+1%	10.1	100.0a	100.0a	100.0a	100.0a
	MAT28+Stalker 10%+1%	8.0	98.6a	100.0a	100.0a	100.0a
	Untreated Check (Chainsaw only)	8.8	83.7b	43.7c	27.3c	10.4c
Sweetgum						
	MAT28 2.5%	8.3	99.2a[1]	86.4c[1]	83.4d[1]	73.1c[1]
	MAT28 5.0%	8.1	99.8a	91.6bc	88.2cd	80.2bc
	MAT28 10.0%	8.1	99.6a	95.9ab	91.1c	81.7bc
	MAT28 15.0%	9.9	99.6a	91.9bc	91.2c	80.2bc
	Garlon 4 Ultra 30%	9.1	100.0a	100.0a	99.7a	99.4a
	Garlon 4 Ultra+Stalker 20%+1%	10.1	99.2a	96.5ab	97.8ab	96.9b
	MAT28+Stalker 10%+1%	8.0	99.7a	93.0b	92.6bc	83.1b
	Untreated Check (Chainsaw only)	8.8	89.9b	66.8d	63.2e	47.7d
Yaupon						
	MAT28 2.5%	13.2	100.0a[1]	98.7a[1]	98.5a[1]	96.8a[1]
	MAT28 5.0%	13.4	100.0a	99.3a	99.7a	98.0a
	MAT28 10.0%	14.2	99.5a	98.7a	98.4a	98.0a
	MAT28 15.0%	12.3	100.0a	99.6a	99.0a	99.0a
	Garlon 4 Ultra 30%	14.2	100.0a	100.0a	100.0a	100.0a
	Garlon 4 Ultra+Stalker 20%+1%	12.6	100.0a	100.0a	100.0a	100.0a
	MAT28+Stalker 10%+1%	12.4	100.0a	100.0a	99.2a	100.0a
	Untreated Check (Chainsaw only)	11.0	91.9b	70.5b	63.4b	52.6b

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

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A range of issues affecting southern forests are addressed, including pine and hardwood silviculture, soil and water, physiology and genetics, carbon and bioenergy, fire and fuels, forest health, restoration, growth and yield, and forest economics.