United States
Department of
Agriculture

Forest Service

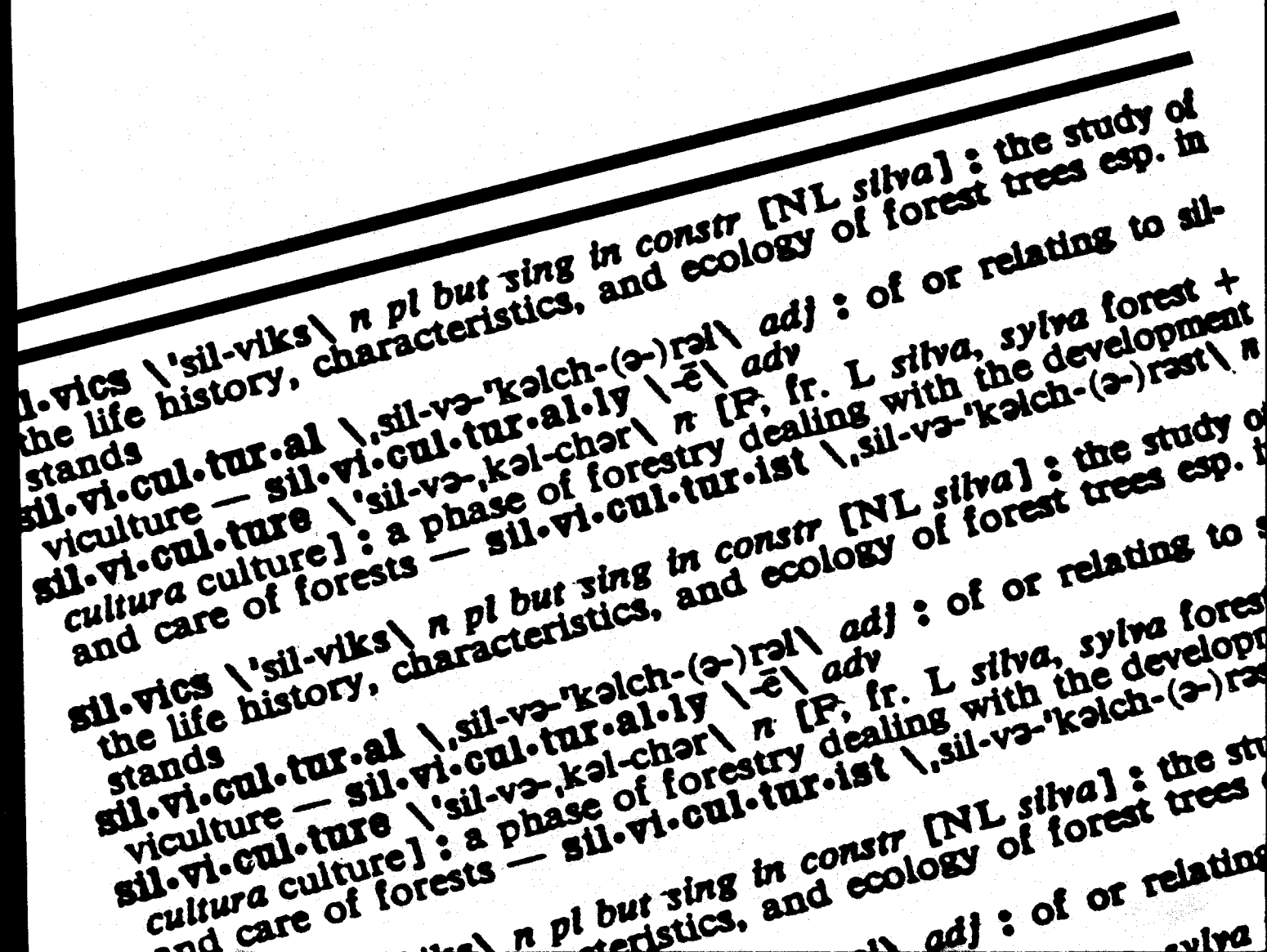
**Southern Forest
Experiment Station**

New Orleans,
Louisiana

General Technical Report
SO-93
July 1993

Proceedings of the Seventh Biennial Southern Silvicultural Research Conference

Mobile, Alabama
November 17–19, 1992



Proceedings of the Seventh Biennial Southern Silvicultural Research Conference

Edited by

John C. Brissette

Mobile, Alabama
November 17-19, 1992

Sponsored by

Southern Forest Experiment Station
Southeastern Forest Experiment Station

Southern Region of the
National Association of Professional
Forestry Schools and Colleges

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Research Council

Silvicultural Working Group
Society of American Foresters

Hardwood Research Council

Southern Group of State Foresters

National Association of Consulting Foresters

Published by

Southern Forest Experiment Station
New Orleans, Louisiana

1993

PREFACE

This proceedings is the culmination of efforts that produced the Seventh Biennial Southern Silvicultural Research Conference. This was the latest in a series of regional conferences that began in 1980. Like the previous conferences, this meeting was designed to provide a forum for (1) the exchange of research information among silviculturists and researchers in related areas, (2) research coordination, (3) review of research in progress, and (4) new approaches or techniques of general interest. The conference, held November 17-19, 1992 in Mobile, Alabama, consisted of a general session, four concurrent sessions, and an optional field tour.

This conference was the first of the series with a technical theme. The general session, the field tour, and approximately 25 percent of the contributed papers focused on wetlands. The general session dealt with a range of scientific and policy issues related to forest wetlands. Unfortunately, not all the speakers prepared papers for the proceedings. The field tour, consisting of two half-day sessions, was outstanding. The hosts were Scott Paper Company and Auburn University. Those who attended the field tour rated it as one of the highlights of the conference.

Acknowledgment is made to the conference chairperson, James Purdue of the Southern Forest Experiment Station, and the steering committee, composed of the following representatives and their sponsoring organizations:

Doug Crutchfield, Westvaco Corporation, Summerville, SC

Conner Fristoe, Union Camp Corporation, Prattville, AL

Jeff Goelz, Southern Forest Experiment Station, Stoneville, MS

Charles Harden, Society of American Foresters, Bethesda, MD

John Hodges, Mississippi State University, MS

Steve Kolison, Tuskegee University, AL

Steve Meadows, Southern Forest Experiment Station, Stoneville, MS

Jim McMinn, Southeastern Forest Experiment Station, Athens, GA

Bruce Miles, Texas Forest Service, College Station, TX

Harry Murphy, Association of Consulting Foresters, Birmingham, AL

Dan Neary, Southeastern Forest Experiment Station, Gainesville, FL

Jack Pitcher, Hardwood Research Council, Memphis, TN

Victor Rudis, Southern Forest Experiment Station, Starkville, MS

Paul VanDeusen, Southern Forest Experiment Station, New Orleans, LA

Jimmie Yeiser, University of Arkansas at Monticello, AR.

The diligence and thoroughness of these individuals are commended. Also commended are the speakers and moderators in the general and concurrent sessions. Overall, the presentations were excellent and received a high ranking on the conference evaluations. Moderators did an admirable job of keeping the sessions on schedule.

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

Special thanks goes to Bertha McAlister who did the word processing needed to transfer the papers from diskette to computer and into the proper format. This proceedings would not have been possible without her perseverance and attention to detail.

John C. Brissette
Program Chair
Southern Forest Experiment Station
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Wetlands: General Session

Moderator:

George W. Bengtson
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PRESERVING FORESTED WETLAND FUNCTIONAL VALUES [1]

Norman L. Brunswig [2]

I have taken the liberty of changing the title of my talk because I want to shift your thinking, at least for the next several minutes, away from the notion of working in, and with, a system which has as its absolute goal, protecting every single acre of forested wetland, no matter its size, type or locality, to one which might, might, have as its goal, maintaining wetland functional values, both natural and cultural. Is that heresy?

Well, please keep that thought.

With all the protection that local, state and federal laws can provide, being implemented by what some describe as legions of overzealous regulators, that are prodded, poked and harassed by us to rigidly enforce those laws, wetlands, including forested wetlands, are continuing to disappear at a staggering rate. The US Fish and Wildlife Service estimates that up to one-half million acres of wetlands per year, of all kinds, are still being lost. The result is, over half of what were here when the Declaration of Independence was signed are already gone. The most discouraging statistic regarding forested wetlands, from my point of view, (I'm both a tree hugger and a duck hunter), is this one. Of the original 24 million acres of bottomland forests that once embraced the Mississippi River (growing trees and mallard ducks) only 3 million remain. Many of the rest are growing subsidized soybeans. NO NET LOSS of wetlands was never an achievable goal, and probably never will be. Legal and illegal human activities nibble and chomp away at our finite wetlands inventory, incessantly. And, they will continue to do so. Roads, bridges, dams, public buildings and other human works that meet the test of providing "compelling public benefits" will continue to be built, sometimes in wetlands. So what.

The WHAT is this.

There are, I think we would all agree, 'compelling public benefits" which result from keeping wetlands functionally intact. What are they? Providing flood control, water and air purification, quifer recharge, fish and wildlife habitat (including that of scores of endangered and threatened species), forest products, hunting and fishing, wildlife corridors, aesthetics, green space, boating, hiking, bird watching, nature study and on and on and on. Some of these benefits, the ones that involve actual human activities, are obvious to the public. But others, such as flood water storage, water purification and aquifer recharge, are not. But they are there, and they are real. And, as the public becomes more and more well informed about them, and we are working hard to make that happen, public support for wetland protection (which is strong now) will get even stronger.

So where am I going with this? Remember the thought I asked you to keep. Well, I'm going back there. Wetland functional values.

For the most part, the way wetland protection laws are being applied, or are purported to be, is this way. For any filling within a jurisdictional wetland, permits must be granted. Most often, if permits are denied, but projects go forward, the wetland is left out of the project area. It is spared. But is it? In the case of real estate developments, and sometimes forest management activities, residual wetlands occur as tiny dots or slivers of habitat within the development, or in the case of forests in much of my region, vast pine plantations. In the case of real estate developments, there are usually no adjacent natural uplands retained to which non-aquatic organisms can move during floods. There are no corridors for animal dispersal to other similar habitats. Often drainage, or other activities, lead to drying of the developed area around the wetland, ultimately drying out the wetland itself. The result being, in many, many cases, isolated islands of wetland plants, often too dry, with no natural buffers. They frequently have lost many of their functional values. I have seen hundreds of examples of little cypress heads as the margins of Florida shopping centers, cypress-gum ponds surrounded by houses in seaside developments and gum ponds (ditched or unditched) in South Carolina flatwoods loblolly plantations.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Assistant Director of Sanctuaries, Sanctuary Department, National Audubon Society, Harleyville, SC.

I guess we could say that we saved the pond but lost the wetland. And did it all well within the law.

It becomes more and more clear to me that to protect wetland functional values we must do several critical things. First, we must accept what to anyone who has been watching must be obvious - keeping all wetlands intact and functioning is impossible; and then, we must determine how we will attempt to mitigate for the functional values lost in future unavoidable wetland destruction. And this is where it really gets tricky.

There are not, at least at this time, very many examples of successful large scale wetlands creation projects. We don't really know how to make new ones from scratch, and the cost of trying is tremendous. We can do enhancement and restoration, but how will we do it, and where, and with what. The South Carolina Coastal Council, the implementing agency for the Coastal Zone Management Act, is using a very interesting approach to mitigating the loss of isolated wetlands that I think provides an interesting model. I would like to tell you about it. In the lower coastal plain, most tracts of land larger than 20-30 acres contain one or more isolated wetlands. When, let's say, a 2-300 acre subdivision plan comes before the Council, almost invariably it contains several wetlands that present great challenges to the development planner. Traditionally, the hard-nosed regulatory approach has been to try to require the developer to maintain them all, at whatever cost. The end result has very often been, several totally isolated, species depauperate, highly diminished, jurisdictional wetlands, with substantially reduced functional value, particularly with respect to wildlife habitat. Not a good result.

The approach that our Coastal Council is trying is this. After an applicant has met all of the legally mandated requirements to attempt to avoid destruction of the wetlands, through project design modification, searching for alternative sites, etc., Council staff offer to work with the developer to reconfigure the project to achieve the optimum results, for both project feasibility and maintenance of wetland functional values. Even when this is successful, the modified plan still results in some net wetland acreage loss. The applicant is required to mitigate for that loss at a fairly high ratio of uplands set aside for wetlands lost. But, the builder builds a better project, the remaining wetlands are significantly buffered, and it practical, connected to each other. The wetlands retained are surrounded by rings or strips of undeveloped habitat, often natural plant communities, significantly increasing the potential diversity of the site, providing a continuum of habitat critical to non-aquatic wetland species, and frequently acting as corridors for species movement in and out of the areas. The buffers also act as setbacks from yards, roads, drainage ditches, golf courses, and other alternations, that each can and do, act to degrade wetlands. As part of the permitting process, the applicant is required to give a conservation easement on the protected property, wetlands and buffers, to some appropriate agency or organization, guaranteeing the permanence of the mitigation.

The result of this approach is that there IS a net loss in wetlands, and a somewhat smaller loss in wetland functional values. But, the loss in values is less than what would have resulted from saving all of the jurisdictional areas, with no buffers and connections.

The concept that guides this approach is that wetlands function as part of complex systems, which include both wetlands and uplands. Isolate or dramatically alter either, and you diminish both, and their combined value.

The really controversial parts of this approach are; whose favorite wetlands will be sacrificed, and is it reasonable and legitimate to mitigate wetland losses with upland habitat. Many of my associates, at least initially, would probably say it isn't legitimate. From my point of view, in many specific instances, it is. But, it sure doesn't result in No Net Loss of Wetlands!! It may, however, minimize the loss of functional value.

By now, some of you are certainly wondering why I used this example with a forestry group, given the freedom from regulation that the silvicultural exemptions provide. Environmental groups are trying to maintain functional wetlands because they are so valuable for so many reasons, and because they are there. We really can't maintain biodiversity on the millions of acres of virgin long leaf pine forest or tall grass prairie that are already gone. Also, they are focusing on protecting wetlands because they can be protected. We have some legal tools to use. And it looks like we might get more.

The growing public enthusiasm for wetlands and biodiversity maintenance, which go hand-in-hand, will make it politically unpopular for anybody, including those with 404 and other exemptions, to destroy wetlands, for any but very compelling reasons. Also, in the new political reality, I don't think it will be possible to define wetlands away.

The forestry community could voluntarily commit itself to giving all wetlands a very high degree of protection. You could buffer them with unconverted habitat when they fall in areas planned for conversion to plantations. You could connect them with strips of natural habitat. You could not drain them. And having done these good deeds, you could then talk about it, and we would help you. The public would really appreciate it.

As silvicultural scientists, you could increase the emphasis you are placing on developing management techniques for bottomland hardwoods that reduce the emphasis on clearcutting, and are less destructive to the site. Even though recent studies seem to indicate that soil disturbance, silting and other impacts of swamp logging, that seem horrendous at the time, are less dramatic and long lasting than I once thought (some comforting information) the impact on wildlife, and particularly forest interior species, and human aesthetics, are significant. As wildlife management emphasis swings, if ever-so-slowly, away from game animals (mostly species of edge habitats that are abundant), to those more dependent on large tracts of relatively unbroken forest, there will be increasing pressure to provide and maintain that kind habitat. Distributing small clearcuts here and there around a forest unit, thereby creating lots of edge habitat and wildlife openings, was once a popular prescription, and one that often meshed well with existing bottomland hardwood harvest techniques. My feeling is that it won't always be in the future. Further, the value of hunting leases to bottomland forest owners is substantial, and, in my experience, aesthetics are very important to many hunters, particularly those able to pay large per acre lease fees. Also, in my own experience, I have known several hunters who have dropped leases, changed hunting clubs, or even quit hunting altogether when their favorite swamp hunting areas were clear-cut.

Harvest strategies that allow for some tree removal, but maintain a forest canopy, would be extremely valuable. Some owners, even the National Audubon Society, might cut in its swamp forests, if it could have its trees and a forest, too.

To provide a real-life context for this last point, in South Carolina right now, many large, private landowners are voluntarily placing very restrictive conservation easements on large acreages of swamp timberlands, in some cases precluding all logging, as part of local wetland protection initiatives, causing considerable anxiety for local hardwood foresters. I am confident that it less destructive, non-clear-cut based strategies for bottomland hardwood management existed, the pressure to "lock these lands up" would be much less.

Another critical aspect needed in future forested wetland conservation planning, and all conservation planning for that matter, is that we must begin to think about it at the landscape level. To really protect wetland functional values and biodiversity, we must think and plan at the biggest possible scale. We must begin to look within a watershed, or even larger geographic units, and decide how much healthy woodland habitat we want to maintain, and use that number as a target. When values are comprised in one part of a watershed, those losses should be mitigated by enhancing others. Mitigation banking, leading to the enhancement of woodland functional values at predetermined key locations, not necessarily near the site of the loss, might be a part of such a plan.

Wetlands, particularly swamps in the south and southeast, are frequently ribbons of undeveloped habitat winding through large areas of varying land uses. Where these resources lie close to towns and cities, they can be almost the only undeveloped land. They are also often the only, or at least the major, wildlife corridors that connect units of good habitat. The sensitivity shown in the management of these corridors (are they buffered or not, kind of cut, size of cut, rotation length) can be extremely important. Because so much swamp habitat is managed by foresters, you have a tremendous opportunity, even obligation, to protect or enhance woodland functional values in these areas.

I would like to let you know that most of the environmental community that I know is not anti-management or anti-forestry. We're just anti-bad forestry. We hope that you will continue to evolve your BMP's in ways that will not only quiet some of those who criticize woodland logging practices and other forestry activities, but will also make it easier for you to admit you're a closet Audubon member.

In closing, I want to tell you about a tremendous conservation initiative in South Carolina today called the ACE Basin Project, in which foresters are playing a major role. An outgrowth of the North American Waterfowl Management Plan, it has become the flagship project of the Atlantic Coast Joint Venture. I can brag about it because Audubon is not a principal cooperator.

The ACE is a totally voluntary state-federal-private cooperative effort to protect from intensive

development the area surrounding the confluence of the Ashepoo, Combahee and Edisto Rivers - hence ACE. The recently revised goal for this ambitious project is to protect 200,000 acres of land, by deed, conservation easement, M.O.U. or other legal vehicle. Protection is defined, in this effort, to mean maintaining the present land use. Private foresters, and much of the corporate forest industry, have shown real leadership, advising landowners and pledging to keep their own timberland growing timber, thereby protecting critical uplands from industrial or other incompatible development, that degrade this pristine area. The ACE is a priceless woodland treasure, being created, in part, by commitment to sensitive forest management practices. I compliment all of those involved, but particularly the forestry leaders. They've stuck their necks way out.

We will protect the ACE, other wetlands systems, and biodiversity at large, only by broad-based cooperative ventures like the ACE. I look forward to them.

Thank you very much.

REGULATORY MANAGEMENT OF FORESTED WETLANDS [1]

J.F. Godbee, Jr. [2]

Good morning. Today I have been asked to speak to you about the regulatory management of forested wetlands. Given the credentials of this audience, it would be presumptuous to me to even attempt to address management from a silvicultural standpoint. We will all have an opportunity to expand our understanding of the science in the concurrent sessions. I will try to provide you with a business and policy perspective of management, and more specifically, issues and their effects on the private and industrial landowners in the South.

Private forest management is perceived to be largely "unregulated" by the public, both our Federal and State policy makers, Federal agency officials and unfortunately too many of our own profession, although the attitudes and awareness level of the latter is rapidly changing.

As we have just heard, private forest management practices are indeed regulated by a complex network of Federal, State and local laws and regulations. The Clean Water Act contains specific legal compliance requirements for normal-silvicultural practices on private forest lands.

America is blessed with a bountiful forest resource. Two-thirds of the forest lands that existed at the opening of the eighteenth century, when settlement began along the eastern seaboard, are still forested today. Nowhere is that more evident than here in the Southeast (includes Alabama) where over 60% or 109.5 million acres remain in highly productive forests. In spite of the fact that as many as 50% of the non-industrial private landowners in the Southeast fail to provide for adequate regeneration of harvested stands, USDA Forest Service statistics indicate growth continues to exceed harvest by around 24%.

Our forests are alive and well. Forest growth is now three times what it was in 1920. Nationwide growth exceeds drain by 37%. Yet a concerned and more often uninformed public is convinced we are running out of forests.

This is not to say we don't have some problems. In spite of the fact that we have an overall record of stewardship that anyone can be proud of, we have done and continue to do some things that just are not acceptable to the public and the majority of our profession. Unfortunately, our entire profession is often held hostage to the actions of a few bad actors.

A survey by the Times/Mirror Group of the public's perception of the seriousness of environmental problems provides insight into why forest management is under fire. We have the safest and cleanest waters in the world. I don't believe any of you bothered to check out the safety of our drinking water before you came to Mobile. Yet 97% of the public believes that we have a serious water pollution problem, and approximately 90% are worried about drinking water quality. The trends for loss of natural areas, endangered species and wetlands are the same.

The public also believes that the responsibility for protecting or providing these values is more important to society than are the rights of the individual. And they indicate a willingness to pay, that is as long as it appears someone else is bearing the costs. The closer to home the responsibility falls, the narrower the margin of support. Facts are often washed out by emotion. Bad education distorts choices and ignores the costs.

With this background in mind, let's take a brief look at the management of forested wetlands.

Water quality and wetlands are regulated under the Clean Water Act (CWA) and the Coastal Zone Management Act (CZMA). Both point and nonpoint sources are addressed. Best Management Practices (BMPs) have been developed and are implemented to minimize water pollution. Surveys generally indicate that properly implemented BMPs are highly effective in protecting water quality. Data from Environmental Protection Agency's 1990 Final Section 319 Nonpoint Source Report indicate that forestry accounted for only 2.3% of the NPS impact to the nation's waters. Furthermore, EPA concluded that forestry was not a major contributor to coastal water quality degradation.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Environmental Group Leader, Forest Resources Group, Union Camp Corporation, Rincon, GA.

However, I believe all of us recognize we still have some problem areas that we as an industry must address. The question is how? A number of states are proposing adoption of mandatory BMPs. EPA has gone as far as to develop uniform specific management measures that states must adopt and impose landowner notification requirements to appropriate agencies under the CZMA. This all encompassing approach imposes a regulatory burden to correct non-problems.

There is a better way. As a society, we must focus our limited resources on the real problems. By using the state BMP surveys to identify both bad practices and bad actors, then concentrating our correction and enforcement efforts, we can be more effective.

The wetlands issue is extremely complex. One of the major benefits is timber production. The compatibility of this use with protection of wetland functions was recognized by National Wetlands Policy Forum. Most of the forested wetlands in the Southeast have been harvested at least once, some several times and yet they are still high functioning wetland ecosystems. Public policies should encourage land uses that are compatible with the continued protection of these functions.

Forestry is regulated under Section 404 of the Clean Water Act, but generally exempt from the permit requirement provided certain conditions are met. Both the limits of jurisdiction and the extent of the exemption have been the source of much controversy over the past few years. Today there is great understanding as to what acres are wetlands, and thus subject to swampbuster, 404, CZMA or other programs. A trip to the field with the regulators will show they too have a problem delineating a wetland.

To further compound the problem, the EPA, the Army Corps of Engineers, US Fish and Wildlife Service and Soil Conservation Service have all attempted to redefine normal silviculture into a neat, tight package of specific practices without regard for the diversity of ownership, landowner objectives and the ecosystems on which wetlands occur and the advent of new technology. It's interesting to note that the Forest Service, the Federal Agency with forest management responsibility, is not included. I question how any of these agencies could presume the mantle of authority for defining normal silviculture.

Nevertheless, individual Corps and EPA districts have attempted to:

1) require permits for the plowing of fire breaks,
2) require proof of written management plans (and often ignored those that existed),
3) prohibit minor drainage, road construction, and the establishment of pine plantations,
4) eliminate wildlife habitat management as being a part of silviculture.

Fear and intimidation have been used to coerce small private landowners into signing consent agreements not to site prepare or to reforest with particular species. Many of these actions are occurring without the site ever having been visited by the agencies or official delineation calls made.

A classic example of the problem occurred in Delaware where EPA issued a compliance order to a forest landowner for land management and reforestation practices on a 12-acre tract. The violation - practices not included under the silviculture exemption. Enhancing wildlife habitat was listed as a primary objective on a forest stewardship plan prepared by the state forester, but in the regulators stated opinion - silviculture is limited to timber management. The plan included four one-quarter acre grass food plots and proposed a future one-half acre pond site.

The current regulatory approach treats citizens as criminals for conducting activities that are common practice and carried out with the government's blessing and federal assistance monies.

The Corps and EPA need to step back and take a broader look at silviculture as defined in academic texts for at least fifty years.

R. H. Westveld - 1939 - Applied Silviculture in the United States - "Silviculture is the forester's tool for making forest land productive of tree and animal crops, useful and attractive to the recreationist, and effective in the conservation of soil and water...Where wildlife is a dominant factor, it may be necessary to sacrifice a certain amount of timber-production value to meet the needs of wildlife."

D. M. Smith - 1962 - The Practice of Silviculture - "Silviculture is normally directed at the creation and maintenance of the kind of forest that will best fulfill the objectives of the owner. Returns from silviculture are generally thought of in terms of timber production, although it is not uncommon for owners to have other goals. The growing of wood may, in fact, have low priority among these objectives or none at all."

T. W. Daniel, et al. - 1979 - Principles of Silviculture - "Silviculture is concerned with controlling the establishment, growth, composition, and quality of forest vegetation. This can be done if there is a clearly defined management objective...Objectives varying among production of wood, water, wildlife and recreation will obviously require forests of quite different structure; that is the presence, absence, or relative abundance of litter, grass, brush, reproduction...."

K. F. Wenger - 1984 - Forestry Handbook, SAF - The Society of American Foresters (SAF) terminology describes silviculture as "...the science and art of cultivating forest crops..., the theory and practice of controlling the establishment, composition...and growth of forests."

"Silviculture is applied forest ecology - a means for protecting and enhancing range, wildlife, water, and soil resources, as well as timber crops. It is the manipulation of forest vegetation for human purposes. Silvicultural treatments are increasingly designed to meet several forest uses simultaneously."

The management of forested wetlands and for that manner all forest management is at a crossroads. We need to ask ourselves some tough questions.

Why the federal government is threatening a private landowner in Escambia County, Alabama with civil and criminal penalties and fines of up to $25,000 per day for harvesting and regenerating sixty acres of forest land?

How did we get to a point in this nation where the EPA issues an administrative order specifying the tree species and spacing that must be established within thirty days on private forest lands?

Why would EPA tell a private landowner in Grifton, North Carolina that he can't use mechanical site preparation to reforest a 130 acre tract that has operated, with no evidence of adverse impacts to water quality, under an SCS forest management plan for thirty years?

How we got ourselves to the point where the U.S. Army Corps of Engineers dictates widths for forest roads?

Why should a landowner in Delaware be subject to legal action for managing twelve acres under a federally-funded and state-developed forest management plan?

These are tough questions that bear looking into.

The authority for land use regulation has historically been vested in the state and local governments. Federal agencies are not using wetlands regulations under the CWA as a means to usurp this authority. These regulators are not trained to make informed decisions that balance land use with environmental and sociological needs. Who else would develop a program which places wetlands preservation above all other uses in every landscape position?

Our federal government must do a better job in allocating scarce resources to solve major wetland problems. We need to quit spending hundreds of thousands of dollars fighting cases like Hoffman Homes where 0.8 acres of isolated wetlands that has been farmed for decades was filled for development. We need to quit harassing small forest landowners who are actively engaged in reforesting their lands and focus our efforts on those that aren't.

The wetlands program needs revamping. Wetlands delineation should be based on landscape position and function with standards and criteria for vegetation, soils and hydrology specific to wetlands types. The exemption for normal ongoing silviculture must be clarified and restated. Forest management should be the salvation not the scapegoat for meeting the nation's goals of wetlands protection.

If we stay on the present course, society risks:

- people giving up land for taxes, reducing local tax base
- people suing for compensation under the taking clause
- higher prices for stumpage, reducing competitiveness and going offshore, initially for fiber then with manufacturing
- Our Society must continue to seek a proper balance between environmental protection and responsible growth. The risks to do otherwise are too great.

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Wetlands: Classification and Ecology

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DISTRIBUTION OF AND TRENDS IN SOUTHERN FORESTED WETLANDS [1]

Frederick W. Cubbage and Curtis H. Flather [2]

Abstract. Despite the public interest, little data are available on the area of forested wetlands in the South. The USDI Fish and Wildlife Service inventories estimated 51.7 million acres of palustrine forested wetlands in the U.S. in total in the 1980s. The 1989 USDA Soil Conservation Service Natural Resource Inventory found 45.0 million acres of nonfederal forested wetlands in the U.S. In the South, there were 29.3 million acres of nonfederal forested wetland in 1987, a decrease from 29.8 million acres in 1982. The Southeastern States of Alabama, Florida, Georgia, and South Carolina had 15.5 million acres of forested wetland, and the Delta States of Arkansas, Louisiana, and Mississippi had 7.9 million acres. The Appalachian states of North Carolina, Tennessee, Virginia, West Virginia, and Kentucky had 4.4 million acres. The Southern Plains States of Texas and Oklahoma has 1.5 million acres.

Introduction

The protection of forested and nonforested wetland has become a national issue over the last few years. Forest management practices, wetlands preservation, wildlife habitat protection, and timber profits will depend greatly on the definition and regulation of silvicultural operations in forested wetland. Various papers presented at this conference and published elsewhere have discussed the importance of forested wetland, but relatively little information is available on the extent and type. This paper summarizes and analyzes the available data on forested wetland distribution and trends in the South. This paper should help clarify to support and focus policy debates about wetland protection.

Wetland Area

The total area of wetland in the United States has been estimated by various agencies and organizations. The difficulties in exactly defining wetland lead to some differences among agencies' wetland classifications and inventories, but as our review will indicate, most area estimates are reasonably close. The most widely cited reference on U.S. wetland is a study that summarized wetlands trends from the 1780s to the 1980s (Dahl 1990). This reference, however, does not include separate state or regional tabulations of the area of forested wetland. Wetland totals from Dahl are summarized by state and subregion of the South in Table 1. A recent USDI Fish and Wildlife Service National Wetland Inventory estimated that there were 103 million acres of wetland in the U.S. in the mid 1980s--51.75 million acres of which were palustrine (fresh-water) forested wetland (Dahl and Johnson 1991).

The USDI Fish and Wildlife Service surveys report estimated wetland losses that occurred in the U.S. over the past 200 years, based on the wetland definitions of Cowardin et al. (1979) and on historical records. According to the USDI data, the U.S. had 104 million acres of wetland in the 1980s, which was about one-half the estimated area in the 1780s (Dahl 1990).

The second principal source of data on wetland areas is the USDA Soil Conservation Service (1982, 1989) Natural Resource Inventory (NRI). The NRI is conducted periodically on all nonfederal land in the United States to estimate land uses and cover types. NRI data collected in 1982 and 1987 include information on forested wetland areas for various regions of the South, based on the SCS crop production subregions shown in Figure 1. The 1982 survey provides enough detail to estimate wetland forest types, as well as total forest area. Table 1 also summarizes the total NRI forested wetland areas by subregion and by year in the South. Table 2 summarizes the 1982 distribution of forested land areas in the South by forest cover type.

According to the NRI data, there were about 81.9 million acres of nonfederal wetland in the U.S. in 1987, down from 83.1 million acres in 1982.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Project Leader, Southeastern Forest Experiment Station, Research Triangle Park, NC, and Research Wildlife Bioligist, Rocky Mountain Forest Experiment Station, Fort Collins, CO.

Table 1. *Wetland Area by State and Region, 1780s to 1980s.*

State/Region	Data Source: Fish & Wildlife Service Palustrine Wetland		Data Source: Soil Conservation Service Natual Resources Inventory			
			Total Wetland		Forested Wetland	
	1780s	1980s	1982	1987	1982	1987
Appalachian						
Kentucky	1,566,000	300,000				
North Carolina	11,089,500	5,689,500				
Tennessee	1,937,000	787,000				
Viginia	1,849,000	1,047,613				
West Virginia	134,000	102,000				
Subtotal	16,575,500	7,953,113	5,912,600	5,733,800	4,576,200	4,430,300
Southeast						
Alabama	7,567,600	3,783,800				
Florida	20,325,013	11,038,300				
Georgia	6,843,200	5,298,200				
South Carolina	6,414,000	4,659,000				
Subtotal	41,149,813	24,779,300	21,922,300	21,614,200	15,600,400	15,524,600
Delta States						
Arkansas	9,848,600	2,763,600				
Louisiana	16,194,500	8,784,200				
Mississippi	9,872,000	4,067,000				
Subtotal	35,915,100	15,614,800	11,506,600	11,314,500	8,146,700	7,938,600
Southern Plains						
Oklahoma	2,842,600	949,700				
Texas	15,999,700	7,612,412				
Subtotal	18,842,300	8,562,112	3,776,700	3,763,300	1,447,400	1,455,200
Southern Total	112,482,713	56,909,325	43,118,200	42,425,800	29,770,700	29,348,700
Conterminous, US						
Total	221,129,638	104,374,314	83,110,100	81,915,700	45,459,500	45,001,700

Source: USDI Fish & Wildlife Service Data: Dahl 1990; Natural Resource Inventory Data: USDA Soil Conservation Service 1989
Note: 2.47 acres = 1 hectare

The 1987 NRI classed 45.0 million acres of the nation's nonfederal wetland as forested wetland, a drop of about 458,000 acres from 1982. In 1987, 29.3 million acres of the forested wetland, or about 65 percent of all forested wetland were in the South. (Another 30 percent of forested wetland were in the Northeast and Lake States--9.5 million acres and 19.6 million acres, respectively (Cubbage et al. 1992)).

In the South, the Southeast subregion had the largest amount of forested wetland, at 15.5 million acres. The Delta subregion had 7.9 million acres of forested wetland, the Appalachian subregion 4.4 million acres. The Southern Plains had only 1.5 million acres, as one would expect in this less forested area. Forested wetland comprised the largest share of total wetland area in the Appalachian subregion, at 77% of all NRI wetland acreage. Forested wetland comprised 72% of the Southeast wetland totals; 70% of the Delta totals; 39% of the Southern Plain totals; and 69% of the entire Southwide totals.

Total Forested Wetland Changes

As measured by the NRI, total nonfederal forested wetland acres in the continental U.S. dropped from 45.5 million acres in 1982 to 45.0 million acres in 1987. In the four SCS crop production regions that make up the Southern U.S., total nonfederal wetland acres decreased 692,400 acres from 1982 to 1987. Total forested wetland area decreased 422,000 acres during the same period. The Delta States of Arkansas, Mississippi, and Louisiana lost the largest amount of forested wetland from 1982 to 1987, at 208,100 acres (a 2.5% decrease of the 1982 area). The Appalachian States lost fewer acres, at 145,900, but they comprised 3.2% of the 1982 forested wetland

area. The Southeast lost only 75,800 acres (0.5% of the 1982 base), and the Southern Plains actually increased their forested wetland area by 7,800 acres (+0.05% of the 1982 base).

NRI data can be used to analyze the causes of loss of forested wetland--i.e., changes from nonfederal forested wetlands to nonwetlands or to nonforested

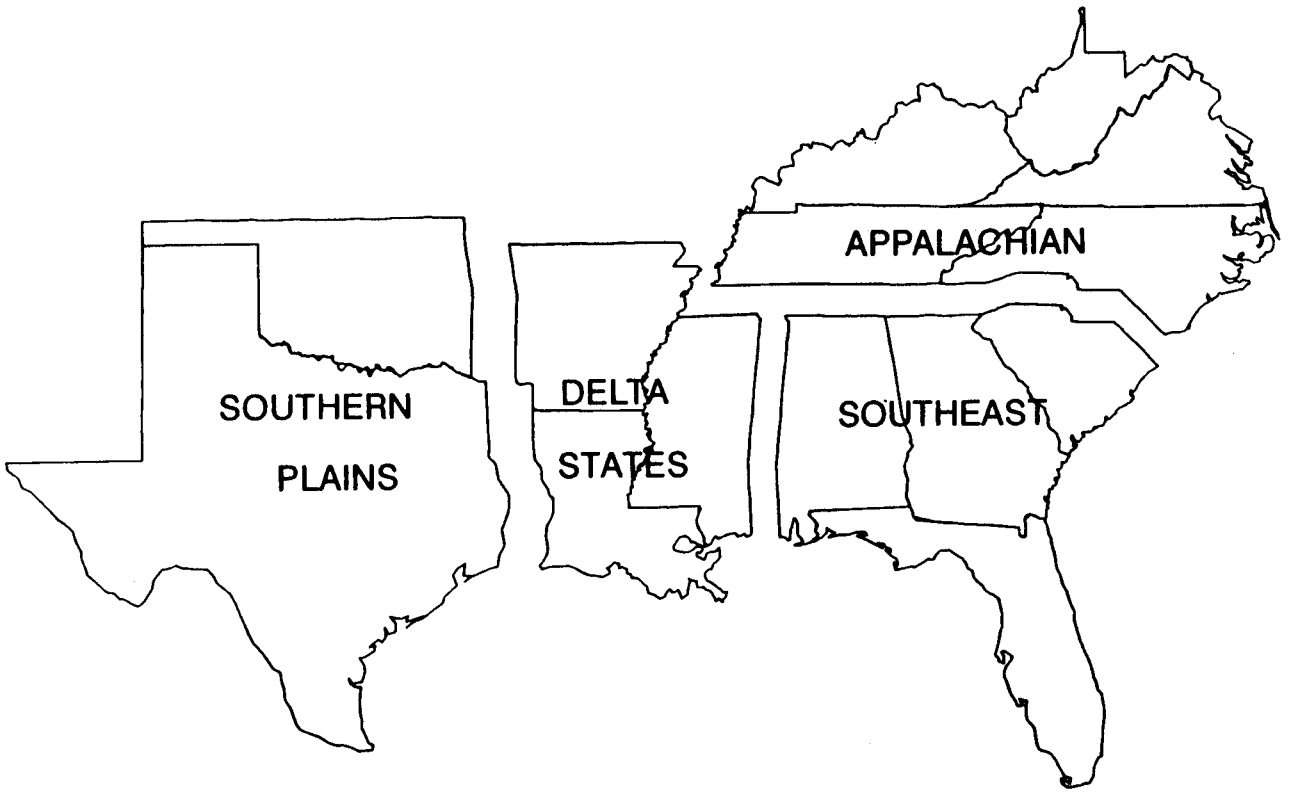

Figure 1. *Regions used for analysis of southern forested wetland trends.*

wetland. About 80,000 acres of 422,000 southern acres lost from 1982 to 1987 changed from forested wetland to urban uses; about 39,000 acres were lost to rural transportation (roads, bridges, etc.). From 1982 to 1987, 74,300 forested wetland acres were cleared and planted in cultivated crops; some 46,200 of these acres were in the Delta States, 28,100 in the Appalachian States, and none in the other regions. Losses to pastureland were only 13,300 acres. Changes of wetlands to bodies of water caused the loss of 12,400 acres in the South. The largest loss of nonfederal wetland was through federal purchase. From 1982 to 1987, 37,000 acres of forested wetland in the Delta became federally owned, as did 116,200 acres in Appalachia, and 40,000 acres in the Southeast, for a total of 193,200 acres. Thus almost one-half of the lost nonfederal forested wetland probably remained in wetland, unless it was flooded by federal dams that were completed in the 1980s.

An additional 152,500 acres that were forested wetland in 1982 were classed as wetland in 1987, but no longer were forested. Over 100,000 acres were cleared in the Delta States, including 36,600 acres classed as bush and 37,500 acres classed as pasture and hayland in 1987.

Forested Wetland Distribution

The 1982 NRI data include an intensive sample that can be used to classify forested wetland areas by the type of wetland. This sample was three times more intensive than the 1987 NRI, so the total forested wetland acres based solely on the 1982 NRI do not equal the Table 1 totals.

The 1982 data divided the forested wetland areas in the South into five classes. Freshwater basins and flats comprise the largest share of nonfederal forested wetland, at almost 15 million acres or 56% of the total. Wooded swamps comprised the second largest forested wetland class, at 10.2 million acres, or 38% of the southern total. Bogs comprised 1.0 million acres, mangrove swamps 0.35 million, and shrub swamps 0.23 million. The Delta States had almost 80% of their nonfederal forested wetlands in freshwater basins; the Southeast had about one-half its

forest wetlands in wooded swamps. It also had 99% of the mangrove swamps.

The 1982 NRI intensive sample also allows breakdowns into broad (Table 2) and specific forest types. By broad forest type, oak-gum-cypress comprised 48.5% (13.0 million acres) of the total in the South. Oak-hickory, (19.6%), oak-pine (14.5%), and loblolly-short leaf pine (7.1%) types constituted the largest share of remaining wetland forest types in the South (a total of 11.0 million acres). Southern pine types comprised 10.24% of all nonfederal wetland, or 2,743,700 acres. The greatest share of wetland pine and oak-pine types occurred in the Southeast--3.7 million acres.

The breakdown of forested wetland by specific forest types provides more interesting detail. The baldcypress-water tupelo type is the largest single forest type, at 4.3 million acres or 16.0% of all nonfederal forest wetlands in the South. Other large forest types include the swamp chestnut-cherrybark oak (14.1%); sweetbay-swamp tupelo (12.6%); mixed hardwoods (11.1%); and loblolly-hardwood (9.6%). Again, the pine types are relatively minor share (7.72%) of the total nonfederal forested wetland area. The Southeast holds the largest pine wetland area, at 1.3 million acres.

Forest Inventory and Analysis Data

Various studies that have used USDA Forest Service Forest Inventory and Analysis (FIA) data to estimate forested wetland trends for the U.S. or parts of the South. Abernethy and Turner (1987) used the FIA forest type groups and local types (i.e., oak-gum-cypress, elm-ash-cottonwood, black spruce) that denote forested wetlands to estimate trends in the U.S. Using this approach, they found that forested wetlands in the South had decreased about 6.8 million acres from 1940 to 1980. They estimated that the Southeastern U.S. had lost 1.1 million acres, and the South Central U.S. had lost 4.6 million acres.

In a more recent analysis, Tansey and Cost (1990) examined the use of FIA data to estimate forest wetland areas in the Southeast (Florida, Georgia, South Carolina, North Carolina, and Virginia). They examined the accuracy of using the forest type data alone versus the official three-part (soils, hydrology, vegetation) wetland criteria. They examined the timberland areas in the Southeast that are classed similar to the palustrine (freshwater) forest and scrub/shrub group as used by the FWS and Cowardin et al. (1979), and the forest group of the estuarine system.

Tansey and Cost classed the FIA forested wetland plots into three groups. Class 1 met the vegetative requirements (greater than 50% stocking with wetland species) and the hydrological requirements. Category 2 met the vegetation requirement but had no evidence of water. Category 3 showed evidence of flooding, but had less than 50% hydrophytic vegetation. Category 4 plots were well-drained uplands. Using this approach, the authors found that there were 9.6 million acres of timberland in Category 1; 4.9 million acres in Category 2; 11.9 million acres in Category 3; and 44.2 million acres in Category 4. The authors noted that the data were taken during the dry 1980s, so little flooding was likely. Pine plantations were not included in the wetland classification analysis. Of all the forested wetlands, 86% were in the Coastal Plain. Deep swamps comprised 8% of the wetland area and 15% were flatwoods. By forest type, 68% were classed as bottomland hardwoods, 18% other hardwood types, 5% as pond pine sites, and 9% as other pine types (Tansey and Cost 1990). These estimates can be compared to the 1987 NRI estimates of 14.7 million acres of nonfederal forested wetlands for the same five Southeastern States.

Tansey and Cost found that general forest type and physiographic class were not good estimates of forested wetland area, based on the Southeastern Station survey data. For instance, nearly 29% of all bottomland hardwood stands in the Southeast are on well-drained mesic sites such as broad floodplains. Another 25% occur in flatwoods, gently rolling terrain, or other types of mesic sites. A portion of other forest types, such as pond pine and slash pine sites, do not meet wetland criteria. Physiographic class also was not accurate. Only 72% of the hydric sties and mesic floodplains had evidence of water during the most recent survey cycle. Hydric sites supported about 1 million acres of upland oak-hickory and 1.2 million acres of other upland species (Tansey and Cost 1990). Other forest experiment stations use somewhat different inventory methods, but it seems that the forest types as reported in FIA publications cannot estimate forested wetland area trends as well. Instead one must use the original FIA plot data, and screen it according to the current accepted federal wetland criteria for vegetation, hydrology, and soils, or supplement it with other information.

Table 2. Forested Wetland Area by Region and Broad Forest Type, 1982

	SCS Natural Resources Inventory Crop Production Region									
	Appalachian		Southeast		Delta States		Southern Plains		Southern Total	
	acres	percent	acres	percent	acres	percent	acres	percent	acres	percent
Wetland Type										
Fresh basin/flat	1,747,300	42.99	6,447,700	45.34	5,589,500	78.20	1,211,800	90.24	14,996,300	56.01
Shrub swamps	42,200	1.04	164,800	1.16	17,600	0.25	5,400	0.40	230,000	0.86
Wooded swamps	1,358,400	33.42	7,182,400	50.51	1,534,900	21.47	118,200	8.80	10,193,900	38.07
Bogs	915,400	22.52	74,400	0.52	3,900	0.05	7,500	0.56	1,001,200	3.74
Mangrove swamps	900	0.02	350,400	2.46	2,000	0.03	0	0.00	353,300	1.32
Total	4,064,200	100	14,219,700	100	7,147,900	100	1,342,900	100.00	26,774,700	100.00
Forest Type										
White-red-jk pine	3,800	0.09	1,900	0.01	0	0.00	0	0.00	5,700	0.02
Spruce-fir	2,700	0.07	0	0.00	0	0.00	0	0.00	2,700	0.01
Longleaf/slash	7,900	0.19	660,000	4.64	158,500	2.22	15,000	1.12	841,400	3.14
Loblolly/shortlf	891,200	21.93	735,700	5.17	202,900	2.84	72,500	5.40	1,902,300	7.10
Oak-pine	407,000	10.01	2,313,400	16.27	717,300	10.04	433,000	32.24	3,870,700	14.46
Oak-hickory	875,500	21.54	2,989,100	21.02	1,194,200	16.71	193,400	14.40	5,252,200	19.62
Oak-gum-cypress	1,448,700	35.65	6,564,400	46.16	4,440,100	62.12	543,300	40.46	12,996,500	48.54
Elm-ash-cottonwd	199,600	4.91	157,800	1.11	348,600	4.88	39,700	2.96	745,700	2.79
Maple-beech-birch	19,500	0.48	5,900	0.04	0	0.00	0	0.00	25,400	0.09
Aspen-birch	3,500	0.09	0	0.00	0	0.00	0	0.00	3,500	0.01
Low productivity	5,500	0.14	77,500	0.55	2,400	0.03	0	0.00	85,400	0.32
Tropical forest	0	0.00	3,300	0.02	0	0.00	0	0.00	3,300	0.01
Nonstocked	187,400	4.61	170,800	1.20	71,000	0.99	22,800	1.70	452,000	1.69
Not specified	11,900	0.29	539,900	3.80	12,900	0.18	23,200	1.73	587,900	2.20
Total	4,064,200	100.00	14,219,700	100.00	7,147,900	100.00	1,342,900	100.00	26,774,700	100.00

Source: 1982 Natural Resources Inventory, USDA Soil Conservation Service 1987
Note: 1982 NRI forested wetland area data totals in Table 1 and Table 2 are not identical because the sampling intensity was three times greater and thus more accurate for Table 2. Data in Table 1 used the lower 1982 sample intensity to match the less intensive 1987 resurvey.

Discussion

According to Dahl (1990), the United States lost almost one-half its original wetland between the 1780s and the 1980s. In the southern states examined here, the total wetland area also decreased by about half, from 112 million acres to 57 million acres. Furthermore, Dahl et al. (1991) estimate that the palustrine (freshwater) forested wetlands in the conterminous U.S. have decreased from 55.15 million acres in the mid-1970s to 51.75 million in the mid-1980s. This represents a loss of 6.2% in 10 years.

We analyzed the SCS Natural Resource Inventory data files to examine the trends in nonfederal forested wetlands more closely. These data estimate wetland areas based on USDI Fish and Wildlife Service Circular 39 (Shaw and Fredine 1956), which recognized 20 wetland types based primarily on their value to waterfowl. The NRI data for private lands should be within 5 percent of FWS data (Cubbage et al. 1992). The data were summarized according to the SCS crop regions, which we aggregated into a combined southern region. The NRI data showed that the U.S. as a whole lost 457,800 acres of forested wetland from 1982 to 1987, (1.0% of the base), and the South lost 422,000 acres of forested wetlands, or 1.4% of the base. The greatest amount of forested wetlands loss in the South from 1982 to 1987 occurred in the Appalachian subregion (3.18%)--probably mostly in North Carolina and Virginia. The Delta States lost 2.55% of their area, and the Southeast only 0.48%. The Southern Plains actually increased their nonfederal forest wetland area 0.54%.

Of the 422,000 acres of forested wetlands that were lost in the southern NRI tallies, 193,200 acres simply shifted into federal ownership and may not have been lost. The Appalachian subregion lost the greatest share due to transfers to federal ownership--116,200 acres. Some of these new federal areas probably were flooded or being purchased in anticipation of flooding from new dams. Overall, 62% of the conversions from nonfederal to federal ownership were forested wetland--slightly less than the 69% average of forested wetlands of the total southern wetlands.

According to the NRI data for nonfederal forest land, several specific forest management types are apt to include most of the southern pine forested wetlands--longleaf pine, slash pine, loblolly pine, shortleaf pine, Virginia pine, pond pine, slash-hardwood, loblolly-hardwood, short-leaf/oak and longleaf-scrub oak. If all wetland in these specifi forest types were subject to federal regulation of som type, 6,588,400 acres of nonfederal forested wetlan in the South, or 24.6% of all southern foreste wetland would be covered. There is little debate ove natural pine management on most acres, wher harvesting and natural regeneration are generall agreed on upon as falling under the Section 40 silvicultural permit exemption. Harvesting natura stands, followed by intensive site preparation an planting, is the most contentious question regardin silvicultural operations in wetlands. Minor or majo drainage during harvesting and regeneration also ar points of contention.

Specific forest types where debates have bee hottest include the approximately 600,000 acres o pond pine in Virginia and the Carolinas; the 700,00 acres of slash pine in the Southeast and Delta; the 1.2 million acres of loblolly throughout the South; and a fraction of the 3.5 million acres of slash/loblolly pine-hardwood throughout the South. In total, this area is small compared to the estimated 26 million acres o pine plantations, 38 million acres of natural pin types, and 25 million acres of mixed pine-hardwoo in the South (USDA Forest Service 1988).

These wetland area estimates help clarify the nature of the wetland protection debates. In the South, most interest groups, government agencies and private landowners agree that some protection should be afforded to wetland functions and values in hardwood forest management and harvests. These areas usually are very wet, and could be construed as environmentally sensitive and valuable. The degree of management, protection, and regulation is still subject to some debate, but not vitriolic disagreement. Thus about 20 million of 26 million acres, or 75% of the forested wetland area, is apt to be less prone to severe conflicts over use.

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LANDSCAPE DIVERSITY AND WETLANDS: AN HISTORICAL PERSPECTIVE FROM INDUSTRIAL FORESTRY [1]

John A. Stanturf and T. Conner Fristoe [2]

Abstract. Historical development of a lower coastal plain landscape in transition to intensive management was examined by analyzing two dates of aerial photographs and geostatistics. Most of the soils in the Hazzards Neck, Camden County, Georgia were hydric (94%). Marsh covers 29% of the study area; of the remainder, only 14% is presently mapped as wetlands by the National Wetlands Inventory. Industrial forest management, over the interval from 1953 to 1978, altered the landscape significantly. Large areas of cutover land and open, fir-maintained woodlands were converted to pine plantations. Within these matrices, hardwood-dominated patches (hardwood runs, bays and ponds, and bottomland stands) have been constant in time and space but have fluctuated in areal extent.

Introduction

Recent studies of the southern coastal plain have attributed significant alterations of wetlands to "forestry", specifically the establishment of pine plantations. In North Carolina, Cashin and others (1992) attributed 53% of total wetland alteration to forestry. Moorhead and Clark (1992) concluded that agriculture caused substantial wetland loss but conversions to pine plantations accounted for an additional 17% of alterations. They reached their conclusions regarding wetland alteration by comparing present landcover with a map of hydric soils. Both studies assumed that hydric soils indicated the extent of pre-colonial wetlands, and that pine plantations significantly altered wetland values or functions. This method ignores immediate past land use, and makes the questionable assumption that wetland functions are diminished by plantations (Campbell and Hughes 1991; Shepard 1992).

We examined the historical development of a forested landscape in the lower coastal plain of Georgia during the transition to intensive forest management. We asked whether industrial forestry had a discernible impact on the lower coastal plain landscape, and investigated the effect on some geostatistical parameters of landscape pattern. Our study did not address the question of whether wetland functions were significantly altered by establishing pine plantations.

Background

The Lower Coastal Plain (LCP) of Georgia consists of several low terraces of marine origin, roughly parallel to the present coastline (Hodler and Schretter 1986). Elevations average between 15 ft. and 25 ft. above mean sea level (msl), and up to 40 ft. above msl at the western escarpment. The western portion of the LCP is flat, with sandy surface soils. On the east, the irregular coastline is marked by a series of barrier islands seaward with intermingled tidal marshes. The LCP is traversed by few rivers (Hunt 1974).

Wetlands are found along the coast where tidal swamps and marshes are locally extensive. Fluviatile (alluvial) swamps are commonly associated with rivers and creeks and are extensive in the floodplains of major rivers such as the Altamaha and Ogeechee. Upland swamps, probably formed in old depressions of the seafloor, are not in floodplains but often are headwaters. The largest and most renowned of these in Georgia is the Okefenokee Swamp but there are many others. Additionally, numerous shallow depressions dot the landscape. Variously termed ponds and bays, these wetlands usually are less than an acre in size. Associated with them are wet flats, particularly in the eastern LCP, locally termed flatwoods.

Most of the LCP forests have a long history of exploitation for wood products, naval stores, agriculture, and grazing (Southern Forest Resource Analysis Committee 1969). The extensive flatwoods

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[1] Paper presented at Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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were subjected to periodic burning, a practice predating European settlement. Early in this century, natural stands were mostly longleaf and slash pines, but because of periodic fires were often not closed forests. Grasses and saw palmetto formed the understory, except that hardwood understories established on wetter sites. In the swamps, cypress dominated. In ponds and bays, selective logging, usually of slash pine and pond pine, released residual hardwoods.

Fire, or the lack of fire, shaped the vegetation over extensive areas. Fire control effectively began in Georgia in 1926 with the establishment of Timber Protective Organizations. During the period from 1931 to 1935, for example, fires burned annually over 27% of the total area of unprotected land. On protected land, only 6% of the area burned annually (Widner 1968). A state-wide fire control act was signed only in 1949. Aerial views of Union Camp land in the late 1940s show a landscape of isolated depressional wetlands, primarily hardwoods but mixed with occasional cypress and pine; extensive areas of cutover pine stands, and small hardwood and cypress runs feeding into larger hardwood-dominated bottomland forests.

Materials and Methods

The Hazzards Neck study area on Union Camp land in Camden County was chosen because it is sparsely populated today, as it has been since the 1800s (Hodler and Schretter 1986), and changes in the landscape are primarily due to forest management. One reason for the low population was poor transportation. One feature of early industrial management was the construction of woods roads, which opened heretofore inaccessible areas to effective fire control.

Two dates of panchromatic aerial photography were manually interpreted to produce landcover maps for February 1953 and March 1978. Company cutting maps of various dates from the 1950s and 1960s assisted interpretation, as did maps of recent stand conditions. Other interpretive aids included a collection of ground level photographs taken during the late 1940s and early 1950s, to document typical conditions and practices on company land; and the National Wetlands Inventory (NWI) map for the Dover Hall Quadrangle, delineated from 1983 color infrared high altitude air photos.

A map of hydric soils in the study area was derived from Union Camp soil surveys. Soils were mapped on company land on a grid 10 ch by 10 ch. Within transect lines, areas were spot checked. Maps were produced at a scale of 1:15,840. We produced a map of hydric soils by referring to the national checklist of hydric series (SCS 1991). Areal extent of hydric soils and wetlands as delineated on the NWI map were determined by electronic planimeter.

The landcover maps interpreted from the 1953 and 1978 air photos were digitized into the IDRISI GIS software (Eastman 1992). We examined landscape pattern, utilizing the spatial analysis capabilities of IDRISI. We looked at three landscape properties: patch size, abundance, and shape. A patch is a polygonal map unit of a landcover class. The descriptors of the three properties in each landcover class were mean patch area and mean patch perimeter for size; and density of patches and percentage of the total area in patches of each class for abundance.

Patch shape descriptors are less intuitive than descriptors of size and abundance. Two descriptors, the mean of the perimeter/area ratio and the mean of the compactness ratio, have similar interpretations: as either ratio increases, the shape is less simple. The compactness ratio is the square root of the area of a patch divided by the area of a circle with the same perimeter length as the patch. A small compactness ratio, therefore, means a more compact patch; a circle represents the most compact shape for a given perimeter length.

Fractal dimension measures the complexity of patch shape, and is based on the area-perimeter relationship. Fractal dimension is computed by regressing the log of patch area against log perimeter; fractal dimension is twice the slope of the regression line (O'Neill et al. 1988; Ripple et al. 1991; Turner 1989). Theoretically, natural landscapes are more complex than human-influenced landscapes (Turner 1989). A fractal dimension greater than 1 indicates a complex shape (Ripple et al. 1991).

Our analysis of landscape pattern concentrated on the hardwood dominated patches, as the present landscape is a matrix of pine plantations. We examined ponds and bays, hardwood runs, and all hardwood-dominated patches together. Statistical analysis of the pattern descriptors, comparing the two dates, used the Wilcoxon Rank-Sum, 2-sample non-parametric test, with the Kruskal-Wallis Chi-Square approximation for significance testing at the 5% level (SAS Institute Inc. 1990).

Results

Most of the soils in the study area are assified as hydric (94%). The principle series are hicket in the marshes and Ellabelle and Olustee in e runs and ponds. The flats are dominated by soils the Pelham, Mascotte, Sapelo, and Plummer series. xclusive of the marsh, these soils are a mixture of ndy surfaced Ultisols and Spodosols with clay at pth (Table 1). Soils of the swamps, runs and ponds e very poorly drained; soils on the flats are poorly ained or better. Small areas of somewhat poorly ained, non-hydric soils are mapped as the Ocilla, agate, and Albany series and occur in a band along e marsh and likely represent a remnant natural vee.

According to the NWI map, marsh accounted r 29% of the study area. Only 14% of the non-arsh area was mapped as wetlands. All the non-arsh wetlands in the study area were palustrine, rested, broadleaved deciduous and needleleaved vergreen, with intergrades between vegetation classes d inundation regimes.

Comparing the landcover in 1953 and 1978 vealed more pine stands in 1978, mostly in antations. The hardwood patches appeared in the me locations in 1978 as in 1953, but diminished in ze. A few small isolated patches in 1978 were eated from larger patches in 1953 by converting ardwood or mixed pine-hardwood stands to pine lantations. The areas of "cutover" land, extensive in 953 and probably including fire-maintained open oodlands, were in pine plantations by 1978.

The acreage in each landcover class on the vo dates is compared in Table 2. The areas in ponds nd bays increased slightly over the 25 years, but the ther hardwood-dominated classes (runs, fringe ardwoods, and hardwood-pine mixes) decreased ubstantially. Cutover and regenerating land declined n area, as did natural pine stands, from 591 to 70 cres. Pine plantations increased from none in 1953 o 877 acres in 1978. The area in "outs" increased ubstantially due to the construction of Interstate 95.

Bays and ponds increased in density, from 19 n 1953 to 40 in 1978 (Table 3). This likely resulted rom fragmentation of larger hardwood patches, such s the one in the center of the study area, but also was ue to better discrimination of bays and ponds in ormer hardwood and cutover areas. On average, ays and ponds became significantly more compact Table 6).

The total area classified as hardwood runs decreased between 1953 and 1978 (Table 2), which is reflected in the percentage of the area in patches of this type (from 22% in 1953 to 10% in 1978; Table 4). Average patch size of hardwood runs declined over the interval, although not significantly so. The shape of individual patches remained similar, as indicated by non-significant changes in the perimeter/area ratio, compactness ratio, and the fractal dimension. Manual overlay of the landcover maps of the two dates indicated that while individual patches retained their shape over the interval, their areas were reduced by "shrinkage" from the edge inward.

Taking all hardwood classes together (Table 5), mean patch area declined significantly (Table 6), from 86 acres to 16 acres. Mean patch perimeter also declined significantly; patches averaged half as long in 1978 as compared to 1953 (Table 3). The total area in hardwoods declined over the 25 year interval, from 22% in 1953 to 13% in 1978 (518 acres to 306 acres). Although the perimeter/area ratio significantly increased, indicating more complex or less compact shapes, the increase in the compactness ratio was not significant.

Discussion

Small depressional wetlands in the study area, classified as ponds and bays, were stable over the 25-year interval. They increased in number (from 19 to 40), but this was probably due to our poor ability to discriminate bays and ponds from other hardwood-dominated types in the black and white photographs. The well-defined hardwood runs remained, although scaled down in size between 1953 and 1978 as indicated by declines in total area and in average patch size. Several large areas of hardwoods in 1953 were converted to pine plantations, but wetter areas (indicated by soil drainage class) within the larger hardwood patches in 1953 appear as isolated ponds and bays in 1978. On the flats, the vegetation pattern now more closely follows soil drainage, with hardwoods in 1978 occurring primarily on the very poorly drained soils of the Ellabelle series and pine plantations on the poorly drained Pelham series.

Industrial forest management has altered the landscape in the study area. The landscape in 1953 was matrix of large areas of cutover land and fire-maintained open woodlands, interspersed with small depressional wetlands and floodplain swamps. The flats were covered by mixed stands on wetter soils and natural pine or open woodland on better drained soils.

Table 1. *Soils of the Hazzards Neck study area, Camden County, Georgia.*

Landform	Hydric	Series	Drainage* Class	Taxonomy
Marsh	Yes	Bohicket	VP	Typic Sulfaquents
Runs, Ponds	Yes	Ellabelle	VP	Arenic umbric Paleaquults
		Olustee	VP	Ultic Haplaquods
Flats	Yes	Pelham	P	Arenic Paleaquults
	Yes	Mascotte	P	Ultic Haplaquods
	Yes	Sapelo	P	Ultic Haplaquods
	Yes	Plummer	P	Grossarenic Paleaquults
Ridges	No	Ocilla	SWP	Aquic arenic Paleudults
	No	Seagate	SWP	Typic Haplohumods
	No	Albany	SWP	Grossarenic Paleudults

* VP = Very Poorly, P = Poorly, SWP = Somewhat Poorly

By 1978, pine plantations formed the new matrix, but were still interspersed with small depressional wetlands and floodplain swamps dominated by hardwoods.

Table 2. *Acreage in Landcover classes compared for two dates (1953 vs. 1978), Hazzards Neck study area, Camden County, Georgia.*

Landcover Class	1953	1978
	---------(acres)---------	
Ponds and Bays	25	31
Hardwoods*	518	306
Cutover and regenerating	333	132
Natural Pine	591	70
Pine Plantation	0	877
Out (Urban, I-95)	150	250
Marsh	717	667
Total	2335	2335

* Includes all hardwood-dominated classes except ponds and bays: hardwood runs, fringes, and hardwood-pine mixes.

We believe that most of the area of hardwood patches converted to pine plantations between 1953 and 1978 were mixed pine/hardwood stands or pine stands with hardwood understories at the turn of the century. These stands were taken over by hardwoods as fire was suppressed, cattle were excluded, and the remaining pine overstory trees were logged. In addition, large areas of cutover land in 1953 were artificially regenerated to pine. Interpretation of aerial photographs from company land, elsewhere in Georgia and in South Carolina, revealed a similar landscape pattern of a matrix of cutover land in the 1940s and 1950s changing to a matrix of pine plantations by the 1970s and 1980s. Within these matrices, the hardwood runs, bays and ponds, and bottomland stands have been constant in both time and space, although they have fluctuated in areal extent.

Acknowledgements

We thank Bill Garbett, Donnie Bradshaw, Bill Wikoff, Joel Moore, Randy Scott, and David Johns of Union Camp for assistance with this study.

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Table 3. *Landscape pattern comparison for ponds and bays on two dates (1953 vs. 1978), Hazzards Neck, Camden County, Georgia.*

Descriptor	Unit	1953	1978
Mean patch area	ft^2(acre)	594,490(1.36)	34,264(0.79)
Mean patch perimeter	ft	1,053	921
Patch density	count	19	40
Percent patches	%	1.05	1.35
Perimeter/area	ratio	0.0265	0.033
Compactness	ratio	0.7554	0.6959
Fractal dimension	index	1.18	1.16

Table 4. *Landscape pattern comparison for hardwood runs on two dates (1953 vs. 1978), Hazzards Neck study area, Camden County, Georgia.*

Descriptor	Unit	1953	1978
Mean patch area	ft^2(acre)	3,759,935(86.3)	1,508,670(34.6)
Mean patch perimeter	ft	18,036	15,151
Patch density	count	6	7
Percent patches	%	22.2	10.4
Perimeter/area	ratio	0.0087	0.0228
Compactness	ratio	0.4214	0.4649
Fractal dimension	index	1.23	1.41

Table 5. *Landscape pattern comparison for all hardwoods on two dates (1953 vs. 1978), Hazzards Neck study area, Camden County, Georgia.*

Descriptor	Unit	1953	1978
Mean patch area	ft^2(acre)	3,759,935(86.3)	702,638(16.1)
Mean patch perimeter	ft	18,036	7,488
Patch density	count	6	19
Percent patches	%	22.2	13.1
Perimeter/area	ratio	0.0087	0.0204
Compactness	ratio	0.4214	0.5085
Fractal dimension	index	1.23	1.38

Table 6. *Significance tests for landscape pattern comparisons on two dates (1958 vs. 1973), Hazzards Neck study area, using Wilcoxon Rank Sums procedure and Kruskal-Wallis chi-square approximation for significance tests at 5% level.*

Comparison	Description	CHI SQ	DF	PROB > CHI SQ
Ponds and Bays	Compactness	6.2329	1	0.0125
All Hardwoods	Mean area	6.4777	1	0.0109
	Mean perimeter	5.8462	1	0.0156
	Perimeter/area	5.2470	1	0.0220

A STATISTICAL DESCRIPTION OF HYDRIC SOILS OF THE SOUTHEASTERN UNITED STATES [1]

James P. Shepard [2]

Abstract. There have been many publications classifying wetlands and describing their geographic distribution, but no large-scale, detailed description of hydric soils has been prepared. The objective of this analysis was to provide statistics that characterize the hydric soils of the Southeastern United States in terms of their areal distribution among states, taxonomic groups, and water table, flooding, and ponding regimes. Hydric soil data from the SCS national list of hydric soils were matched with areal estimates for each soil and the areal distribution among states. The Southeast has more hydric soils and wetlands than any other region of the conterminous United States. All nine of the taxonomic soil orders that occur in the Southeast have some hydric soils. Hydric Entisols were most common, although the areal distribution into soil orders differed greatly among the southeastern states. Most hydric soils were in the Poorly Drained or Very Poorly Drained classes. The majority of southeastern hydric soils were considered hydric because they meet both the inundation and saturation criteria. However, a significant percentage (35%) meet only the saturation criteria. The areal distribution of hydric soils among criteria classes differed markedly among states.

Introduction

The term "hydric soil" was introduced in the vetland classification system of Cowardin et al. 1979). Since then, the USDA Soil Conservation Service (SCS), in cooperation with the US Fish and Wildlife Service (FWS), have been developing and efining criteria to aid in recognizing hydric soils. Hydric soil is one of three characteristics, along with ydrophytic vegetation and wetland hydrology, used o identify wetlands for purposes of regulatory urisdiction for Section 404 of the Clean Water Act Environmental Laboratory 1987 and Federal nteragency Committee for Wetland Delineation 989).

The SCS is responsible for mapping and lassifying soils in the United States through the National Cooperative Soil Survey. The soils of pproximately 87% of the land area of the 48 onterminous states have been mapped since the urvey program began about 1899. The soil lassification system used by the SCS is hierarchial Soil Survey Staff 1975) and includes more than 8,000 soil series and over 33,000 phases subdivisions of series). Physical and chemical data n each series and phase are maintained in the SCS oil Interpretations Record (SIR) data set (Mausbach 992).

The National Technical Committee for Hydric Soils (NTCHS) is a committee of soil scientists from the SCS and academia, as well as representatives from the FWS, the US Environmental Protection Agency, US Army Corps of Engineers, and the USDA Forest Service. According to the NTCHS "A hydric soil is a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part" (SCS 1991).

The NTCHS have developed and continue to refine a set of criteria used to identify those soils in the SIR data set that are potentially hydric (SCS 1991). These criteria specify limits for the frequency and duration of inundation and water table depths according to soil drainage class, texture, and permeability for all taxa that could be hydric.

A computer program was developed that searches all soils in the SIR data set and identifies those that meet any one of the criteria. These soils are included in the national list of hydric soils. The most recent list specifies approximately 3400 soil series and phases (SCS 1991). The national hydric soils list is updated periodically since the SIR database is dynamic, with new soils being added as the remainder of the United States is mapped and as old surveys are revised. In addition, new national hydric soils lists are created when changes are made in the criteria to reflect better understanding of hydric soils.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Forest Environmental Scientist, National Council of the Paper Industry for Air and Stream Improvement, Gainesville, FL.

soils lists are created when changes are made in the criteria to reflect better understanding of hydric soils.

There have been many publications classifying wetlands and describing their geographic distribution (Shaw and Fredine 1956, Tiner 1984, Dahl 1990, and Dahl et al. 1991). Correlations between hydric soils and vegetation have been investigated (Scott et al. 1989 and Segelquist et al. 1990) and hydric soils have investigated locally (Moorhead and Cook 1992). However, there has been no large-scale, detailed description of hydric soils.

The objective of this paper is to provide statistics that characterize the hydric soils of the southeastern United States in terms of their areal distribution among states, taxonomic groups, and water table, flooding, and ponding regimes.

Methods

I obtained hydric soil data from the Iowa State University Statistical Laboratory, which maintains the SIR and hydric soils data for the SCS. The data consisted of all information published in SCS (1991) plus the total area mapped for each soil as well as the areal distribution by state. In addition, the data set contained soils not yet classified to the series level that meet at least one hydric soil criterion.

Soil mapping is not yet complete for some states. To estimate whole-state hydric soil area, I divided the total area mapped by the fraction of the state that has been mapped. The SCS delineation of the Southeast was used in this paper (Fig. 1).

Statistics were calculated using SYSTAT software, version 5.0 (Systat, Inc., Evanston, IL).

Results and Discussion

Areal Distribution Among Southeastern States

Louisiana and Florida have the greatest acreage of hydric soils among the southeastern states and are similar with both having approximately 13.7 million acres (Fig. 1). Oklahoma has the least hydric soil acreage with less than a million acres (Fig. 1).

For the region as a whole, hydric soils are 14.2% of the land area. However, half of the southeastern states (AR, LA, MS, NC, SC, and FL) have more than 25% of their land area in hydric soils and nearly half of Louisiana's soil is hydric (Fig. 1). Texas and Oklahoma had the least amount of hydric soils relative to land area. Both states contain areas more arid than the majority of the region. In general, states with large coastlines (LA, FL, SC, and NC) had the greatest fractions of their land areas in hydric soils due to coastal wetlands.

The conterminous 48 states contain 179 million acres of hydric soils. The southeast, with 76.7 million acres, has more hydric soils than the Northeast (22.0 million acres), the Midwest (70.1 million acres) and the West (10.6 million acres). The Southeast region represents 28% of the conterminous United States land area but accounts for 43% of its hydric soils. The Southeast also accounts for 54% of the conterminous United States wetlands (Dahl 1990).

Areal Distribution Among Soil Taxa

Nine of the 11 soil orders of Soil Taxonomy (Soil Survey Staff 1975) are represented in southeastern hydric soils (Table 1). The other two orders, Oxisols and Andisols, do not occur in the region. Hydric Entisols were most common and made up 23% of the hydric soil acreage (Table 1). Entisols are soils that have undergone little pedogenic development (Soil Survey Staff 1975). Over 60% of the hydric Entisol area is in the great group Fluvaquents, which occur in wet areas of flood plains. Alfisols and Inceptisols were also common and represented about 20% each of the region's hydric soil area.

Although wetlands are often thought of as being swamps and bogs with organic soils, only about 10% of the regions hydric soil area are Histosols, the organic soil order (Table 1). Histosols are separated into suborders on the basis of moisture regime and the degree to which the organic material has been decomposed. The majority of southeastern hydric histosols were in the suborder Saprists, soils whose organic matter is almost completely decomposed. Three states (FL, LA, and NC) accounted for 93% of the Southeast's hydric Histosols.

There were over a hundred thousand acres of hydric Aridisols (Table 1). These soils were found exclusively in Texas and were all in the great group Salorthids, salty soils found in dessert depressions where groundwater saturates the soil (Soil Survey Staff 1975). Texas also had the majority (93%) of the Southeast's hydric Vertisols.

Spodosols account for only four percent of the Southeast's hydric soils (Table 1). Spodosols are extensive in Florida, however, and represent 18% of it's hydric soils. Florida alone accounts for 71% of the Southeast's hydric spodosols.

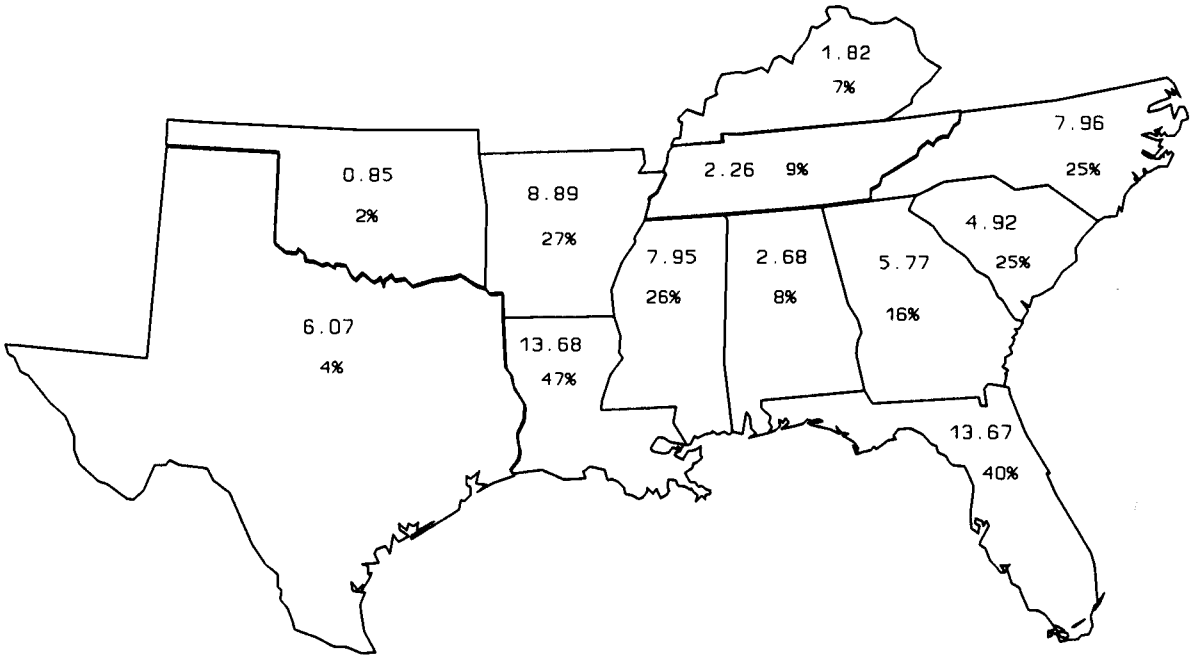

Figure 1. *Areal distribution of hydric soils of the southeastern United States. Upper numbers are millions of hydric soils acres. Lower numbers are hydric soils as a percent of the state's land area.*

Water Table, Drainage, and Inundation Characteristics

The majority of the Southeast's hydric soils are in the Poorly Drained class, followed by Very Poorly Drained and Somewhat Poorly Drained (Fig. 2). There are approximately four million acres in Moderately Well Drained and better drained classes, although these are a small fraction (5%) of the region's hydric soils.

The average depth of the seasonal high water table was deeper for better drained classes (Fig. 2). Only the Very Poorly Drained class had average seasonal high water tables (upper estimate) above the surface. Many individual soils, however, in classes from Moderately Well to Very Poorly Drained had water tables above the surface, as indicated by the one standard deviation bar (Fig. 2).

Over one-fifth of southeastern hydric soil area has a flood frequency regime of None (Fig. 3). The average seasonal high water table is above zero for the upper estimate of the None flood frequency class, so many of these soils do experience ponding. The SCS draws a distinction between flooding and ponding. Flooding is the temporary covering of the soil surface by flowing water whereas ponding is standing water in a closed depression with water being removed only by percolation or evapotranspiration (SCS 1983). Both conditions are included in the hydric soil criteria (SCS 1991).

The average depth to seasonal high water tables increased with increasing flood frequency and was deepest for soils in the Frequent class (Fig. 3). About 30% of southeastern hydric soil area is associated with the Frequent flood class. A similar amount of hydric soil area is in the Common flood frequency class. Since the Common class is a hybrid of the Occasional and Frequent classes, we know only that these soils have a flooding probability of >5%.

Based on the one standard deviation bars (Fig. 3), many soils in all of these flood frequency classes have seasonal high water tables above the surface and thus experience ponding.

Southeastern hydric soils were separated into four groups according to which of the NTCHS criteria in SCS (1991) caused them to be on the national hydric soils list. The groups were: (1) inundated soils (those meeting NTCHS criteria 3 or 4 for flooding or ponding), (2) organic soils (those meeting NTCHS criterion 1), (3) saturated soils (those soils that meet NTCHS criteria 2A, 2B1, 2B2, or 2B3), and (4) inundated and saturated soils (those soils meeting NTCHS criteria 2A, 2B1, 2B2, or 2B3 and NTCHS criteria 3 or 4).

Table 1. *Areal distribution of mapped southeastern hydric soils among soil taxa (Soil Survey Staff 1975).*

Order	Great group	Area (acres)	Relative Area Order (%)	Relative Area Southeast (%)
Alfisols	Albaqualfs	908,741	6.2	1.2
	Fragiaqualfs	583,846	4.0	0.8
	Fragiudalfs	3,584	<0.1	<0.1
	Glossaqualfs	6,136,732	41.9	8.3
	Hapludalfs	664,533	4.5	0.9
	Natraqualfs	807,735	5.5	1.1
	Ochraqualfs	5,269,972	36.0	7.2
	Paleudalfs	1,344	<0.1	<0.1
	Umbraqualfs	279,744	1.9	0.4
	Sum	14,656,231	100.0	19.9
Aridisols	Salorthids	140,713	100.0	0.2
Entisols	Fluvaquents	10,419,242	61.1	14.1
	Haplaquents	57,964	0.3	0.1
	Hydraquents	1,854,972	10.9	2.5
	Psammaquents	1,750,414	10.3	2.4
	Quartipsamments	3,562	<0.1	<0.1
	Sulfaquents	948,737	5.6	1.3
	Udifluvents	1,996,386	11.7	2.7
	Udipsamments	10,834	0.1	<0.1
	Sum	17,042,111	100.0	23.1
Histosols	Medihemists	175,263	2.5	0.2
	Medisaprists	6,556,689	93.6	8.9
	Sulfimemists	257,191	3.7	0.3
	Troposaprists	18,452	0.3	<0.1
	Sum	7,007,595	100.0	9.5
Inceptisols	Dystrochrepts	3,128,839	21.5	4.2
	Eutrochrepts	407,194	2.8	0.6
	Haplaquepts	8,565,926	58.9	11.6
	Humaquepts	2,446,851	16.8	3.3
	Sum	14,548,810	100.0	19.7
Mollisols	Argiaquolls	899,029	29.1	1.2
	Argiudolls	4,560	0.1	<0.1
	Calciustolls	10,890	0.4	<0.1
	Haplaquolls	1,452,368	47.0	2.0
	Hapludolls	720,122	23.3	1.0
	Sum	3,086,969	100.0	4.2
Spodosols	Haplaquods	3,265,175	100.0	4.4
Ultisols	Albaquults	853,756	7.4	1.2
	Fragiaquults	286,341	2.5	0.4
	Hapludults	17,038	0.1	<0.1
	Ochraquults	2,239,867	19.3	3.0
	Paleaquults	7,411,464	63.9	10.1
	Umbraquults	788,191	6.8	1.1
	Sum	11,596,657	100.0	15.7
Vertisols	Chromuderts	181,007	7.8	0.2
	Chromusterts	10,540	0.5	<0.1
	Pelluderts	1,475,103	63.2	2.0
	Pellusterts	668,180	28.6	0.9
	Torrerts	560	<0.1	<0.1
	Sum	2,335,390	100.0	3.2
	Southeast Sum	73,679,651		

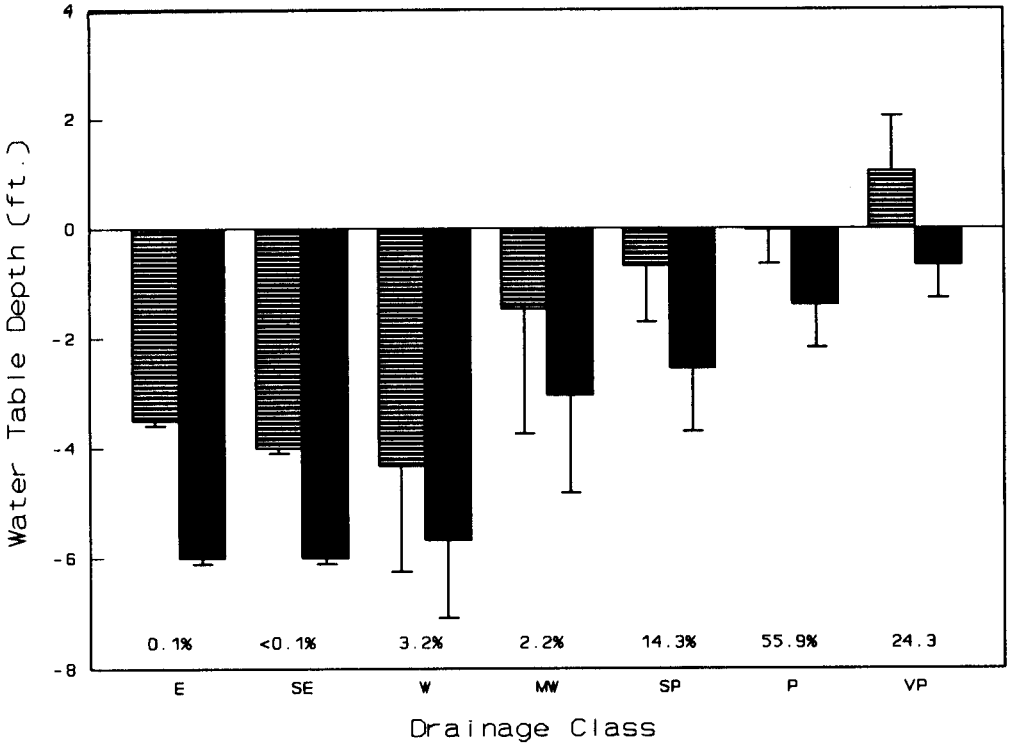

Figure 2. *Average seasonal high water tables by soil drainage classes for southeastern hydric soils. Upper and lower estimates follow conventions in SCS (1991). Percentages listed in lower portion of figure are the relative areal distribution among drainage classes.*

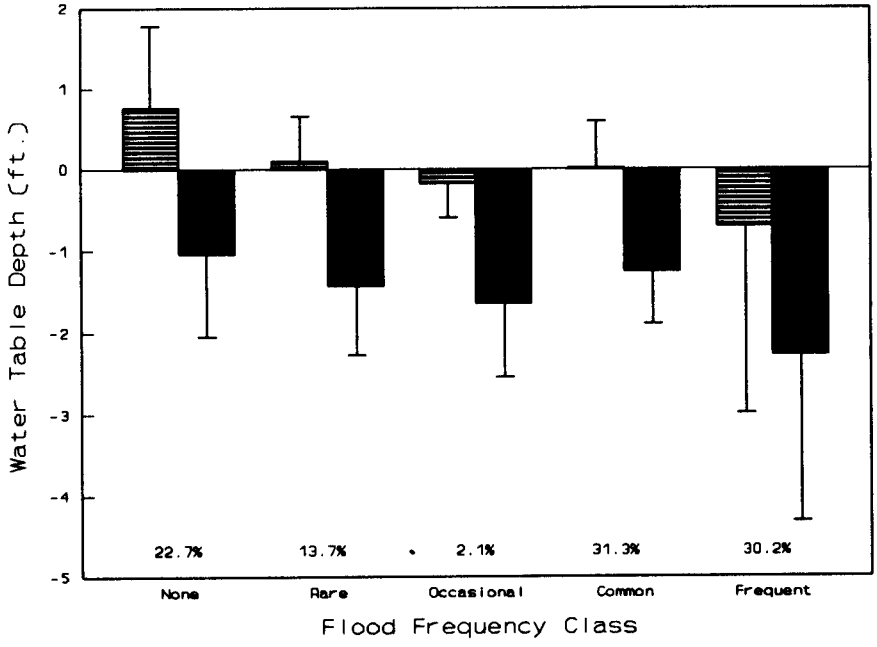

Figure 3. *Average seasonal high water tables by flood frequency classes for southeastern hydric soils. Upper and lower estimates follow conventions in SCS (1991). Flood frequencies are defined by probability of flooding in a given year (SCS 1983) and are: None (near 0%), Rare (0 - 5%), Occasional (5 - 50%), and Frequent (>50%). Common is a hybrid of the Occasional and Frequent classes. Percentages listed in lower portion of figure are the relative areal distribution among drainage classes.*

Approximately 10% (seven million acres) of southeastern hydric soil area are on the national hydric soils list (SCS 1991) because they were organic soils. Nineteen percent (14 million acres) are considered hydric because they are inundated, either ponded or flooded. Thirty-five percent (26 million acres) meet only the saturation criteria. The remaining 36% (27 million acres) of southeastern hydric soils area meet both inundation and saturation criteria.

The 26 million acres of hydric soils that are considered hydric solely because of the saturation criteria are not organic soils, are not ponded, and either do not flood, or have flood frequencies less than Frequent (less than 50% chance of flooding) or flood for less than long duration (less than seven days). Approximately 79% of these soils have the upper estimate of their seasonal high water tables as 0, indicating at the surface. Another 20% have their highest seasonal high water table six inches below the surface. About 1% of the soils considered saturated had the upper estimate of their seasonal high water table at 12 inches below the surface.

There were striking differences among states in the proportional representation among the criteria groups. For example, the percentage of a state's hydric soils accounted for by the inundation criteria ranged from a low of less than 1% for Florida to a high of 67% for Kentucky. States varied in percentages associated with inundated and saturated criteria from 21% for North Carolina to 47% for South Carolina. Percentages accounted for by soils meeting the saturation criteria only ranged from 8% for Kentucky to two states with more than 50% of their hydric soils being saturated only; North Carolina with 52% and Georgia with 56%.

Conclusions

The Southeast has more hydric soils and wetlands than any other region of the conterminous United States. There is considerable variability among southeastern states in hydric soil characteristics. These differences in soils can be attributed primarily to differences among southeastern states in climate, topography, and proximity to the Atlantic Ocean or Gulf or Mexico. A substantial fraction (about one-third) of the Southeast's hydric soils are considered hydric because they meet the criteria for saturation, but are not significantly flooded or ponded. Such soils may be problematic in delineating wetlands for regulatory purposes.

Acknowledgements

I would like to thank Mr. Harvey Terpstra and Mr. Douglas Tschopp of the Statistical Laboratory at Iowa State University for providing the hydric soil data. I greatly appreciate the assistance of Dr. Maurice Mausbach, Soil Conservation Service, Washington, DC for providing access to the hydric soils data. In addition, our many discussions greatly enhanced my understanding of hydric soils. The results and conclusions presented in this paper are the sole responsibility of the author and may not reflect the views or policies of the USDA Soil Conservation Service.

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FOREST FRAGMENTATION OF SOUTHERN U.S. BOTTOMLAND HARDWOODS [1]

Victor A. Rudis [2]

Abstract. The magnitude and character of forest fragmentation are evaluated for bottomland hardwoods in the Southern United States. Fragment size class is significantly associated with the frequency of bottomland hardwood species, stand size and ownership classes, and land use attributes. Differences in the frequency of indicators of multiple values (range, recreation, timber, water, and wildlife) are apparent. Two diverse hypotheses are suggested for further study: (1) fragmentation favors drier over wetter bottomland hardwood community types and (2) fragmentation shifts bottomland hardwood communities toward a younger successional stage and species typical of drier habitats. The first hypothesis suggests that drier stands are more vulnerable--and wetter stands less vulnerable--to fragmentation. The second hypothesis suggests that, on average, younger stands and dry-end bottomland species result from fragmentation of more mature and wetter stands. Data from recent South Central States forest surveys are used. Recent area changes suggest fragments are becoming smaller in selected regions.

Introduction

Today's wetland ecosystems in the onterminous United States have been reduced to half f their original area, largely due to extensive land learing for agriculture since pioneer days (Dahl 990). Because forested wetlands often are the last reas to be developed, they are frequently portrayed s wild, unaltered natural environments. Yet many of he remaining forested wetlands may have altered ydrology and geomorphology. Species changes and nultiple (e.g., range, recreation, timber, water, and vildlife) values have likely been altered as well.

Assessments of bottomland hardwood forests n the South Central States suggest that the rate of rea decline has slowed in recent years (McWilliams nd Rosson 1990). However, the rate belies the umulative effects of landscape-scale change and past uman disturbance on remaining bottomland hardwood rea. This study initiates an exploration of cumulative ffects from available data.

Forest fragmentation is the disruption of ontinuity in forest cover by water and nonforest land i.e., agricultural land, and urban or built-up land, ncluding roads). Fragmentation affects some faunal pecies distributions (Harris 1988), is a central issue n wildlife conservation (Wilcove 1990), and can have n effect on plant species distributions (Zacharias and Brandes 1990). Fragmentation also may affect nultiple values of existing forested wetlands.

Historical data from permanent plots over a span of several lifetimes often are needed to test fragmentation effects on forest resources. Such data are rarely available. This report provides a synthesis of bottomland hardwood forest fragmentation. Information is from recent forest surveys of the South Central States (Alabama, Arkansas, Mississippi, east Oklahoma, Tennessee, and east Texas) by the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis Unit, Starkville, MS. Fragment size class is compared with the distribution of overstory tree species, forest proximity, and forest stand attributes.

The goal of the study is exploratory, namely to assess the significance of forest fragmentation for Southern United States forested wetlands. Specific objectives of the study are: (1) to evaluate the significance of forest fragmentation on bottomland hardwoods and associated multiple values and (2) to generate hypotheses for further study on how fragmentation affects bottomland hardwoods. Exploration can help focus on the direction needed in analytical techniques and auxiliary data acquisition to monitor multiple values of bottomland hardwood forests.

Methods

As used in this report, a forest fragment is a contiguous land area at least 10 percent of which is covered with trees and unbroken by nonforest land.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Research Forester, USDA Forest Service, Southern Forest Experiment Station, Starkville, MS.

A forest is a land area covered with trees, 1 acre or more in size and 120 feet (ft) or more in width. Fragment boundaries are nonforest land areas 120 ft or more in width. Pipelines and powerlines by themselves are not considered limiting. Fragments may be composed of different forest types and age classes. Fragments are inventoried in acreage classes as: 1 to 10, 11 to 50, 51 to 100, 101 to 500, 501 to 2,500, 2,501 to 5,000, and over 5,000 acres. Land cover interpretation is accomplished with National high-altitude color aerial photographs at 1:58,000 scale for those taken between 1986 and 1991, and 1:40,000 scale for color or 1:24,000 scale for black-and-white photographs for those taken between 1975 and 1985.

Approximately 1-acre sample plots are located systematically in each county at the intersection of perpendicular grid lines spaced at 3-mile intervals. Plots defined as timberland are surveyed for physical characteristics. Timberland is forest land not reserved from timber production and capable of producing industrial wood at a rate of 20 ft^3/acre/year or more. Timberland comprises 98 percent of the forests of the region.[3] Fragment size, proximity from selected nonforest land, and evidence of human uses are sampled as part of the survey as well. Water proximity and sources seen on the plot are estimated from observations made during field visits.

Information on tree species composition and distribution by other attributes are derived from the most recent survey of timberland sample locations. Species composition is derived from a cluster of 10 points around each sample location (Forest Inventory and Analysis Research Work Unit 1989). Current tree sampling favors interior forest species, as clustered points are rotated toward the sample location when points are within 33 ft of the forest edge. At each point, live trees at least 5 inches in diameter at breast height (d.b.h.) are selected on variable-radius, 37.5 factor prism plots. On points stocked with fewer than two trees greater than 5 inches in d.b.h., the four most dominant trees are selected. Trees 1.0 to 4.9 inches in d.b.h. are measured on fixed, 7.1 ft radius plots centered on the first three points.

This report focuses on an assessment and recent changes in bottomland hardwoods associated with forest fragments of varying size. Bottomland hardwoods are classified based on the stocking of tree species typical of wetland conditions (Anonymous 1972). For comparison purposes, the region is split into four physiographic boundaries: Mississippi Valley, East Gulf Coastal Plain, West Gulf Coastal Plain, and Interior Highlands (fig. 1).

Unless otherwise noted, the analysis consists of cross-tabulation of the presence and absence of an attribute on plots for each of seven fragment size classes. Only frequencies of an attribute's presence are listed. A Chi-square (X^2) test of significant differences is performed to test the hypothesis of no association between an attribute and fragment size classes at the 0.05 probability level. Fragment size classes with expected presence or absence values <5.0 are combined with the next nearest size class. If the hypothesis of no association is rejected, direction of the association is determined from the sign of the Pearson product-moment correlation (SAS Institute Inc. 1985). Correlations that include zero with one standard error are noted. Significant differences in attributes with numerical values are determined by comparing averages plus or minus 2 standard errors. Species' shade tolerance classes are derived from Burns and Honkala (1990). Species' soil and water associations are derived from Hupp (1992).

Results

Total bottomland hardwood area, 15.7 million acres, varies by region and fragment size class and highlights the abundance of the intermediate (501 to 2,500 acres) fragment size classes (fig. 2). Regional differences are apparent, with the Interior Highlands having the least amount of bottomland hardwoods and a plurality in the smaller ($\leq$500 acres) fragment size classes (fig. 3).

Area change since the survey of a decade earlier represents a decline of 1.0 million acres. This decline varies significantly with fragment size class in the West Gulf Coastal Plain, Interior Highlands, and Mississippi Valley, but not in the East Gulf Coastal Plain (fig. 4). Area shifts are toward smaller fragment size classes.

Species richness is greatest for the 101 to 500 and 501 to 2,500 acre fragment size classes, a pattern also reflected within regions (fig. 5). However, species richness is sensitive to sample size.

[3] Rudis, Victor A.; Tansey, John B. Landscape-scale assessment of remote forests and black bear habitat from regional forest inventories. (1992 draft, 35 p.)

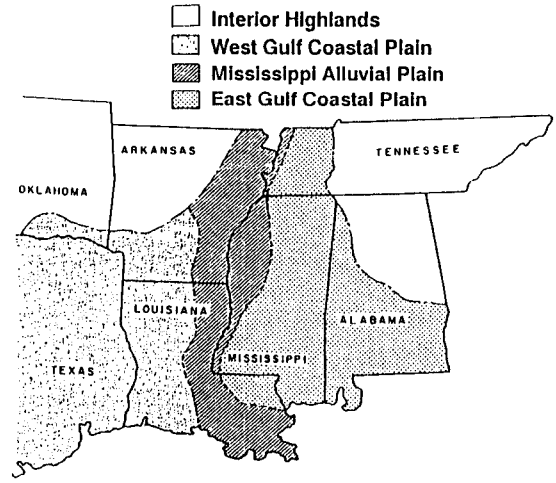

Figure 1. *Physiographic regions of the South Central United States (adapted from Fennemann 1938).*

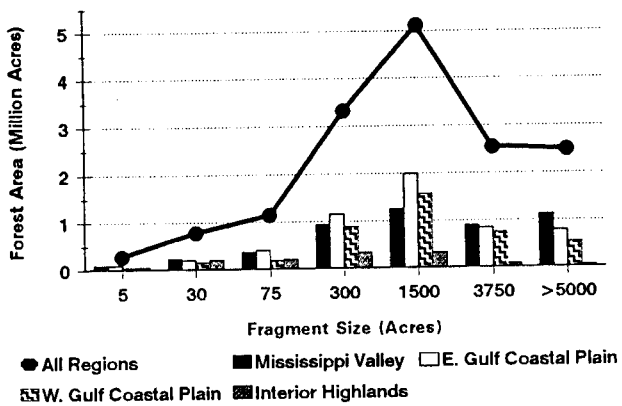

Figure 2. *Relation between bottomland forest area and forest fragment size class in the South Central United States and by region, 1986-91.*

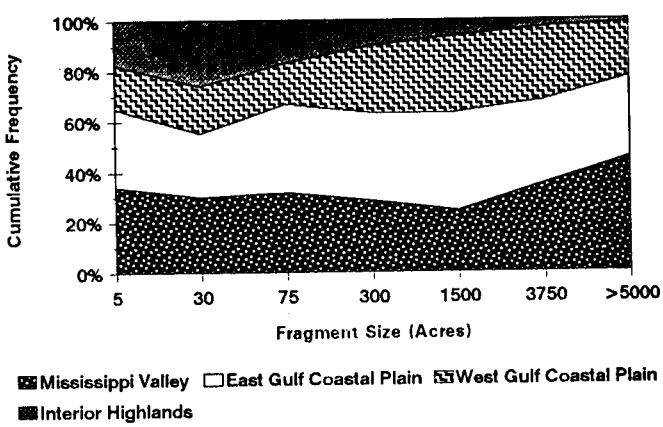

Figure 3. *Frequency of bottomland hardwood forest area by fragment size class and region, South Central United States, 1986-91.*

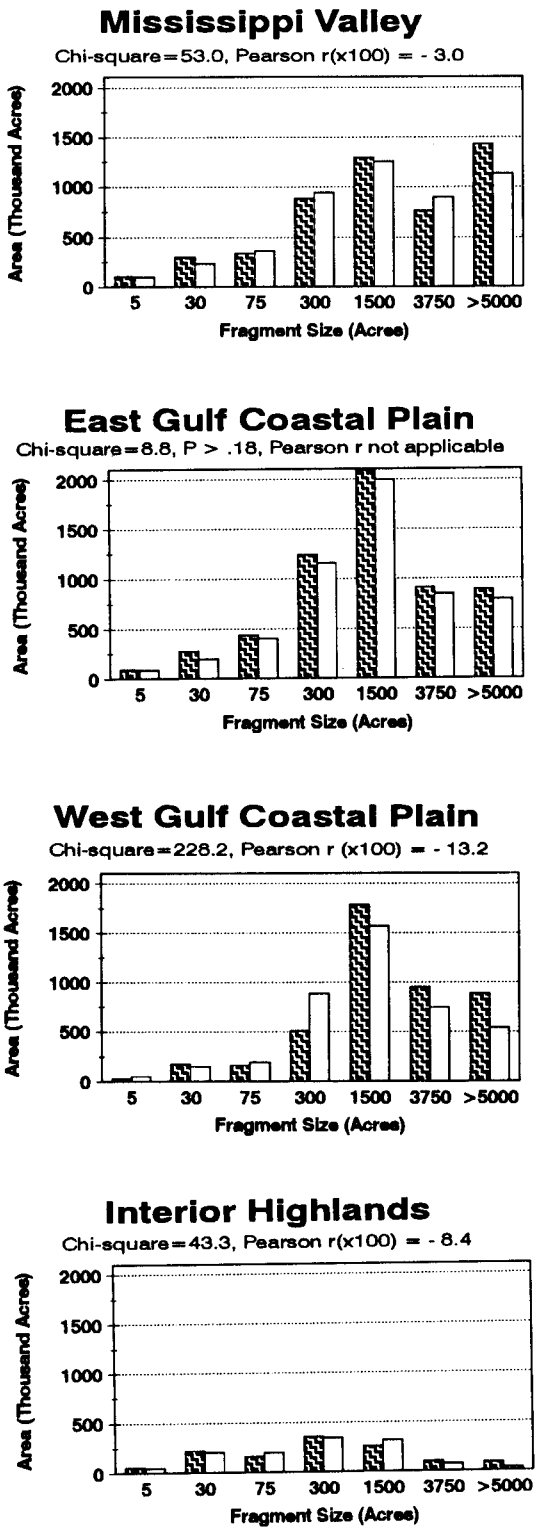

Figure 4. *Area of bottomland hardwood forests by forest fragment size class, region, and survey period: 1975-84 (shaded) and 1986-91 (unshaded), South Central United States. Comparisons are made between forest area in each survey period and fragment size class. P(Chi-square > 43.0) < 0.001.*

Statistical differences in average species richness are slight, except between the 1 to 10 acres and >5,000 acres, and the 11 to 5,000 acre fragment size classes (fig. 6).

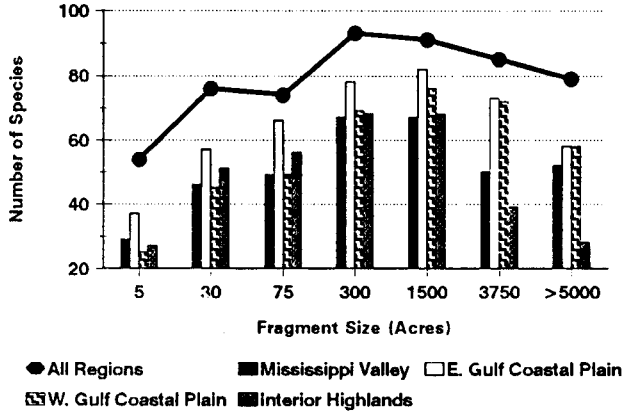

Figure 5. *Relation between the number of species surveyed in bottomland hardwood forests and forest fragment size class in the South Central United States and by region, 1986-91. Sample size = 2,666 plots.*

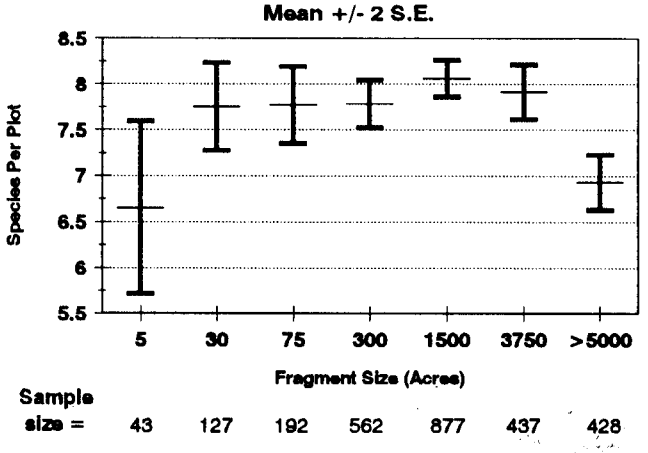

Figure 6. *Average species per plot surveyed in bottomland hardwood forests by forest fragment size class, South Central United States, 1986-91. Listed also is sample size per fragment size class.*

Significant frequency differences by fragment size class are apparent for several species (tables 1 and 2). Baldcypress (*Taxodium distichum* (L.) Rich.), overcup oak (*Quercus lyrata* Walt.) and others at the wetter end of the spectrum of bottomland hardwood tree species are more frequent in larger (>2,500 acres) fragments. Drier-end bottomland species such as winged elm (*Ulmus alata* Michx.) and early colonizers of recently disturbed stream channels such as river birch (*Betula nigra* L.) are more frequent in smaller fragments.

The majority of commercial tree species positively associated with fragment size class are shade tolerant species typical of stable soil and water flow and late successional or mature forests (table 1). The majority of commercial tree species negatively associated are shade intolerant species typical of unstable soil and water flow and early successional or pioneer forests (table 2).

Species with no significant association or of insufficient sample size are listed in table 3. The few frequently occurring species with no significant association are intolerant of shade (e.g., willow oak, *Quercus phellos* L.) or are typical of drier sites (e.g., post oak, *Quercus stellata* Wagenh.). Cottonwood (*Populus deltoides* Bartr. ex Marsh.) is typical of disturbed stream channels but is not significantly associated with fragment size classes (table 3).

Forests associated with smaller fragments are more likely to be in private ownership, in sapling-seedling or poletimber size class, and contain a higher percentage of rough and rotten trees. Forests associated with larger fragments are more likely to be in corporate or public ownership, to be sawtimber size class, and contain a higher percentage of growing-stock trees (figs. 7a,b, and 8). Differences in thefrequency of water sources seen when surveying plots are slight. Fragment size class is associated with water sources seen on the plot during field visits, principally permanent swamps (fig. 9).

Proximity of forest fragments from nonforest land suggests that fragmentation is most closely associated with agricultural land use. Fences and roads are also associated. Urban land use is less important. Hunting club signs are significantly more frequent near large fragments, suggesting that these hold greater value for primitive-oriented recreation than smaller fragments. Smaller fragments are more accessible, an indicator of urban-oriented recreation value (table 4).

More frequently, a smaller fragment includes containers and other trash, an indicator of the increased potential to accumulate discarded materials. Discarded materials represent human intrusions that are disliked strongly by people with primitive-oriented recreational preferences (Rudis 1987). Evidence of livestock use, an index of agroforestry value, also is greater in smaller fragments. Artifacts positively associated with fragment size class include Spanish moss (*Tillandsia usneoides* L.), an indicator of unique and esthetically-valued habitats, and logging debris, an indicator of past timber production value (table 5).

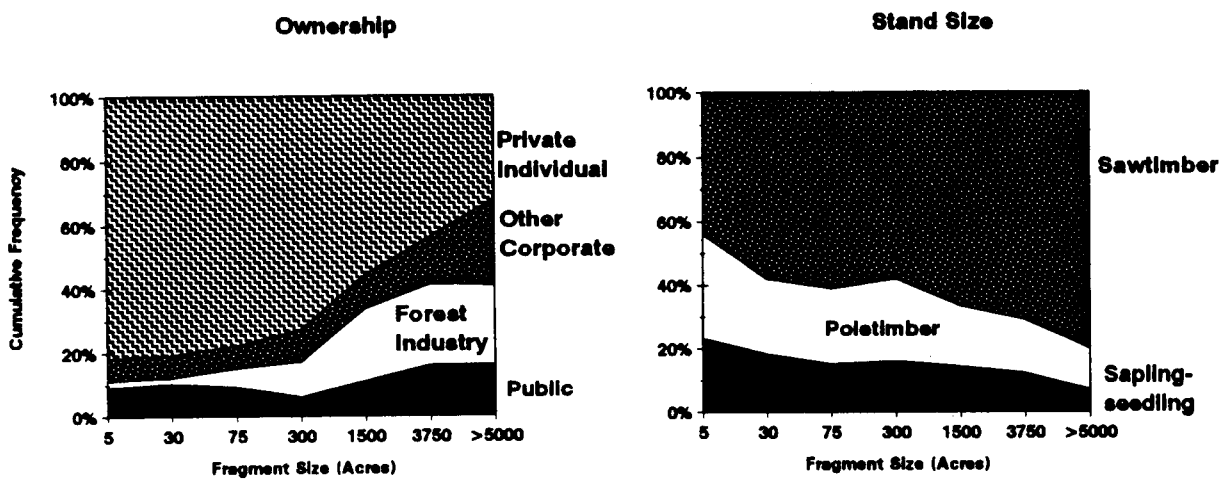

Figure 7. *Frequency of bottomland hardwood forest area by fragment size class and (a) ownership class, (b) stand size class, South Central United States, 1986-91.*

Discussion And Conclusions

Causes for Fragmentation

Agricultural development is significantly associated and is suggested as a primary cause for forest fragmentation of southern bottomland hardwoods. Fragmentation by urban influences likely plays a minor role in the South Central States. Agricultural development as a principal cause for hydric forest community fragmentation corroborates findings from a detailed examination of selected Southeastern United States river systems.[4] With additional study, differences in the regional distribution of fragment size classes and the documented shift toward smaller fragments from selected regions may suggest other, more localized, landscape-scale influences that favor fragmentation.

Species Changes

Smaller fragments are more frequently composed of early successional or dry-end bottomland or upland species. Larger fragments have more late successional, mature, or wetter bottomland hardwood species. If an acceptable classification for old growth bottomland hardwoods is available, most old growth stands are likely to occur in larger fragments.

There are two diverse hypotheses. One is that fragmentation favors drier over wetter bottomland hardwood community types. On average, smaller fragments represent drier subsets of bottomland community types; larger fragments represent wetter subsets.

If this hypothesis is true, then wetter habitats are less vulnerable--or more resistant--to fragmentation. An implication of this hypothesis is that drier bottomland hardwoods have the greatest potential for fragmentation. This hypothesis parallels that proposed by McWilliams and Rosson (1990); namely that drier bottomlands of the Southern Coastal Plain are more vulnerable to land clearing.

A second, alternative hypothesis is that fragmentation shifts bottomland hardwood communities toward a younger successional stage and species typical of drier habitats. On average, fragmentation is independent of the dryness or wetness of habitats. Rather fragmentation induces the establishment of pioneer species, widely-adaptable species, and those typical of unstable hydrology and geomorphology. Vegetation in smaller fragments may mature if left undisturbed, and hydrology and geomorphology may stabilize with time. However, short-term survival of flora and fauna of larger fragments with species typical of mature and wetter bottomland forests and stable hydrology and geomorphology are threatened.

[4] Wein, G.R.; Collins, B.S. Bottomland hardwood forest fragmentation on three southeastern rivers with different land use histories. Paper presented at the annual meeting of the Society of Wetland Ecologists; June 1992, New Orleans, LA. [1992 draft, 14 p.]

Table 1. Percent frequency among 2,666 plots by species and forest fragment size class, South Central United States bottomland hardwoods, 1986-91. [Significant positive association, $P(X^2) < 0.05$.] [1]

Species	Plots occupied	Fragment size (acres) Class midpoint value 5	30	75	300	1500	3750	>5000	X^2	Pearson r(x100)
	(percent)									
Fraxinus pennsylvanica Marsh.	38	37	34	37	36	34	42	47	24.0	8.3
Acer rubrum L.	32	21	17	24	32	34	33	36	25.1	5.6
Celtis laevigata Willd.	28	33	37	33	27	25	29	30	14.0	.6
Quercus lyrata Walt.	24	9	14	20	18	23	33	31	55.2	13.3
Taxodium distichum (L.) Rich.	22	12	16	14	17	17	26	43	141.8	21.3
Carpinus caroliniana Walt.	22	2	12	15	21	27	25	18	42.5	1.4
Carya aquatica (Michx. f.) Nutt.	16	9	17	17	14	14	21	20	18.0	6.6
Salix spp. L.	13	21	17	14	12	9	11	20	37.8	5.4
Quercus nuttallii Palmer	12	12	9	12	11	10	17	15	18.3	6.9
Nyssa aquatica L.	10	-	2	2	8	8	12	25	135.8	20.2
Diospyros virgininana L.	10	5	9	17	8	9	11	10	14.2	.9
Quercus laurifolia Michx.	8	7	4	4	6	9	8	9	13.3	4.8
Fagus grandifolia Ehrh.	7	2	2	3	6	9	9	4	28.9	.5
Ilex opaca Ait.	6	-	2	2	5	9	8	4	30.5	1.9
Ulmus crassifolia Nutt.	6	2	2	9	5	4	8	6	18.8	3.3
Ostrya virginiana (Mill.) K. Koch	5	-	2	4	4	7	7	3	18.2	.4
Planera aquatica J.F. Gmel.	4	2	4	3	3	4	4	8	14.6	6.3
Pinus glabra Walt.	3	-	1	1	2	4	3	2	13.1	1.6
Miscellaneous spp.[2]	4	2	5	2	3	3	4	7	12.7	5.5

[1] One standard error (Pearson r x 100) ≤ 2.0.

[2] Includes shrub species with stems ≥ 5.0 inches in d.b.h. and tree species rarely encountered in the region.

- = None among sampled trees.

Table 2. Percent frequency among 2,666 plots by species and forest fragment size class, South Central United States bottomland hardwoods, 1986-91. [Significant negative association, $P(X^2) < 0.05$.] [1]

Species	Plots occupied	Fragment size (acres) Class midpoint value 5	30	75	300	1500	3750	>5000	X^2	Pearson r(x100)
	(percent)									
Liquidambar styraciflua L.	54	44	50	52	57	59	52	44	32.6	−7.4
Quercus nigra L.	41	26	40	41	45	46	38	28	45.7	−9.6
Ulmus americana L.	27	47	35	33	28	27	24	23	19.7	−6.3
Nyssa sylvatica Marsh.	27	21	14	25	26	33	28	17	47.6	−4.2
Carya spp. Nutt.	22	12	22	25	20	25	22	16	20.8	−4.1
Quercus falcata var. *pagodifolia* Ell.	17	16	21	14	20	18	18	11	19.0	−5.5
Ulmus alata Michx.	17	12	28	27	18	18	12	1	51.1	11.9
Pinus taeda L.	12	12	6	9	13	17	12	6	38.7	−5.5
Platanus occidentalis L.	12	23	22	16	12	11	10	13	22.1	−3.4
Acer negundo L.	11	16	24	11	11	9	10	13	29.4	−1.4
Quercus alba L.	11	5	10	10	10	13	12	5	21.7	−4.4
Liriodendron tulipifera L.	10	5	9	12	14	11	8	4	33.7	−9.7
Magnolia virginiana L.	9	2	6	7	11	12	8	4	32.1	−6.3
Gleditsia triacanthos L.	6	16	14	7	7	4	7	7	33.0	−1.1
Carya illinoensis (Wangenh.) K. Koch	6	12	14	5	6	5	5	5	22.2	−3.0
Quercus falcata Michx.	5	7	6	8	7	5	5	2	20.2	−7.5
Betula nigra L.	5	5	6	9	6	5	3	3	15.9	−7.0
Morus rubra L.	4	9	6	5	3	5	5	2	14.0	−2.2
Quercus shumardii Buckl.	4	5	9	6	4	4	2	1	25.8	−8.1
Prunus serotina Ehrh.	3	5	7	3	3	5	3	1	17.3	−5.5
Celtis occidentalis L.	3	5	7	6	3	3	2	2	15.0	−5.8
Pinus elliottii Engelm.	2	2	-	1	3	4	3	1	16.9	−1.7
Maclura pomifera (Raf.) Schneid.	1	5	3	4	2	1	1	X	19.8	−6.5
Quercus velutina Lam.	1	2	2	3	2	1	1	-	17.1	−6.7
Pinus echinata Mill.	1	-	-	1	2	1	1	-	6.2	−4.2

[1] One standard error (Pearson r x 100) ≤ 2.0.
X = Less than 0.5 percent.
- = None among sampled trees.

Table 3. *Percent frequency among 2,666 plots by species and forest fragment size class, South Central United States bottomland hardwoods, 1986-91. [No significant association, $P(X^2) \geq 0.05$].*

Species	Plots occupied	Fragment size (acres) Class midpoint value 5	30	75	300	1500	3750	>5000
	(percent)							
Quercus phellos L.	24	21	18	27	22	24	27	23
Quercus michauxii Nutt.	11	5	9	7	9	13	13	11
Ulmus rubra Muhl.	10	9	6	10	10	11	11	8
Quercus stellata Wangenh.	6	14	8	5	7	8	5	1
Fraxinus americana L.	6	2	8	9	6	6	4	4
Populus deltoides Bartr. ex Marsh. var. *deltoides*	5	2	7	6	6	5	5	6
Crataegus spp. L.	5	5	3	5	5	5	6	7
Cornus florida L.	5	2	3	3	5	6	5	3
Nyssa sylvatica var. *biflora* (Walt.) Sarg.	5	-	2	4	5	5	4	7
Magnolia grandifolia L.	2	-	2	2	2	4	2	1
Gleditsia aquatica Marsh.	2	2	2	2	2	3	3	2
Acer saccharinum L.	2	-	2	4	1	2	3	2
Sassafras albidum (Nutt.) Nees	2	-	2	1	2	2	1	1
Persea borbonia (L.) Spreng.	1	-	1	1	2	2	1	1
Cercis canadensis L.	1	-	1	2	2	2	1	X
Quercus rubra L.	1	-	2	3	2	1	1	X
Prunus spp. L.	1	-	1	1	-	2	1	1
Acer barbatum Michx.	1	-	-	-	-	2	1	1
Oxydendrum arboreum (L.) DC.	1	-	1	1	1	1	1	1
Quercus palustris Muenchh.	1	-	1	3	1	1	1	X
Acer saccharum Marsh.	1	-	2	1	X	1	1	X
Sapium sebiferum (L.) Roxb.[1]	1	5	2	2	X	1	X	X
Juniperus virginiana L.	1	-	1	1	2	1	1	-
Juglans nigra L.	1	5	3	3	X	1	X	1
Vaccinium arboreum Marsh.	1	-	1	1	2	1	X	X
Quercus virginiana Mill.	1	2	1	-	1	1	X	1
Tilia americana L.	1	-	2	1	1	1	1	X
Quercus coccinea Muenchh.	1	-	1	2	X	X	X	X
Quercus bicolor Willd.	X	-	1	1	X	X	1	X
Magnolia acuminata L.	X	-	-	1	1	X	1	X
Quercus macrocarpa Michx.	X	2	2	1	X	X	-	X
Quercus muehlenbergii Engelm.	X	-	1	2	1	X	1	-
Quercus stellata var. *paludosa* Sarg.	X	2	2	1	X	X	1	-
Quercus prinus L.	X	-	-	-	X	X	1	-
Robinia pseudoacacia L.	X	-	2	-	1	X	-	-
Morus alba L.	X	-	-	1	1	X	X	-
Melia azedarach L.	X	2	1	-	X	X	X	-
Pinus palustris Mill.	X	-	-	-	X	X	-	X
Tilia heterophylla Vent.	X	-	-	-	X	X	X	-
Magnolia macrophylla Michx.	X	-	-	-	X	-	1	X
Catalpa spp. Scop.	X	-	-	-	X	X	X	-

Table 3. Percent frequency among 2,666 plots by species and forest fragment size class, South Central United States bottomland hardwoods, 1986-91. [No significant association, $P(X^2) \geq 0.05$]. Continued

Species	Plots occupied	Fragment size (acres) Class midpoint value 5	30	75	300	1500	3750	>5000
		(percent)						
Quercus marilandica Muenchh.	X	-	-	-	X	X	X	-
Amelanchier spp. Medic.	X	-	-		X	X	-	-
Ulmus pumila L.	X	-	1	1	X	-	X	-
Quercus durandii Buckl.	X	-	-	-	1	X	-	-
Aesculus octandra Marsh.	X	-	-	1	X	X	-	-
Aesculus glabra Willd.	X	-	-	-	-	X	-	X
Aesculus spp. (other than above)	X	2	-	1	-	X	-	-
Ulmus serotina Sarg.	X	-	-	-	-	X	-	X
Chamaecyparis thyoides (L.) B.S.P.	X	-	-	-	-	X	-	X
Fraxinus profunda (Bush) Bush	X	-	1	-	-	-	X	-
Halesia carolina 4 L.	X	-	-	-	-	X	-	-
Gymnocladus dioicus (L.) K. Koch	X	-	1	-	X	-	-	-
Juglans cinerea L.	X	-	-	-	-	-	-	X
Malus spp. Mill.	X	-	-	-	-	-	-	X
Castanea dentata (Marsh.) Borkh.	X	-	-	-	X	-	-	-
Quercus incana Bartr.	X	-	-	-	X	-	-	-
Paulownia tomentosa (Thunb.) Sieb. & Zucc. ex Steud.[1]	X	-	-	-	X	-	-	-
Quercus laevis Walt.	X	-	-	-	X	-	-	-
Ailanthus altissima (Mill.) Swingle	X	-	-	X	-	-	-	-
Castanea pumila Mill.	X	-	-	X	-	-	-	-
Pinus serotina Michx.	X	-	-	1	-	-	-	-
Ulmus thomasii Sarg.	X	-	-	1	-	-	-	-

[1] Identified as a category apart from "miscellaneous" only for Tennessee 1990 and Louisiana 1991 surveys.
X = Less than 0.5 percent.
- = None among sampled trees.

Table 4. *Percent frequency among 1,853 plots by land use or cover proximity within 0.25 mile and by forest fragment size class, South Central United States bottomland hardwoods, 1986-90.*[1,2]

Land use or cover	Plots occupied	Fragment size (acres) Class midpoint value 5	30	75	300	1500	3750	>5000	X^2	Pearson r(x100)
	(percent)									
Agricultural land ≥10 acres	55	86	90	90	74	49	31	22	364.0	−41.3
Open water ≥0.125 acre in size or ≥120 feet wide	52	41	59	54	48	50	50	60	10.7	[3]
Gravel or dirt roads and no paved roads	49	69	54	56	51	51	42	37	29.2	−11.5
Fences	44	69	64	59	55	44	25	23	137.0	−26.5
Without roads	38	10	22	27	30	37	51	61	107.1	23.5
Paved roads	13	21	24	17	19	12	7	2	57.3	−16.8
Hunting restricted, hunting club signs	5	-	3	1	5	6	7	7	13.0	5.9
Urban or built-up land ≥10 acres	2	3	11	4	3	2	X	X	33.6	−9.9

[1] Excludes Louisiana 1991--data has been collected but not yet compiled.
[2] Significance of association: $P(X^2=29.2) < 0.001$; $P(X^2=13.0) < 0.03$. One standard error (Pearson r x 100) ≤2.3.
[3] Not applicable, $P(X^2=10.7) > 0.09$.
X = Less than 0.5 percent.
- = None observed.

Table 5. *Percent frequency among 1,853 plots by artifacts seen on 1-acre plots and by forest fragment size class, South Central United States bottomland hardwoods, 1986-90.*[1,2]

Artifact(s)	Plots occupied	Fragment size (acres) Class midpoint value 5	30	75	300	1500	3750	>5000	X^2	Pearson r(x100)
	(percent)									
Beverage container(s)	33	38	47	39	31	31	35	32	13.6	−1.4
Other container(s), including trash (excluding beverage and food containers)	29	38	40	33	32	28	27	21	15.2	−7.6
Logging debris	22	14	22	14	19	25	25	22	14.0	4.8
Spanish moss (*Tillandsia usneoides* L.)	12	7	1	6	11	11	14	23	42.5	13.1
Evidence of livestock use	12	31	26	24	15	10	6	2	86.2	−18.3
Food container(s)	10	31	23	15	8	9	7	8	42.1	−6.7
Building, foundation, or fence associated with a former or currently used homesite	5	10	8	3	6	5	3	2	12.1	−6.2

[1] Excludes Louisiana 1991--data has been collected but not yet compiled.
[2] Significance of association: $P(X^2=42.1) < 0.001$, $P(X^2=12.1) < 0.04$. One standard error (Pearson r x 100) ≤2.3.

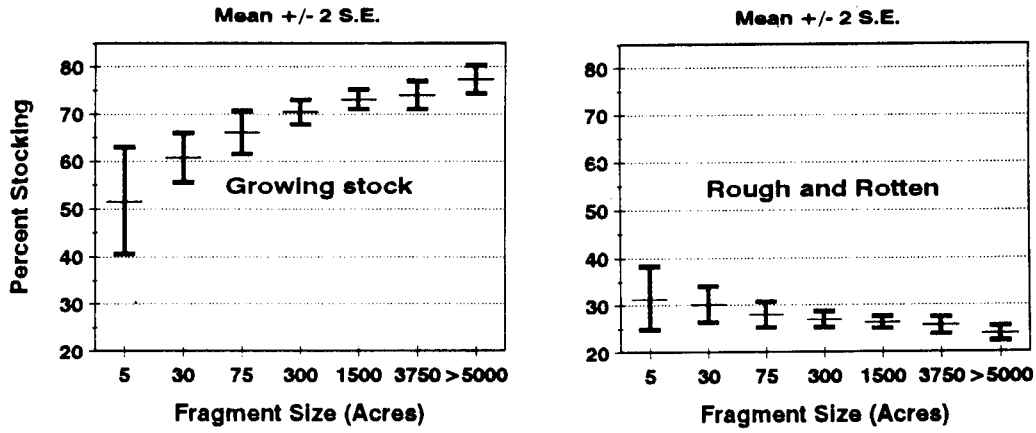

Figure 8. *Average stocking of trees per plot surveyed in bottomland hardwood forests by forest fragment size class, South Central United States, 1986-91. Sample size = 2,666 plots.*

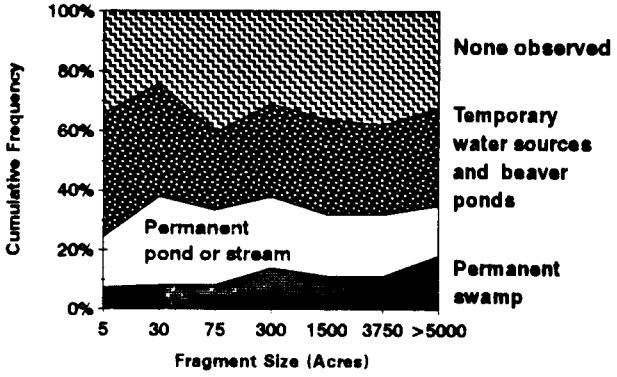

Figure 9. *Frequency of bottomland hardwood forest area by fragment size class and water sources seen during field visits, South Central United States, 1986-90. (Excludes Louisiana 1991. Data has been collected but not yet compiled).*

If true, the Interior Highlands is most vulnerable, as the region contains the least amount of bottomland hardwood area of all other regions. Most Interior Highlands area is in the smaller fragment classes. Connecting mature and wetter bottomland hardwoods with other forests along stream channels also could assist in maintaining habitats for fauna dependent on large forest fragments, e.g., black bear (*Ursus americanus)* (Rudis and Tansey 1992).

With existing data, analyses that may be useful in elucidating ecological community patterns include clustering of species' importance values and ordination along the fragment size class gradient. Combining existing data with understory plant surveys, especially surveys of shorter-lived herbaceous species, is more likely to reflect recent changes in microclimate implied by the second hypothesis.

Georeferenced information on soils, hydrology, landform, and elevation may be useful in clarifying hypotheses. Hydrology, geomorphology, and vegetation succession have been used to explain species frequency patterns following recovery from stream channelization (Hupp 1992). Combining landform and direction with existing nonforest proximity measures is suggested to improve their utility as indicators of change to hydrology and geomorphology for bottomland hardwood communities. Another inventory technique practical currently only for watershed-scale inventories includes georeferencing of fragment area over time from available photo archives and plot records.

Multiple Values

Smaller fragments are more frequently owned by individuals and are accessible by roads. Larger fragments are more frequently owned by corporations or public agencies and less accessible by roads. Smaller fragments are more likely to be associated with fences and contain human-associated litter than larger fragments. These influences increase the primitive-oriented recreation potential of larger fragments.

Regardless of the hypothesis, results indicate that fragmentation alters the multiple values of remaining bottomland hardwood communities. Associated value changes include reduced timber stocking of remaining trees in smaller fragments, increased livestock grazing, increased accessibility, and increased accumulation of discarded materials of human origin.

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LANDSCAPE ECOSYSTEM CLASSIFICATION OF FORESTED WETLANDS IN THE UPPER EDISTO BASIN OF SOUTH CAROLINA [1]

B. Cole and S.M. Jones [2]

Abstract. The Edisto River is the longest undisturbed blackwater river in the United States, approximately 250 miles from its headwaters in the upper coastal plain of South Carolina to the Atlantic Ocean. The Edisto floodplain represents a complex hydrology gradient from very poorly drained, frequently flooded landform to somewhat poorly drained bottomland-upland transition areas which rarely flood. Associated with this hydrology-drainage gradient is a forest vegetation continuum. The Landscape Ecosystem Classification approach was employed to describe the relationship between the vegetation, soil, landform-hydrology characteristics of thirty-three stands within the upper Edisto River basin. Five vegetative types were identified through ordination and cluster analysis procedures. Through stepwise discriminant analysis significantly discriminating soil and landform-drainage variables were related to the five site units. A conceptual model and a set of discriminant models were developed to classify sites within the Edisto River basin.

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Graduate Student and Assistant Professor, respectively, Clemson University, Clemson, SC.

SPECIES COMPOSITION AND STAND DEVELOPMENT 21 YEARS AFTER CLEARCUTTING IN A BOTTOMLAND/WETLAND FOREST [1]

Harvey E. Kennedy, Jr., and James S. Meadows [2]

Abstract. A 40-acre tract on the Delta Experimental Forest was clearcut during the fall and winter of 1970 and allowed to regenerate naturally. Stand composition at the time of cutting was elm (*Ulmus* spp.), ash (*Fraxinus* spp.), and oak (*Quercus* spp.). Seventy-two 1/20-acre plots were established on nine transects across the new stand. Species, total height, and d.b.h. were measured on trees on each plot. Topographic elevations were measured along each transect for elevation changes. Present analyses indicate different species composition and stand development in relation to site topographic elevations. Oaks occupy the higher ridges, mixed stands are on the slopes, and ash are on the lower flats. Elevation differences between the oak ridges and ash flats are 1 to 2 feet. Over time, the oaks will probably assume a more dominant position because of differences among species in shade tolerance and patterns of growth.

Introduction

Many southern bottomland forests are in a degraded condition because of past harvesting methods, which were in reality high-grading practices. Only 20 percent of the hardwood land supports trees of good form and vigor and of acceptable species (Smith and Linnartz 1980). Partial harvests such as single-tree selection and shelterwood cuts have been ineffective for regenerating bottomland hardwood stands because of the preponderance of cull residuals left in the overstory and shade-tolerant trees left in the understory (Bowling and Kellison 1983). More desirable, shade-intolerant species can be reproduced in complete openings created by clearcutting (Johnson 1978), while frequent selective cuttings and incomplete openings favor shade-tolerant species. Developmental quantification of stands following complete clearcutting is lacking. Species composition and stand development of a bottomland hardwood stand in west-central Mississippi that was clearcut in 1970 are reported here.

Methods

This study was conducted in a 21-year-old stand on the Delta Experimental Forest near Stoneville, Mississippi. The current stand originated after a mature stand, dominated by oak (*Quercus* spp.), elm (*Ulmus* spp.), and ash (*Fraxinus* spp.), was logged in 1970. The soil on the 40-acre tract is in the Sharkey series (very fine, montmorillonitic, nonacid, thermic Vertic Haplaquepts). The series consists of deep, poorly drained, very slowly permeable, clayey soils on broad floodplains. The soil formed in clayey slack water sediments deposited from the Mississippi River. Slopes range from 0 to 3 percent. Site index at base age 50 years is 80 feet for green ash (*Fraxinus pennsylvanica* Marsh.) and 88 feet for Nuttall oak (*Quercus nuttallii* Palmer) (Broadfoot 1976).

The objective of the study was to determine regeneration, species composition, and uniformity of a 40-acre tract on the Delta Experimental Forest 21 years after a clearcut harvest. The main species present before clearcutting were Nuttall oak, water oak (*Q. nigra* L.), willow oak (*Q. phellos* L.), green ash, sugarberry (*Celtis laevigata* Willd.), American elm (*Ulmus americana* L.), and cedar elm (*U. crassifolia* Nutt.). Most regeneration was from seeds or advanced regeneration (Francis 1986). Advanced regeneration was present in openings where large trees had died.[3]

Nine transects were run in an east-west direction across the 40-acre tract. The first transect was approximately 75 feet from the south boundary, and the remaining transects were 145 feet apart. Eight 1/20-acre circular plots were located on each transect, resulting in a sample size of approximately

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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10 percent of the area. The first plot was approximately 85 feet from the east boundary, with remaining plots 165 feet apart.

Species and d.b.h. were recorded on a total of 4,289 trees. Heights were measured on a subsample of 20 trees per plot (1,440 total trees in all plots). Because the upper canopy trees were considered most important, the subsample consisted of 12 dominant/codominant, 4 intermediate, and 4 suppressed trees, or 60, 20, and 20 percent in the respective crown classes.

Topographic elevations were measured along each transect at each plot center and midway between plot centers to determine elevation changes over the entire area.

Species composition by elevation was determined for the whole tract. The tract was divided into three broad species groups according to species basal area in each plot. If 50 percent or more of the basal area was green ash, the plot was designated a green ash-dominated plot; if 50 percent or more of the basal area was oak, it was an oak-dominated plot; if neither green ash nor oak dominated, it was designated a mixed-species plot.

Results and Discussion

Preharvest inventory data for the clearcut tract were not available. Therefore, a 5 percent inventory was made on two adjacent 40-acre tracts, one north and one west of the clearcut, and it was assumed that these two tracts are representative of the clearcut area before harvest. Composition of these two tracts is given in table 1. The current stand is dominated by oaks, ash, and elms with 92 trees per acre and a basal area of 93 ft^2/acre. Almost half of the trees per acre and about 80 percent of the basal area are in trees of the dominant/codominant crown class. Red oaks are among the largest trees and make up 41 percent of the basal area. Green ash makes up 34 percent of the basal area.

One year after clearcutting, the new stand contained about 3,600 green ash, 96 oak, and numerous sweetgum (*Liquidambar styraciflua* L.) trees per acre.[3] Francis (1984) reported that the stand was quite heterogeneous at 11 years. The number of stems averaged 5,888 per acre with a basal area of 55 ft^2/acre. Green ash accounted for 64 percent of the basal area. Only a few oak, sugarberry, and sweetgum trees had grown in his sample area.

After 21 growing seasons, the total number of trees had declined to 1,192 per acre (table 2). Green ash, with 508 trees per acre, elms with 297, and red oaks, with 91, dominated the important commercial species. There were about 300 trees per acre in the free-to-grow dominant/codominant crown class, slightly fewer than 200 in the intermediate crown class, and approximately 700 in the suppressed crown class (fig. 1). As the stand ages, more and more trees in the suppressed and intermediate crown classes will succumb to mortality.

Site (topographic elevation) and dominating species exerted tremendous influence on species composition and stand development (table 3). The oak- dominated stands had 220 trees per acre in the dominant/codominant crown class (140 red oaks and 80 green ash). These stands contained 780 trees per acre across all crown classes with a total basal area of 54 ft^2/acre. The green ash-dominated stand had 370 trees per acre in the dominant/codominant crown class; 290 were green ash and 20 were red oaks. These stands contained 1,740 trees per acre across all crown classes with a total basal area of 89 ft^2/acre.

Topographic elevations are shown in figure 2. Three site differences by elevation are evident: ridges (the higher elevations), slopes (transition areas from the ridges to the lower elevations), and flats (the lower elevations). Elevation differences from the flats to the ridges are 1 to 2 feet. Oak stands occupy the ridges (fig. 3), which make up about 22 percent of the area; mixed stands are found on the slopes, which make up about 22 percent of the area; green ash stands occupy the flats, which make up about 56 percent of the area.

Average d.b.h., height, and basal area by crown class and species are given in table 4. Size and basal area indicate that the final stand will be an ash-oak-elm stand. Even the green ash-dominated stands appear to have enough red oaks (20 trees per acre) to be managed if oaks are the major species preferred by the landowner. With thinnings and stand management to favor oaks in the ash-dominated stands, oak could be a major component of the final stand.

Total basal area per acre by species and diameter class is given in table 5. Basal area distribution again shows an ash-oak-elm-dominated stand. Red oaks generally are the largest trees, and most basal area is in the 5-to 9-inch d.b.h. range. Ash and elms tend to be smaller than the oaks. In ash, most basal area is concentrated in the 3-to 6-inch d.b.h. range, and in elms, in the 2-to 5-inch d.b.h.

Table 1. *Composition of two mature 40-acre blocks adjacent to 40-acre clearcut.*

Species	Crown Class: Dominant/Codominant			Intermediate			Suppressed			Total	
	Trees/ac.	D.b.h. (in.)	BA (ft^2/ac)	Trees/ac.	D.b.h. (in.)	BA (ft^2/ac)	Trees/ac.	D.b.h. (in.)	BA (ft^2/ac)	Trees/ac.	BA (ft^2/ac)
Elms[1]	4.0	15.3	5.3	4.5	10.1	2.6	10.0	5.5	1.8	18.5	9.7
Green ash	14.0	16.7	23.8	9.5	8.6	4.6	7.0	5.1	1.1	30.5	29.5
Sugarberry	3.5	20.1	8.4	3.5	9.3	1.8	5.5	5.4	1.0	12.5	11.2
Maple	-	-	-	0.5	8.4	0.2	-	-	-	0.5	0.2
Bitter pecan	1.0	14.3	1.2	2.0	6.4	0.5	-	-	-	3.0	1.7
Red oaks[2]	13.5	19.7	29.3	3.0	12.0	2.7	2.0	10.3	1.7	18.5	33.7
White oaks	2.5	13.6	2.8	2.0	8.3	0.8	1.5	7.2	0.4	6.0	4.0
Other[3]	-	-	-	1.0	9.5	0.5	-	-	-	1.0	0.5
Noncommercial[4]	-	-	-	0.5	4.1	0.1	0.5	6.9	0.1	1.0	0.2
TOTAL	38.5		70.8	26.5		13.8	26.5		6.1	91.5	90.7

[1] American elm (*Ulmus americana* L.) and cedar elm (*U. crassifolia* Nutt.).
[2] Nuttall (*Quercus nuttallii* Palmer), water (*Q. nigra* L.), and willow (Q. phellos L.) oaks.
[3] Includes persimmon (*Diospyros virginiana* L.), honeylocust (*Gleditsia triacanthos* L.) boxelder (*Acer negundo* L.), mulberry (*Morus rubra* L.), and cottonwood (*Populus deltoides* Bartr. ex. Marsh.).
[4] Includes swamp dogwood (*Cornus stricta* Lam.), hawthorn (*Crataegus* spp.), swamp-privet [*Forestiera acuminata* (Michx) Poir.], and deciduous holly (*Ilex decidua* Walt.).

range. The oaks, green ash, and elms contain 81 percent of the total basal area.

Conclusion

A commonly accepted principle among hardwood silviculturists is that oak will be a component of the next stand only if oak advanced reproduction was present in the previous stand (Bowling and Kellison 1983). Johnson and Krinard (1988) reported that the composition of postharvest regeneration in two sweetgum-red oak stands was quite different from that of the parent stands, but the stands appear, through the process of normal development, to be progressing toward essentially the same composition as the parent stands. Stand density peaked between ages 15 and 18 years. The oak component as a proportion of total overstory stocking increased with stand age.

Bowling and Kellison (1983) found that with increasing age vertical stratification takes place, with the more shade-tolerant oaks assuming dominance over the less tolerant species. Sweetgum seedlings and sprouts were about five times more prevalent at age 10 from harvest than water oaks, but the oaks became the dominant species by age 19.

Trends similar to those found by Johnson and Krinard (1988) and Bowling and Kellison (1983) appear to be developing in this stand. Francis (1984, 1986) found when the stand reported in this paper was 11 years old, green ash dominated, with 82 percent of the stems and 64 percent of the basal area. Over the next 10 years, green ash stems decreased from about 4,800 trees per acre to 508 trees per acre. Green ash accounted for 64 percent of the basal area at 11 years and 52 percent at 21 years. In the dominant/codominant class on the oak-dominated stands, there are 140 red oaks and 80 green ash per acre. There are 290 green ash and 20 red oaks per acre in the green ash-dominated stands. Over the whole 40-acre clearcut, red oaks make up 24 percent of the basal area in the dominant/codominant trees. In the adjacent 40-acre mature stands, 41 percent of the basal area is red oaks and 34 percent is green ash.

Our results, like those of other researchers, indicate that with increasing age, vertical stratification will occur, with the oaks assuming a more dominant position, probably because of differences among species in shade tolerance and patterns of growth over time. There should be enough oaks to manage through rotation age, with oaks making up a large proportion of the mature stand.

Table 2. *Total number of trees per acre by species and diameter class 21 years from harvest.*

D.b.h.	Bitter pecan	Elms[1]	Green ash	Sugar-berry	Red oaks[2]	White oaks	Other[3]	Non-commercial[4]	Total
(in.)		(Total number stems/acre)							
1	5.6	123.6	42.2	23.9	6.1	0.3	7.2	68.9	277.8
2	9.2	93.9	139.7	15.0	10.3	2.2	10.3	53.9	334.5
3	13.3	41.1	135.6	10.6	12.8	1.1	10.8	13.0	238.3
4	8.1	19.2	95.3	5.6	11.1	0.3	3.9	3.6	147.1
5	3.9	12.5	60.6	4.2	20.0	1.7	3.9	0.3	107.1
6	1.1	4.2	26.1	3.6	14.4	0.6	2.2		52.2
7	0.3	1.7	6.1	1.9	8.9	0.8	0.8		20.5
8		0.3	2.2	0.6	4.4	0.3	0.6		8.4
9			0.3		2.8		0.8		3.9
10					0.3		0.3		0.6
11							0.6		0.6
12									
13					0.3		0.3		0.6
>13			0.3						
Total by Species	41.5	296.8	508.1	65.4	91.4	7.3	41.7	139.7	1,191.4
Percent of Total	3.6	24.9	42.7	5.5	7.7	0.11	3.6	11.7	100

[1] American elm and cedar elm.
[2] Nuttall, water, and willow oaks.
[3] Includes persimon, honeylocust, boxelder, mulberry, and cottonwood.
[4] Includes swamp dogwood, hawthorn, swamp-privet, and deciduous holly.

Table 3. *Stand development in the oak- and green ash-dominated stands.*

Species and Crown Class	Oak-Dominated Stand			Green Ash-Dominated Stand		
	Trees (per acre)	BA (ft^2/acre)	D.b.h. (in.)	Trees (per acre)	BA (ft^2/acre)	D.b.h. (in.)
Doms./Codoms.						
Red oaks	140	31	6.3	20	5	7.2
Green ash	80	8	4.2	290	38	4.6
Elms				40	5	7.2
Other				20	6	6.6
TOTAL	220	39		370	54	
Intermediates						
Green ash	20	1	2.7	100	6	3.2
Elms	20	1	2.7	40	3	3.5
Sugarberry	60	2	2.6	40	4	3.6
Red oaks				10	1	3.7
Other	40	2	2.8			
TOTAL	140	6		190	14	
Suppressed						
Green ash	40	1	1.7	300	8	2.2
Red oaks	20	1	3.3	20	1	2.2
Sugarberry	40	1	1.7			
Elms	20	1	1.8	720	9	1.5
Other	20	1	2.7	20	1	2.2
Noncommercial	280	4	1.6	120	2	1.5
TOTAL	420	9		1,180	21	
GRAND TOTAL	780	54		1,740	89	

Table 4. *Average d.b.h., height, and total basal area by crown class and species on the 40-acre clearcut.*

Species	Crown Class								
	Dominant/Codominant			Intermediate			Suppressed		
	D.b.h. (in.)	Ht. (ft)	BA (ft^2/acre)	D.b.h. (in.)	Ht. (ft)	BA (ft^2/acre)	D.b.h. (in.)	Ht. (ft)	BA (ft^2/acre)
Bitter pecan	41.4	36.5	1.41	3.3	32.5	0.62	2.0	18.0	0.47
Elms[1]	4.7	37.2	3.48	3.3	30.7	1.92	1.7	19.8	4.39
Green ash	4.6	41.3	23.2	3.1	35.0	5.55	2.2	26.7	6.02
Sugarberry	5.3	39.5	2.1	3.2	33.0	0.69	1.7	19.9	0.73
Red oaks[2]	6.1	41.2	11.6	3.7	35.6	0.81	2.4	26.1	0.99
White oaks	5.9	38.5	0.43	5.9	37.0	0.22	2.4	-	0.13
Other[3]	5.6	40.7	2.75	3.1	30.3	0.47	2.0	25.2	0.52
Noncommercial[4]	3.0	27.0	0.03	3.8	25.1	0.27	1.7	18.1	2.35

[1] American elm and cedar elm.
[2] Nuttall, water, and willow oaks.
[3] Includes persimmon, honeylocust, boxelder, mulberry, and cottonwood.
[4] Includes swamp dogwood, hawthorn, swamp-privet, and deciduous holly.

Table 5. *Total basal area (ft²/acre) by species and diameter class 21 years from harvest.*

D.b.h.	Bitter pecan	Elms[1]	Green ash	Sugar-berry	Red oaks[2]	White oaks	Other[3]	Non-commercial[4]	Total
(in.)					(ft²/acre)				
1	0.05	1.05	0.39	0.19	0.05		0.07	0.61	2.41
2	.21	2.03	3.35	.34	.23	0.05	.23	1.09	7.53
3	.68	2.05	6.83	.50	.66	.07	.54	0.61	11.94
4	.74	1.63	8.33	.46	.98	.02	.31	.31	12.78
5	.51	1.68	8.29	.59	2.81	.22	.55	.03	14.68
6	.23	0.84	5.09	.69	2.95	.11	.45		10.36
7	.07	.42	1.60	.51	2.44	.24	.22		5.50
8		.09	0.77	.19	1.57	.09	.19		2.90
9			.12		1.25		.38		1.75
10					0.15		.16		0.31
11							.38		0.38
12									
13					0.26		.28		0.54
>13									
Total by Species	2.49	9.79	34.77	3.47	13.35	0.80	3.76	2.65	71.08
Percent of Total	3.5	13.8	48.9	4.9	18.8	1.1	5.3	3.7	100

[1] American elm and cedar elm.
[2] Nuttall, water and willow oaks.
[3] Includes persimmon, honeylocust, boxelder, mulberry, and cottomwood.
[4] Includes swamp dogwood, hawthorn, swamp-privet, and deciduous holly.

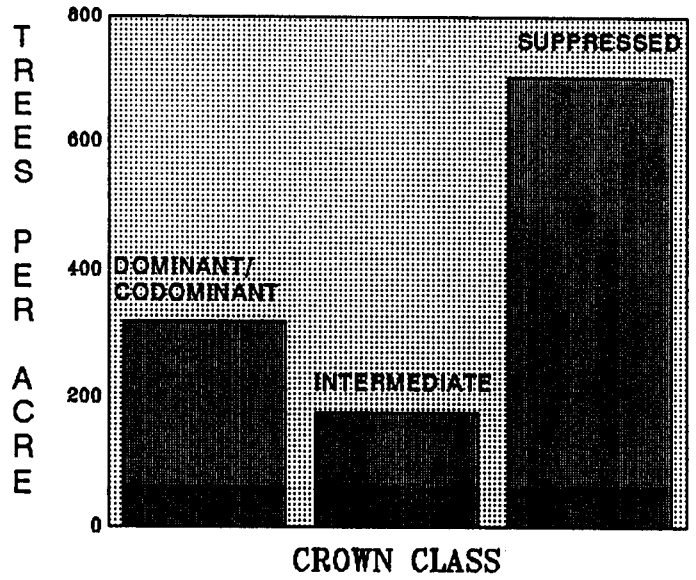

Figure 1. *Trees per acre by crown class in the 40-acre clearcut.*

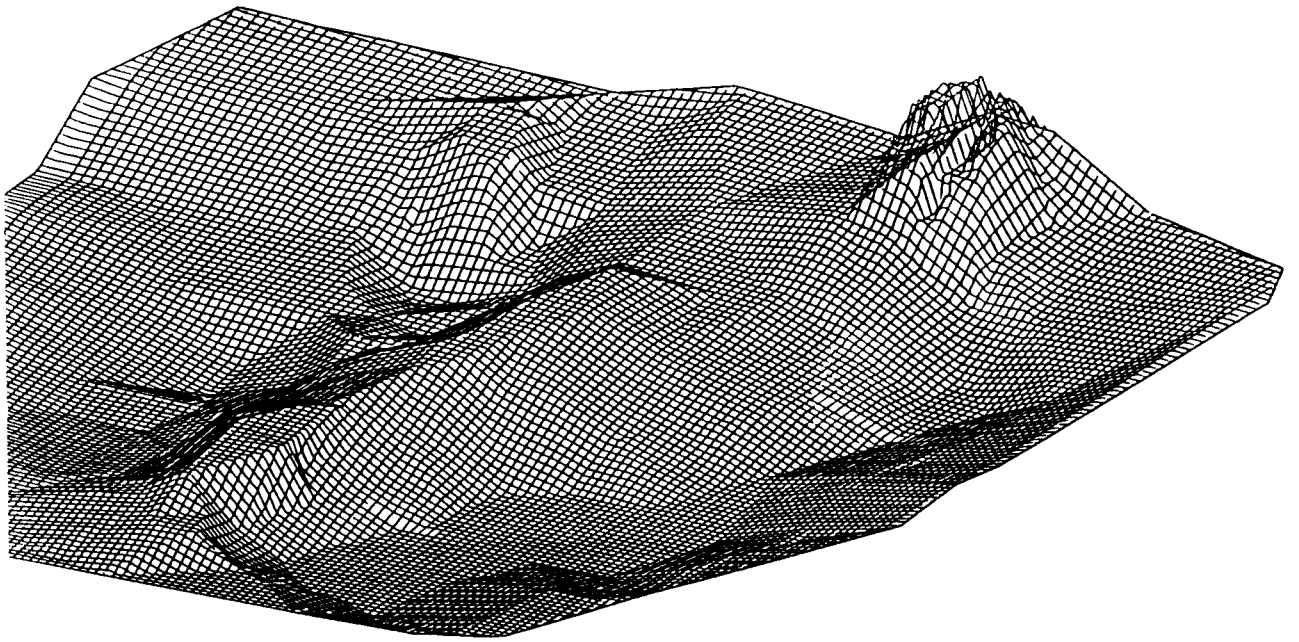

Figure 2. *3-D image of elevations on the 40-acre clearcut. Elevations are multiplied by 36 to portray differences in the image. Actual elevation differences from flats to ridges are 1 to 2 feet.*

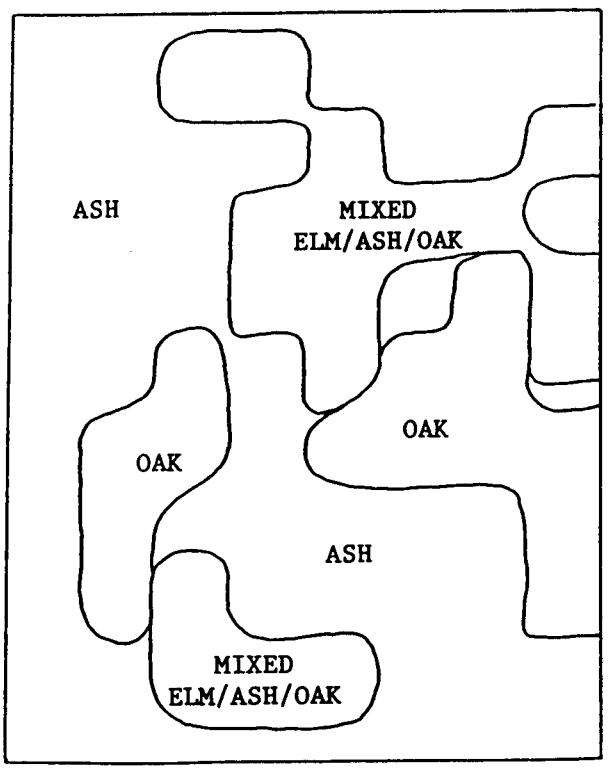

Figure 3. *Species dominance by site topographic elevations. Oaks occur on the ridges, mixed species, on the slopes, and green ash, on the flats.*

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SITE PREPARATION AFFECTS GROUND BEETLES IN A CLEARCUT BOTTOMLAND HARDWOOD FOREST IN SOUTHEASTERN ARKANSAS [1]

L.C. Thompson and R.T. Allen [2]

Abstract. Ground beetles (*Coleoptera: Carabidae*) were pitfall trapped for 26 consecutive weeks 3 years after clearcutting a 40-acre bottomland hardwood stand. Four 10-acre areas were site prepared with the following treatments: 1) no additional site preparation (harvest-only), 2) stem-injection of cull trees two years after harvest (inject), 3) shearing of all residual stems (shear), and 4) drum-chopping (chop). In addition, an adjacent stand representing preharvest conditions was sampled to make additional comparisons (check).

Results using cluster analysis of two beetle assemblage similarity coefficients (Simple 1 matching presence-absence and Bray-Curtis' species-abundance) revealed few differences in beetle assemblages among similar silvicultural treatments. The presence-absence dendrogram showed that the inject and harvest-only treatments were very similar and that the chop treatment was slightly different from the inject and harvest-only cluster. However, the shear treatment was different from the inject, harvest-only and chop treatments, and the check was very different from all harvested treatments.

The species-abundance dendrogram showed that similar treatments clustered together. The chop and shear treatments were very similar, as were the inject and harvest-only treatments. However, the chop-shear and inject-harvest-only clusters were very different from each other. The untreated check clustered by itself although it was more like the harvest-only and inject treatments than the chop and shear treatments. These results, and an assessment of species occurrence and abundance, show that the quality and quantity of beetles found in the harvested treatments was positively influenced by intensive site preparation. It also shows that beetle assemblages found in the inject and harvest-only treatments were influenced more by the harvesting disturbances than by whether the trees remaining on the site were live or dead.

Species from the tribes Agonini and Harpalini show promise as indicator species of forest disturbance. All species were more common in the highly disturbed sites and they were absent from the check.

Introduction

Forests are ecologically complex units subject to considerable debate about how they should be managed to maintain their multiple values (e.g., wood, water, wildlife, recreation). Land managers spend considerable time and effort, especially on federal lands, developing, modifying, and defending forest management plans. As such, it behooves land managers, as well as the people they serve, to understand the long- and short-term implications that scheduled management activities (or lack of) have on the organisms that live within a particular forest or stand. Unfortunately, insufficient ecological information exists on the effects forest management activities have on many plants and animals. Additional knowledge is needed on the biology and ecology of forest-inhabiting species if sound decisions are to be made regarding how forests are, or should be, managed.

Forestry practices may drastically change the environment of a forested site. Studies documenting some of these changes have been reviewed in books and symposia (State University New York 1979, American Society Civil Engineers 1980, Spurr and Barnes 1980, Burgess and Sharpe 1981, Kimmins 1987, Swank and Crossley 1988). However, a forested site is not a collection of individual environmental factors but the interaction of all factors

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992. Published with the approval of the Director, Arkansas Agricultureal Experiment Station, Fayetteville, AR.

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to create the habitat in which organisms live. *Ecological succession in changing habitats* is a well-documented phenomenon. But we still lack good information about changes of fauna and flora in many situations, especially secondary forest succession caused by the actions of humans.

One method of characterizing change in habitats is the use of living organisms (Lenhard and Witter 1977). Living organisms integrate the individual environmental factors that make up their habitat and thus may be expressions of what the habitat currently is, or, if observed over time, of how the habitat may have changed. This approach has been commonly used with plants (e.g., Daubenmire 1968) but has received less attention with insects (see review in Lenhard and Witter 1977).

Ground beetles are of interest in agricultural and forested habitats because of their predatory nature. Many species are predators of small, ground-inhabiting invertebrates, but some also feed on seeds (Allen 1979). These seed-eating habits, especially consumption of the seeds of commercial tree species, may influence successional direction.

The faunal character of ground beetles in habitats should reflect habitat changes. This is because individual insect species are often narrowly adapted to a particular habitat. Thus, some microclimatic and ecological influences of forestry practices may be explained by studying the ground beetles that inhabit these sites.

Much of the literature on ground beetles has been reviewed in Thiele (1977), Erwin et al. (1979), den Boer et al. (1986) and Stork (1990). Ground beetles comprise one of the largest families of insects. They are cosmopolitan and omnipresent in terrestrial habitats. Thiele (1977) emphasizes that individual species are often narrowly adapted to a particular habitat, and these preferences are related to microhabitat and food.

Ground beetles are suitable candidates as biological indicators of environmental change because of their: 1) extensive distribution, 2) often narrow habitat preferences, 3) mobility, and 4) presence often in large numbers. Thiele (1977) cites many examples of the fauna associated with different plant communities, including major differences in the species composition of forests and adjacent open land.

Some studies have been published on ground beetles in forests disturbed by humans (Thiele 1977). Typically, field-inhabiting beetles are captured in cleared sites, but they leave the area as it reforests. Ground beetles may also be influenced by stand disturbances caused by natural phenomena, such as defoliating insects (Kulman 1974) and fire (Harris and Whitcomb 1974, Richardson and Holliday 1982, Holliday 1984). Allen and Thompson (1977) have the only published literature on ground beetles inhabiting Arkansas' forest types. Of the 55 species they collected, 15 were unique to bottomland hardwoods, 12 were unique to upland pines (*Pinus taeda* L.), and 4 were unique to an upland oak-hickory (*Quercus-Carya)* stand.

An effort is underway in southern Arkansas to explain the short- and long-term influences of forestry practices on ground beetles. This study reports on one of these investigations; it had two objectives: 1) to assess the influence that silvicultural treatments had on ground beetle assemblages and 2) to evaluate the potential for using ground beetles as indicators of recovery from forest disturbance.

Methods

The study site was a managed bottomland hardwood forest located by the Saline River in Bradley County, Arkansas. Preharvest stand basal area averaged 110 ft^2/acre, represented by the following species or species groups: red oaks (Q.: Erythrobalanus) 34%, white oaks (*Q.: Leucobalanus)* 18%, sweetgum (*Liquidambar styraciflua* L.) 20%, other desirable species 6%, and cull species 22%. Soil was a Bibb silt loam (coarse-loamy, siliceous, acid, thermic, Typic Haplaquents). The forest included a 40-acre tract that was operationally harvested in mid October 1983 by removing all merchantable trees. The clearcut site was then split into four 10-acre blocks (figure 1), and each block was experimentally site prepared in late October. Site preparation treatments included: 1) drum-chopping, 2) shearing of all residual stems, 3) stem-injection of cull trees with a DBH > 1 inch using glyphosate herbicide in 1985 (two years postharvest), and 4) no site preparation, leaving cull trees that are live and standing. An adjacent area representing the preharvest condition was also sampled to make additional comparisons with undisturbed forests. In further references to these treatments, they will be called chop, shear, inject, harvest-only, and check, respectively. Three years after harvest the ground vegetation of all harvested treatments was dominated by blackberry (*Rubus* spp.), Japanese honeysuckle (*Lonicera japonica* Thumb.), and hardwood regeneration. By contrast, the ground vegetation of the check was sparse because of its dense overstory.

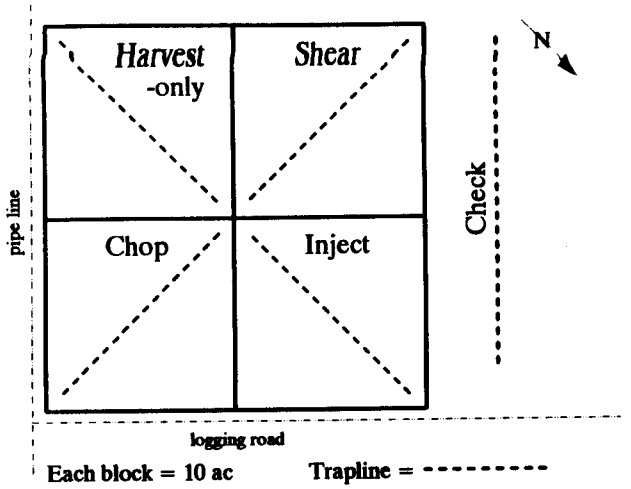

Figure 1. *Location of ground beetle traplines within site preparation treatments and the unharvested check.*

Trapping was conducted for 26 consecutive weeks, from May 1 to October 31, 1986. Beetles were trapped using 20 pitfall traps per treatment, with the traps at 30-foot intervals along a transect bisecting each treatment. Pitfall trapping is not a good measure of absolute abundance because trap catches are influenced by the activity of each species or by differences in their trapability. Pitfall traps are typically used in ecological studies because they give reasonable estimates of beetle relative abundance and they are easy to use.

Each trap consisted of a cylinder made from a tin 1-qt oil can with both ends removed. The cylinder was buried vertically (with one open end up) and level with the ground surface. A 16-oz. clear plastic drinking cup was placed in the cylinder and filled about one-third full with preserving fluid, a 1:1 mixture of antifreeze (ethylene glycol) and water. To simplify content removal, a strainer (made from another plastic cup and aluminum window screen) was placed into the bottom of each drinking cup. A 1-ft^2 plywood rain lid, held about two inches over the cup using three large nails as legs, reduced the amount of water entering each trap. Traps were serviced weekly. Beetles were separated from the trap contents in the laboratory, soaked in 80% ethyl alcohol for one month, and then pinned for identification.

Beetles were identified to tribe and genus using Ball (1973) and then to species using the most recent taxonomic revisions for each group. Sometimes identification to species was difficult because recent taxonomic revisions were not available. Representative specimens of some beetles were sent to specialists for identification. Sometimes we could identify specimens only to genus or subgenus. As an example, members of the genus *Brachinus* are difficult to identify to species. We were unable to identify our specimens, although we knew that four species were trapped from this forest (G.E. Ball personal communication). The four *Brachinus* species identified by Ball include **alternans** Dejean, *fumans* Fab., *microamericanus* Erwin, and *perplexus* Dejean. These 4 species are treated as one in all statistical analyses.

Faunas were evaluated using richness (number of species) and species habitat preferences (frequency of occurrence in each habitat). The influence of treatments on beetle assemblages was analyzed using two similarity indices. The first was the qualitative Simple matching presence-absence coefficient and the second the quantitative Bray-Curtis species-abundance coefficient (Romesburg 1984). Both coefficients measure similarity on a 0 to 1 scale, with 0 equal to perfect dissimilarity and 1 perfect similarity. Each coefficient is calculated by making species by species comparisons of paired treatments. As an example, each species in the chop treatment was compared against the same species in the shear treatment. This technique was used until all possible treatment pairs were compared. These paired comparisons created a resemblance matrix that was then analyzed using the cluster analysis procedure found in many statistical packages. We used the average linkage clustering method (UPGMA) and the squared Euclidean distance measure of the CLUSTER ANALYSIS routine within the SPSS/PC+ statistical package (Norusis 1988).

The Simple matching coefficient provides a value of 1 for 1-1 and 0-0 matches and a value of 0 for 0-1 and 1-0 matches. A 1-1 match shows that the species was present on both sites, and a match of 0-0 shows the species was absent from both sites. This coefficient was used because the trapping was conducted in a limited area and we assumed that each species collected from a treatment was there because the insect selected the treatment and not because it was not present in the area. The equation for calculating the coefficient is:

$$C_{jk} = \frac{a + d}{a + b + c + d}$$

where j is one treatment, and k is another, and a = total number of 1-1 species matches, b = 0-1 matches, c = 1-0 matches, and d = 0-0 matches.

Before the Bray-Curtis coefficient was calculated, the quantitative data for each treatment was standardized by converting the total number of beetles collected for each species to percentages based on the

total number of beetles collected from that treatment. This standardization forces each treatment to provide equal weight to the resemblance matrix. The equation for calculating the coefficient is:

$$b_{jk} = 1 - \frac{\sum_{i=1}^{n} |x_{ij} - x_{ik}|}{\sum_{i=1}^{n} (x_{ij} + x_{ik})}$$

where b_{jk} is the Bray-Curtis coefficient, i = species i, n = number of species to be compared, j = treatment j, k = treatment k, and x = proportional abundance of each species. This coefficient is commonly used in assessing similarity among ecological assemblages (Romesburg 1984).

Results and Discussion

We collected 10 tribes, 18 genera, and 34 species of ground beetles. Based on numbers of species, the tribes Chlaeniini, Harpalini, and Pterostichini dominated the site (table 1). Based on species abundance, the genera *Brachinus, Chlaenius, Cyclotrachelus* and *Pterostichus* dominated the site (table 1).

Cluster analysis of the Simple matching coefficients (figure 2a) showed that: 1) the inject and harvest-only treatments were very similar, 2) the chop treatment was somewhat different from the inject and harvest-only treatments, and 3) the shear treatment clustered by itself although it was more like the inject, harvest-only, and chop treatments than the check. Clearly, the check was very different from all harvested treatments as it clustered with them only at the maximum relative distance. The check was different because relatively few species were collected there (only 13) and it possessed the only specimens of *Pinacodera* sp. and *Dicaelus ambiguus* LaFerte. [*Pinacodera* are tree inhabiting ground beetles (Ball 1973) not typically collected in pitfall traps, and *D. ambiguus* is a species found in moist forests (Ball 1959).] However, the check was similar to all other treatments because it shared 9 of its 13 species with them (table 1).

As expected, the heavily disturbed chop and shear treatments had the highest species richness values (figure 2a). The literature is replete with examples where disturbance diversifies the character of the soil and flora of the forest floor, which in turn provides new habitats for ground dwelling animals (e.g., Coyle 1981, Sustek 1981, Lenski 1982, Mossakowski et al. 1990, McIver et al. 1992). The shear treatment (with a species richness of 25) included 6 unique species compiled from the tribes Agonini, Chlaeniini, Harpalini, and Scaritini. These tribes prefer open sites (Ball 1973). Only one unique species was recorded from the chop, and it was from Pterostichini, a tribe with mixed habitat preferences. These beetles provide evidence that the shear treatment may produce more ground-level habitat diversity. There was little conspicuous visual evidence to suggest differences between these two treatments other than the fact taht the slash on the sheared treatment was in taller piles because it had not been chopped.

The species-abundance dendrogram also showed that similar treatments clustered together (figure 2b). The chop and shear treatments were very similar, as were the inject and harvest-only treatments. More important, the chop-shear and inject-harvest-only clusters were very different from each other. The untreated check clustered by itself although it was more like the inject and harvest-only treatments. Cluster analysis and an assessment of species occurrence and abundance, shows that the quality and quantity of beetles found in the harvested treatments were positively influenced by intensive site preparation. Similarity of the inject and harvest-only treatments show that the beetles were indifferent to whether the standing trees were live or dead.

Only species in the genera *Brachinus* and *Progaleritula* showed preferences for the closed-canopy forest. The preferences of these genera were as expected, based on beetle collections from upland forests (L.C. Thompson unpublished data). Nine of the 13 species collected in the closed-canopy forest were also collected in the harvested treatments. Thus, using cutting practices that leave standing trees may not aid conservation of most of these ground beetles.

Most species showed distinct preferences for the harvested sites. This is especially true for species in the tribes Agonini, Carabini, and Harpalini (table 1). Species in these tribes are generally reported to be polyphagous, consuming small invertebrates, fruits, and seeds (Johnson and Cameron 1969). Perhaps these tribes are present in the harvested sites because of increased availability of preferred foods.

Although our data are from an unreplicated study conducted over one growing season, species from several tribes show potential as indicator species

Table 1. Species abundance (percentage) based on total ground beetles trapped per treatment.

	Treatments				
TRIBE/Species	Chop	Shear	Inject	Harvest -only	Check
AGONINI					
Agonum punctiforme Say	2.7	0.7	0.9	0.5	0.0
Agonum sp.	0.0	0.4	0.0	0.0	0.0
Calathus opaculus LeConte	0.4	0.4	0.0	0.0	0.0
BRACHININI					
Brachinus spp.	1.5	7.7	25.5	24.1	53.5
CARABINI					
Calosoma say Fab.	0.4	0.7	0.5	0.0	0.0
CHLAENIINI					
Chlaenius emarginatus Say	1.5	0.7	0.0	0.2	0.3
Chlaenius erythropus Germar	4.2	1.8	24.1	15.4	2.3
Chlaenius nemoralis Say	0.0	0.0	0.0	0.2	0.0
Chlaenius pusillus Say	1.1	1.5	1.4	0.5	2.3
Chlaenius sp.	0.0	0.4	0.0	0.0	0.0
Chlaenius tomentosus (Say)	0.0	0.4	0.0	0.0	0.0
DRYPTINI					
Progaleritula spp.	1.1	1.5	0.5	4.3	4.0
HARPALINI					
Anisodactylus rusticus (Say)	2.3	2.9	0.5	0.2	0.0
Anisodactylus sp.	0.8	3.3	0.9	0.0	0.0
Harpalus pennsylvanicus Say	5.3	6.2	5.0	1.4	0.0
Harpalus sp.	1.9	2.9	0.5	0.7	0.0
Selenophorus sp.	1.5	4.4	5.0	0.7	0.0
Stenolophus sp.	0.0	0.7	0.0	0.0	0.0
LEBIINI					
Pinacodera sp.	0.0	0.0	0.0	0.0	0.3
LICININI					
Dicaelus ambiguus LaFerte	0.0	0.0	0.0	0.0	0.3
Dicaelus elongatus Bonelli	3.4	2.2	1.4	0.5	1.3
PTERSTICHINI					
Cyclotrachelus convivus LeConte	31.2	25.3	11.4	27.7	24.1
Cyclotrachelus obsoletus Say	0.4	0.0	0.5	0.0	0.0
Cyclotrachelus seximpressus (LeConte)	23.2	12.8	14.1	14.2	3.0
Loxandrus sp.	0.4	0.4	0.0	0.0	0.0
Pterostichus chacites Say	0.4	0.0	0.0	0.0	0.0
Pterostichus permundus (Say)	12.5	19.4	5.5	8.4	7.9
Pterostichus sp.	0.4	0.0	0.0	0.0	0.3
SCARITINI					
Ardistomis puncticollis (Dejean)	0.0	0.7	0.0	0.0	0.0
Aspidoglossa subangulata (Chaudour)	0.0	0.4	0.0	0.0	0.0
Scarites subterraneus Fab.	3.4	2.2	2.7	0.7	0.3
Total Number Trapped	(263)	(273)	(220)	(415)	(303)

of forest disturbance. All species in the tribes Agonini, Carabini and Harpalini were absent from the check, and were most common in the highly disturbed treatments (table 1). These data suggest that finding members of either tribe in a bottomland forest would indicate a disturbed condition. However, when Allen and Thompson (1977) trapped beetles from undisturbed bottomland hardwood forests along the White and Arkansas Rivers, they recovered species from each of these tribes, 4 from Agonini, 2 from Carabini, and 6 from Harpalini, and none were collected frequently. Allen and Thompson also collected 4 species in the tribe Scaritini, including *Pasimachus elongatus* LeConte, which was abundant

at the White River site. Experience with trapping ground beetles in upland sites (L.C. Thompson unpublished data) shows that these 4 tribes (Agonini, Carabini, Harpalini, and Scaritini) are typically found in disturbed forests. When species from these tribes were found in closed-canopied forests, they were commonly trapped from locations with openings caused by treefalls or tree mortality. Perhaps these four tribes were collected by Allen and Thompson because the forests in which they were collected were "breaking up" due to old age. The senior author has recently traversed some stands in the White River National Wildlife Refuge typical of those in which Allen and Thompson trapped, and these old forests have abundant openings. Maybe these tribes dislike only younger closed-canopy forests, and old growth forests with natural gaps and disturbed forests with manmade gaps provide suitable habitats for these disturbance-preferring species. Luff (1990) has commented that ground beetles may be used as indicator species if occasional species are omitted from species lists, and that quantitative ground beetle data, incorporating the relative abundance of species, may be sensitive to local variations in habitat. Because of this habitat sensitivity, Luff suggests that when monitoring habitats, pitfall traps must be strategically placed in uniform habitats or enough traps used to average out local habitat variations. Still to be resolved is whether these beetles can be reliably used as indicators of disturbance; also, can they discern levels of disturbance as small as a single treefall?

Faunal differences appear to be the rule in bottomland forests. The two bottomland hardwood sites sampled by Allen and Thompson (1977) shared only 5 of 29 total species, although they are geographically close (the White River site [Arkansas County] is one county north of the Arkansas River site [Desha County]). In addition, our Saline River site shared 1/2 the species with each of the White River and Arkansas River sites. These differences should be considered when contemplating the use of ground beetles to monitor disturbance, or recovery from disturbance. Obviously, additional studies are needed to clarify species habitat qualities.

The fauna collected in unmanaged bottomland forests of the White and Arkansas Rivers by Allen and Thompson (1977) differed somewhat from that reported from this managed forest. Dominant species reported by Allen and Thompson were *Pasimachus elongatus, Cyclotrachelus convivus* LeConte, and *Pterostichus permundus* (Say). In this study, *C. convivus* and *P. permundus* were common, and *P. elongatus* was not collected. *C. convivus* is a flightless species (as are all *Cyclotrachelus)* commonly trapped in closed canopy pine-hardwood upland forests (L.C. Thompson unpublished data). *P. permundus* prefers open locations (Ball 1973, Thompson unpublished data). However, it is evidently a habitat generalist that tolerates forest situations, because we collected it in all treatments (table 1), and Allen and Thompson also collected it in oak-hickory and loblolly pine stands. *P. elongatus* reportedly inhabits dry, open woodlands and prairies with sparse vegetation (Ball 1973). It has been collected infrequently in upland forests of southern Arkansas (L.C. Thompson unpublished data). Two species, *C. seximpressus* (LeConte) and *Dicaelus elongatus* Bonelli, were common in the bottomlands reported here but were absent from the bottomlands reported by Allen and Thompson. However, *C. seximpressus* was collected from the oak-hickory and pine stands and *D. elongatus* from the oak-hickory stand (Allen and Thompson 1977). *D. elongatus* prefers moist sites (Ball 1959) and *C. seximpressus* prefers open sites (Freitag 1969). Both species are commonly collected from upland forests in southern Arkansas (L.C. Thompson unpublished data).

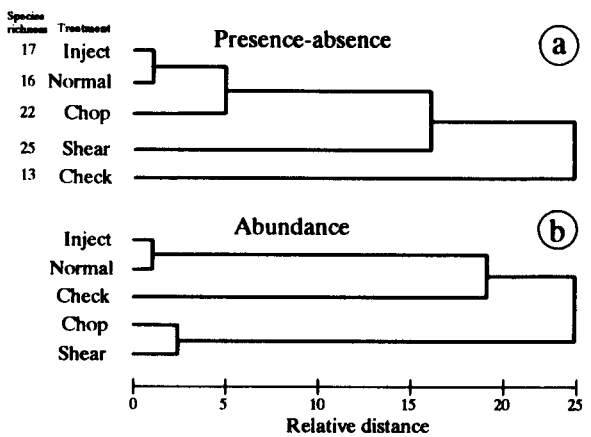

Figure 2. *Species richness and cluster analyses showing similarity of ground beetle assemblages as influenced by site preparation treatments to a clearcut bottomland hardwood stand: a. Species richness and presence-absence dendrogram using Simple matching coefficients; b. Abundance dendrogram using Bray-Curtis coefficients.*

Acknowledgements

Thanks to Vic Harding, Bobby Webb, and Lang Kirshberger undergraduate forestry students, who assisted with plot installation, and beetle

trapping, sorting and pinning; to Dr. George Ball, Department of Entomology, University of Alberta, for *Brachinus* identifications; and to our manuscript reviewers, Drs. Mike Shelton, Brian Lockhart and Phil Tappe.

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GROUNDWATER FLOW IN PINE-CYPRESS FLATWOODS [1]

H. Riekerk [2]

Abstract. A baseline study has been set up for model development of pine-cypress flatwoods hydrology for future testing with silvicultural treatment effects. The site is a very poorly drained spodosol (Ultic Haplaquods) underlain by a clay layer and with a thinned 26-year old slash pine plantation and interspersed cypress ponds on ultisols (Aquults). Three ponds were instrumented with 3-ft deep groundwater well transects and monitored monthly with a heat-pulse flowmeter for 18 months. The data revealed an average flow of 0.4 ft/day with more flow near the pond margins and less in the pine lands. Groundwater flow decreased during the dry spring and fall seasons with lowering watertables, but also after the winter rains recharged the soils and the ponds flowed over. Groundwater flows near the margins tended to be outward from the ponds, with the exception of one pond with a distinct inflow pattern and little surface outflow. This pond had a thinner and oxidized clay bottom and supported dense vegetation.

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Associate Professor, University of Florida, Gainesville, FL.

RELATION OF SOME PHYSICAL AND CHEMICAL SOIL PROPERTIES TO THE GROWTH OF SYCAMORE, SWEETGUM, AND GREEN ASH [1]

R. Larry Willett and M. Victor Bilan [2]

Abstract. Soil properties were related to height growth of three small plantations on a second terrace in East Texas: 1.5 acres of 5-year-old sycamore (*Platanus occidentalis* L.), 1.5 acres of 6-year-old sweetgum (*Liquidambar styraciflua* L.), and 3.0 acres of 6-year-old green ash (*Fraxinus pennsylvanica* Marx.). Five soil sample pits in each stand represented variation in height classes. Stepwise regression analysis was used to determine significant height growth predictors. Height of the sycamores ranged from 3.1 to 16.4 feet. Height at age 5 was negatively correlated with percent clay at a depth of 1.0 foot and positively correlated with pH at 0.5 foot. Clay slowed drainage on this generally low, wet site, while pH of the best sites favored optimum nutrient availability. Sweetgum heights ranged from 3.2 to 15.5 feet. Height at age 6 increased with increasing fine material at a depth of 2.5 feet, which improved moisture retention on this high, well-drained plantation. Green ash heights ranged from 4.5 to 18.1 feet. Height at age 6 increased directly with pH of the A1 horizon and decreased with increasing potassium in the A1. The pH levels of the better sites favored optimum nutrient availability, but the effect of potassium could only be explained as sample variation.

Introduction

The first commercial planting of hardwood in the South took place in 1960 when the Crown Zellerbach Corporation established a 15,000-acre cottonwood plantation in the Mississippi Delta (Johnson 1983). Within five years, at least six other companies had established large-scale commercial plantations of cottonwood.

Interest in planting hardwoods began to develop in East Texas in the early 1960's. One timber company established a series of small test plantings on a terrace of the Neches River in southeastern Texas. Subsequently, large variations in height growth were apparent within a 5-year-old plantation of sycamore and within 6-year-old plantations of sweetgum and of green ash. This study was begun in the fall of 1968 to determine whether the height growth differences might be correlated with specific quantifiable site characteristics as a first step in development of a soil/site evaluation system.

Methods

The Study Area

The 1.5 acre sycamore plantation, 1.5 acre sweetgum plantation, and 3.0 acre green ash plantation were growing on a terrace or former floodplain of the Neches River in Tyler County, Texas. The site had previously supported a mixed hardwood and pine forest. Following harvest, the site had been prepared by piling and burning the slash. The sweetgum had been planted at an 8 feet by 8 feet spacing and the sycamore and green ash at 12 feet by 12 feet. Following plantation establishment, competing vegetation was controlled by mowing.

The sweetgum plantation was located at the highest elevation, but elevations within the plantation differed by as much as 6 feet. The green ash site was generally lower than the sweetgum plantation but it was upslope from the sycamore plantation which it adjoined. The sycamore plantation was lowest in elevation.

Field Procedure

Heights of trees in each plantation were measured and mapped. Five soil sample pits were located in each plantation to represent variation in height classes. The average height of the two closest trees to each soil pit was used as an estimate of site quality. A soil profile description was prepared for each pit, including such information as thickness of

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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the horizons, color, texture, structure, consistence, and pH. Soil samples were taken from each horizon.

Laboratory Procedure

Soil samples were oven-dried. Standard methods were used to determine soil texture; separate soil particle sizes;, determine percent organic matter; and determine exchangeable phosphorus, potassium, sodium, manganese, zinc and magnesium. Data were compiled by soil horizon and also by depths of 0.2, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 feet.

Statistical Analysis

For each species, average heights were plotted over soil values at each soil horizon or depth to discern trends. Simple linear correlation analysis were used to quantify the trends. Stepwise regression analyses were then used to determine significant predictors of average tree height.

Results

Sycamore

Average height for the sycamore plantation was 7.56 feet and heights ranged from 3.1 to 16.4 feet. Simple linear correlation analysis showed highly significant (0.01 level) negative correlations between tree height and percent clay at a depth of one foot and also between height and percent clay in the B1 horizon. Significant (.05 level) positive correlations were found between tree height and Ph at 0.5 foot and in the A1 horizon, parts per million calcium at 0.5 foot, and percent organic matter at 0.5 foot. Significant negative correlations were found to exist between tree height and percent clay at 0.5 foot; clay plus silt at 1.5 feet, 2.0 feet, and 3.0 feet; and parts per million sodium at a depth of 2.5 feet.

When the data were analyzed using stepwise regression techniques, percent clay content of the soil at a depth of 1 foot -- within a range of 17 to 52 percent clay -- was found to be negatively correlated to tree height and significant at the 1% level (Table 1). Soil pH at a depth of 0.5 foot -- with a range of pH 3.9 to 5.9 -- was also highly significant but positively correlated. The equation to predict average height for sycamore, where percent clay at one foot accounts for 92.21% of the statistical variation in tree height and pH at 0.5 foot for 7.78% is:

$$Y = 6.3779 - 0.1889\ X_1 + 2.0347\ X_2$$

$R^2 = 99.99\%$[3]
$Sy.x = 0.0715$,[4] and
where Y = tree height in feet
X_1 = % clay at a depth of 1 foot, and
X_2 = pH at a depth of 0.5 foot

Table 1. *Analysis of variance for the regression equation to predict average sycamore height.*

Source	df	SS	MS	F
Clay at 1.0 ft.	1	92.91	92.9126	18218.2**
pH at 0.5 ft.	1	7.85	7.8451	1531.6**
Residual	2	0.01	0.0051	
Total	4	100.77		

** $F_{.01} = 98.49$

Sweetgum

In the sweetgum plantation, tree heights ranged from 3.2 to 15.5 feet and averaged 7.17 feet. Simple linear correlation analysis showed a highly significant positive correlation between tree height and the percent fine material (less than 60 mesh) at a depth of 2.5 feet and a significant positive correlation between tree height and percent fine material at a depth of 2.0 feet. There was a significant negative correlation between tree height and parts per million of manganese in the B1 horizon.

Stepwise regression showed that after the effect of the percent fine material at 2.5 feet was eliminated, other measured criteria were not significant (Table 2). In these samples, the proportion of fine material at a depth of 2.5 feet ranged from 93.23 to 99.53 percent. The equation to predict tree height for sweetgum at age 6 where percent fine material is positively correlated at the 1% level and accounts for 92.67% of total variation is:

[3] R^2 = percent of variation in height accounted for.

[4] Sy.x = standard error of the estimate.

$$Y = 148.3638 + 1.64578\ X,$$

with $R^2 = 92.67\%$,
$Sy.x = 1.5602$ feet, and
where Y = tree height in feet, and
X = % fine material at 2.5 feet.

Table 2. Analysis of variance for the regression equation to predict average sweetgum height.

Source	df	SS	MS	F
Fines at 2.5 ft.	1	92.30	92.2954	37.916**
Residual	3	7.30	2.4342	
Total	4	99.60		

** $F_{.01} = 34.12$

Green Ash

Tree heights in the green ash plantation averaged 11.1 feet with a range of 4.5 to 18.1 feet. Simple linear correlation analysis showed a highly significant positive correlation between tree height and pH of the A1 horizon. There was a significant positive correlation between height and the amount of potassium in the A1 horizon. A correlation of 0.97 was found between pH and potassium in the A1 horizon. In addition, there was a significant negative correlation between height and percent fine material (less than 60 mesh) at a depth of 2.5 feet and also between height and the amount of sodium present at a depth of two feet.

Stepwise regression showed that pH of the A1 horizon, in the range of pH 4.15 to 6.35, accounted for 94.64% of the variation in tree height. The potassium content of the A1 horizon, in the range of 52 to 260 parts per million potassium, accounted for 5.02% of the variation. Table 3 presents the analysis of variance, with pH of the A1 horizon positively correlated to tree height and significant at the 1% level and exchangeable potassium of the A1 negatively correlated and also significant at the 1% level. The equation to predict tree height for green ash at age 6 is:

$$Y = -39.9436 + 11.5165\ X_1 - 0.0576\ X_2,$$

with $R^2 = 99.66\%$,
$Sy.x = 0.4513$ foot, and
where Y = tree height in feet,
X_1 = pH of the A1 horizon, and
X_2 = ppm potassium in the A1 horizon

Table 3. *Analysis of variance for the regression equation to predict average green ash height.*

Source	df	SS	MS	F
pH of the A	1	114.01	114.0136	559.7**
K of the A	1	6.05	6.0480	9.7 *
Residual	2	0.41	0.2037	
Total	4	120.47		

** $F_{.01} = 98.49$
* $F_{.05} = 18.51$

Conclusions

Height growth of sycamore to age five was found to decrease with increasing percent clay content at a depth of one foot within the range of 17 to 52 percent clay. This was apparently due to the effect of clay in slowing drainage and reducing soil aeration on this low-lying site. Sycamore usually grows best where the water table drops enough during the growing season to permit good soil aeration (Wells and Schmidtling 1990). Tree height was found to increase with higher soil pH at a depth of one foot within the pH range of 3.9 to 5.9. The best sites in this plantation approach the pH range of 6.0 to 7.0 at which plant nutrients in the soil are most readily available (Buckman and Brady 1969) and the pH range of 6.0 to 7.5 which Spurway (1941) suggested as optimum for sycamore.

Sweetgum height at age six was positively correlated with percent fine material in the soil at a depth of 2.5 feet, within the range of 93.23 to 99.53 percent fines. This plantation was situated on a relatively high elevation so there would likely be a moisture deficiency during part of the growing season. A greater amount of fine material at a soil depth of 2.5 feet would allow good drainage of the upper soil horizons while still favoring water retention and increasing storage capacity in the subsoil of this generally well-drained site.

Height growth of green ash was found to increase with the pH of the A1 horizon in the range of pH 4.15 to 6.35 and to decrease with an increasing potassium content of the A1 horizon within the range of 52 to 260 parts per million of potassium. A soil pH range of about 6.0 to 7.0 is associated with optimum availibility of plant nutrients (Buckman and Brady 1969). The best sites in this plantation were within that range of pH. The effect of potassium is

more difficult to explain. When used alone as a predictor, potassium content of the A1 horizon was positively correlated with tree height, as would be expected where exchangeable potassium levels are relatively low. Sample variation may be the only explanation for the negative relationship of potassium in the equation when its effect is combined with the effect of pH of the A1 horizon.

This study found strong correlations of soil microsite differences with large differences in early growth within small plantations of sycamore, sweetgum, and green ash. Obviously, however, the excellent fit of the regression equations to predict tree height must be viewed in the context of the very small sample size and the single study location.

This preliminary research was never expanded into the broader study which was envisioned initially. Interest in planting hardwoods quickly declined as it became feasible to use abundant, cheap, mixed upland hardwoods for pulp. In addition, we recognized the clear merits of the Baker and Broadfoot (1979) comprehensive approach to hardwood site evaluation.

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Wetlands: Silviculture and Management

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FIRST-YEAR RESULTS OF BOTTOMLAND OAK REESTABLISHMENT IN ALLUVIAL SOILS OF THE LOWER MISSISSIPPI VALLEY [1]

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Abstract. Wetland restoration efforts in the Lower Mississippi Valley often include reestablishment of bottomland hardwood species, especially oaks. However, success of oak establishment is inconsistent. There is a need for information on relationships among seedling growth, planting methods, soil properties, and hydrologic conditions to promote these wetland restoration projects. The objective of this study was to evaluate the influence of these factors on oak seedling performance on a site being converted from farmland to forestland. Seedlings and acorns of cherrybark oak (*Quercus pagoda* Raf.), Nuttall oak (*Q. nuttallii* Palmer), Shumard oak (*Q. shumardii* Buckl.), and water oak (*Q. nigra* L.) were planted in three common alluvial soil series. A lack of Spring flooding and adequate soil moisture during the growing season resulted in high first-year seedling survival in each soil using either seedling planting or direct seedling of all four oak species. Nuttall and water oaks germinated throughout the growing season under a range of soil conditions. This adaptability may be critical when site conditions are less favorable than they were during the first year of this study. Rapid height growth of planted Nuttall and water oak seedlings and of direct-seeded Nuttall oak shows that these species may be less susceptible to submergence by flood water and subsequent mortality.

Introduction

The major forested wetland functions, which provide the foundation for various wetland values, are floral and faunal population dynamics, biogeochemical cycling, and hydrologic cycling. Wetland values include wildlife habitat, floodwater buffering, erosion control, water purification, groundwater recharge, biomass production, recreation, and aesthetics (Burke et al. 1988).

Restoration of forested wetlands is critical because of historical and current rates of loss (Burke et al. 1988, Want 1989). The public has recently begun to appreciate the beneficial values of wetlands. Because of increased environmental concerns and growing awareness of wetland losses, wetland conversion has become a sensitive issue, and pressures have mounted for wetland preservation and restoration. The U.S. Army Corps of Engineers with oversight from the U.S. Environmental Protection Agency is authorized to regulate wetland development and to conduct wetland mitigation programs based on Section 404 of the Federal Water Pollution Control Act of 1972 (Kruczynski 1989). Despite this legislation, wetland areas continue to decrease every year (Turner et al. 1981).

Artificial regeneration of bottomland hardwoods, which comprise the majority of forested wetlands in the southeastern U.S., has been studied by numerous investigators. Prior studies show the importance of plant physical adaptations to flooding (Hosner 1959), late-Spring flooding effects on bottomland hardwood seedlings (Bonner 1966), species-site relations of bottomland hardwood species (Francis 1983; Johnson and Krinard 1985a, 1985b, and 1987; Kennedy and Krinard 1985), and variation in water tolerances of bottomland hardwood species (McKnight et al. 1980). However, information on heavy-seeded bottomland hardwood reestablishment is still limited (Kruczynski 1989). In particular, there is a lack of knowledge about oak species germination and seedling performance in wetland soils in relation to wetland hydrology and specific soil properties. The objective of this study is to evaluate the reestablishment of cherrybark oak (*Quercus pagoda*

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[1] Paper presented at Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992. Contribution No. PS8182 of the Mississippi Agricultural and Forestry Experiment Station.

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Raf.), Nuttall oak (*Q. nuttallii* Palmer), Shumard oak (*Q. shumardii* Buckl.), and water oak (*Q. nigra* L.) in relation to soil and hydrologic characteristics of three common Lower Mississippi Valley alluvial soils.

Materials and Methods

This study is part of the Lake George Wildlife Wetland Restoration Project (Lake George Project), which was designated by the U.S. Army Corps of Engineers for the mitigation of terrestrial wildlife losses resulting from the Yazoo Area and Satartia Area Backwater Levee Projects (U.S. Army Corps of Engineers 1990). The 8,000-acre project site was converted from bottomland hardwood forest to agriculture in the 1960's and has been intensively farmed in cotton, soybeans, and rice. The project site is in Yazoo County, Mississippi, and is bounded by the Delta National Forest to the southwest and by the Panther Swamp National Wildlife Refuge to the northeast. One of the objectives of the Lake George Project is to reestablish a bottomland hardwood forest which will connect these two fragmented forest systems.

Three common soil series which represent a range of edaphic conditions commonly occurring on the site and throughout the Lower Mississippi Valley alluvial floodplain were studied: 1) Dundee fine-silty, mixed, thermic, Aeric Ochraqualfs, which form on old river ridges characterized by slight elevation above adjacent areas (SCS-USDA 1975). This soil usually contains a large amount of silt and is somewhat poorly drained; 2) Forestdale fine, montmorillonitic, thermic, Typic Ochraqualfs (SCS-USDA 1975) is characterized by more clay (35-60%) than Dundee, lower landscape position, and is poorly drained; and 3) Sharkey very fine, montmorillonitic, nonacid, thermic, Vertic Haplaquepts (SCS-USDA 1975) which occurs along drainages or low areas and is characterized by high montmorillonitic clay content and poor drainage. The Forestdale and Sharkey series are classified as hydric soils (SCS 1991).

The study design is a randomized complete block with split-split plots. Three blocks were established within the restoration site. Each block included three soil series (Dundee, Forestdale, and Sharkey) as main treatment plots with four different oak species (cherrybark oak, Nuttall oak, Shumard oak, and water oak) within split plots. Each split plot was separated into a split-split plot by two different planting methods (direct seeding and seedling planting). Each split-split plot is planted in seven rows with seven planting locations per row in a 3 x 3 m spacing. Each split-split plot includes 49 planting locations consisting of 24 buffer locations surrounding 25 measurement locations.

One-year old, nursery-grown seedlings were hand-planted in December, 1991, and acorns were hand-planted at a depth of 5-8 cm in March, 1992. Seedlings were obtained from Delta View Nursery in Leland, MS, and from the Mississippi Forestry Commission Nursery in Winona, MS. Nuttall oak acorns were collected in the Mississippi Delta region, and cherrybark, Shumard, and water oak acorns were collected near Starkville, MS. Planted seedling survival was evaluated every two weeks from May 15 through August, 1992, and then monthly until October, 1992. Seedling mortality prior to May was difficult to determine because of high variability in growth initiation. Acorn germinant survival was measured every two weeks from April through August, 1992, and then monthly until October, 1992. Final measurements of survival, height, and groundline diameter for the first growing season were conducted in October, 1992.

An integrated soil moisture reading was taken between 0-30 cm of soil every two weeks from January through August, 1992, and then monthly through October, 1992. Measurements were made at a central location in each split-split plot using either Time Domain Reflectometry or gravimetric sampling. These data were converted to soil water potential values using soil water desorption curves. Soil temperature was measured at a depth of 15 cm every two weeks from January through August, 1992, and then monthly through October, 1992, in each split plot.

Intact soil samples from each split plot were collected at depths of 0-10, 10-20, and 20-30 cm using a double-cylinder core sampler. Physical properties, including bulk density, saturated hydraulic conductivity, total-, macro-, and micro-porosity, and water retention were analyzed by standard methods (Klute 1986).

In each split-split plot, a 2-cm-diameter push tube was used to collect composite soil samples for chemical analysis. Composite samples were comprised of five subsamples collected at 0-30 cm depth. Samples were air-dried, ground, and sieved

through a 2-mm screen prior to analysis. All chemical analyses were conducted by the Soil Testing Laboratory at Mississippi State University. Soil reaction was determined in the supernatant of a 1:2 soil/water slurry with a pH electrode (McLean 1973). Organic matter was analyzed by the DeBolt procedure (DeBolt 1974). Extractable phosphorus, potassium, calcium, and magnesium were determined by the Lancaster method (Lancaster 1970).

Results and Discussion

Soil Characterization

Soil physical properties reflect the alluvial gradient at the study site (Table 1). The soil texture of Dundee, Forestdale, and Sharkey is silt loam, silty clay loam, and clay, respectively. Bulk density of Dundee, Forestdale, and Sharkey is 1.58, 1.54, and 1.32 Mg/m^3, respectively, and gravimetric moisture content of each soil at sampling time was 20%, 25%, and 39%, respectively. These bulk density values are higher than values reported by Broadfoot (1976) for the same soil series on forested sites. Since this study site has been intensively farmed using large mechanical equipment, it is likely that surface soil compaction has occurred. In addition, these soils have a high shrink-swell capacity and differences in bulk density may be caused by differences in soil moisture when samples were collected. Broadfoot (1976) did not report soil moisture levels for bulk density samples.

Porosity properties of the three soil series follow their textural- and bulk density gradients (Table 1). The macro-porosity of the Dundee and Forestdale series is significantly higher than the Sharkey series because of their coarser soil texture. In contrast, the micro- and total-porosity of the fine-textured Sharkey series are higher then the other two series and result in relatively low bulk density. The macro-porosity values of all three soils in this study are approximately one-half of those reported by Broadfoot (1976) for the same soil series occurring in forested conditions. This decrease in macro-porosity is further evidence that soil compaction from intensive farming practices has occurred on this site.

Saturated hydraulic conductivity was 52.1, 36.1, and 13.6 cm/day for the Dundee, Forestdale, and Sharkey series, respectively (Table 1). This range of values is attributable to differences in macro-porosity among the soils. Hydraulic conductivity is a critical property for seedling survival in soils which are susceptible to inundation. Poor drainage, resulting from low hydraulic conductivity, increases the frequency and duration of saturated soil conditions. Bottomland hardwood seedling mortality is often positively correlated with the frequency and duration of soil saturation (Bonner 1966, Harms 1973, Pezeshki 1991).

Although extractable nutrients and organic matter in the Dundee soil were approximately one-half of those in the Forestdale and Sharkey soils, these differences were not significant because of high spatial variability within each soil series (Table 2). Soil comparisons were also complicated by different cropping and fertilization histories. Nutrient critical levels for bottomland oak species have not been reported in the literature, and foliar nutrient levels were not evaluated in this study. However, visual symptoms of nutrient deficiencies were not observed during the first growing season.

Acorn Germination and Seedling Survival

Soil temperature and moisture are the major factors controlling acorn germination (Kramer and Kozlowski 1979). In Figure 1, percent germinant survival is the sum of cumulative germination, germinant mortality, and resprouting at a given date. Since there was not a significant soil x species interaction for germinant survival, the values were pooled among soils for each date (Fig. 1C). Furthermore, soil temperature was not significantly different among soils, so these values were also pooled among soils for each date (Fig. 1A).

Germination of Shumard and cherrybark oaks was first observed in late April when soil temperature exceeded 20°C (Fig. 1A and 1C). By early May, germination of Shumard and cherrybark oaks was 57% and 21%, respectively. Germination rates for these two species decreased by late June and percent germination remained the same for the duration of the growing season. In contrast, germination of Nuttall and water oaks was not observed until mid-May. The rate of increase in Nuttall oak germination was relatively high through late July and then leveled off during the remainder of the growing season. Water oak germination started slowly, then steadily increased through the remainder of the growing season. These results show two germination patterns: (1) rapid early germination of Shumard and cherrybark oaks with

Table 1. *Physical properties of three Lower Mississippi Valley alluvial soils*[1].

Property[2]	Dundee	Forestdale	Sharkey
Texture[3]	Silt Loam	Silty Clay Loam	Clay
Bulk density[4] (Mg/m^3)	1.58 a[5] (0.02)[6]	1.54 a (0.02)	1.32 a (0.03)
Macro porosity (%)	5.7 a (0.01)	4.9 a (0.01)	3.0 b (0.008)
Micro porosity (%)	41.8 a (0.006)	45.7 a (0.009)	55.8 a (0.02)
Total porosity (%)	47.5 a (0.009)	50.6 a (0.007)	58.8 a (0.02)
$K_{sat.}$[7] (cm/day)	52.1 a (11.3)	36.1 ab (13.7)	13.6 b (9.1)

[1] Values are mean of 36 samples.
[2] Measured at 0-10, 10-20, 20-30 cm depth.
[3] Values from Broadfoot (1976).
[4] Gravimetric moisture content of Dundee, Forestdale, and Sharkey is 20%, 25%, and 38%, respectively.
[5] Means followed by the same letter within a row are not significantly different at the 0.05 level.
[6] Standard error of mean.
[7] Saturated hydraulic conductivity.

Table 2. *Chemical properties of three Lower Mississippi Valley alluvial soils*[1].

Property[2]	Dundee	Forestdale	Sharkey
pH	5.4 (0.07)[3]	5.5 (0.07)	5.6 (0.07)
P (mg/kg)	9 (0.8)	17 (2.0)	30 (5.4)
K (mg/kg)	123 (5.8)	199 (12.5)	199 (14.9)
Ca (mg/kg)	1820 (120.8)	3239 (269.5)	3143 (247.2)
Mg (mg/kg)	475 (35.7)	962 (65.8)	810 (43.2)
OM (mg/g)	7.9 (0.03)	12.9 (0.10)	13.2 (0.07)

[1] Values are means of 24 composite samples.
[2] Measured at 0-30 cm depth.
[3] Standard error of the mean.

most occurring by mid-growing-season; and (2) slow, steady germination of Nuttall and water oaks throughout the growing season. Johnson and Krinard (1985b) observed similar germination patterns for Nuttall and water oaks in a Mississippi Delta old field.

Germinant survival after one growing season was relatively high for all four species (Table 3) compared with other studies on similar sites (Johnson and Krinard 1985a and 1985b). This can be attributed to favorable soil moisture conditions. Soil water potential in each soil decreased in May and July; however, the duration of these soil moisture deficits was insufficient to lower germinant survival (Fig. 1B and 1C). The cherrybark oak germinant survival of 43% was significantly lower than the other three species. However, Johnson and Krinard (1985b) reported cherrybark oak germination of 36%, indicating that successful direct seeding of cherrybark oak on these sites may require more acorns per acre than the other species.

Planted seedling survival is the number of living seedlings at each measurement date. Dieback and resprouting accounted for fluctuations in percent survival during the growing season (Fig. 2B). However, there was no decrease in survival for any of the species between the initial measurement in May and the final measurement in October. Survival of cherrybark, Nuttall, Shumard, and water oak in May was 85, 75, 68, and 79%, respectively, and survival for these species in October was 82, 80, 72, and 76%, respectively (Table 3). Soil moisture deficits which occurred in May and July may have caused some seedling dieback but did not lower seedling survival (Fig. 2A and 2B). This shows that hydrologic and edaphic conditions between May and October did not limit planted seedling survival. It also suggests that

Table 3. *First-year survival and growth of four bottomland oak species in Lower Mississippi Valley alluvial soils*[1].

Species	Planted seedlings		Acorn germinants		
	Survival	Height growth	Survival	Height growth	Diameter growth[2]
	(%)	(cm)	(%)	(cm)	(cm)
Cherrybark oak	82 a[3]	9.5 b	43 b[4]	8.7 c	0.17 c
Nuttall oak	80 a	18.8 a	71 a	17.1 a	0.37 a
Shumard oak	72 a	9.9 b	72 a	10.5 b	0.24 b
Water oak	76 a	18.9 a	65 a	7.7 c[4]	0.16 c

[1] Values are means of 9 split-split plots.

[2] Groundline diameter.

[3] Means followed by the same letter within a column are not significantly different at the 0.05 level.

[4] Significant difference at the 0.05 level between planting methods.

most of the seedling mortality probably occurred during storage, planting, or prior to bud break in the Spring.

Seedling Growth

Species x soil series interactions were not significant for measured growth parameters; therefore, results were pooled among soil series. Height growth of planted Nuttall and water oak seedlings was twofold greater than that of cherrybark and Shumard oaks (Table 3). Groundline-diameter growth comparisons among planted seedlings were not made because of unsettled initial soil conditions associated with planting. Germinant height- and groundline-diameter growth were highest for Nuttall oak, followed by Shumard, cherrybark, and water oaks (Table 3). There were no differences in height growth between planted seedlings and acorn germinants of Nuttall, Shumard, and cherrybark oaks. However, water oak seedling height growth of 18.9 cm was significantly higher than germinant height growth of 7.7 cm (Table 3). The greater height growth of planted and direct-seeded Nuttall oak and of planted water oak seedlings could be advantageous for avoiding inundation on sites susceptible to flooding.

Conclusions

Growing conditions at the Lake George Project site during 1992 were very suitable for oak establishment. There was no flooding, and soil moisture was adequate during the growing season to maintain high survival rates for all four bottomland oak species. Under these conditions, first-year survival shows that all four oak species can be successfully planted as seedlings and acorns on any of the three soil series. Acorn germinant survival of 43% for cherrybark oak is relatively high compared with other studies; however, higher survival of planted cherrybark oak seedlings suggests that this method has advantages for cherrybark oak establishment on this type of site.

Nuttall and water oaks germinated throughout the growing season under a range of soil temperatures and moisture. This adaptability may be critical when site conditions are less favorable than they were during the first year of this study. Rapid first-year height growth of planted Nuttall and water oak seedlings and of direct-seeded Nuttall oak indicates that these species may be less susceptible to submergence by flood waters and subsequent mortality.

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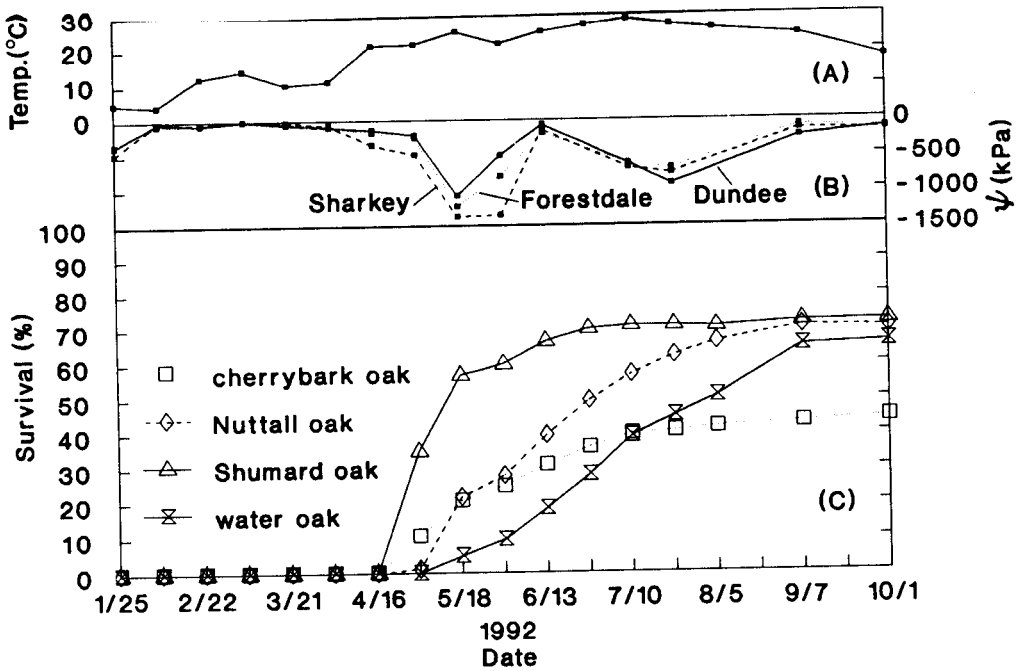

Figure 1. *The relation among soil temperature (°C), soil water potential (ψ), and oak germinant survival (%) in Lower Mississippi Valley alluvial soils.*

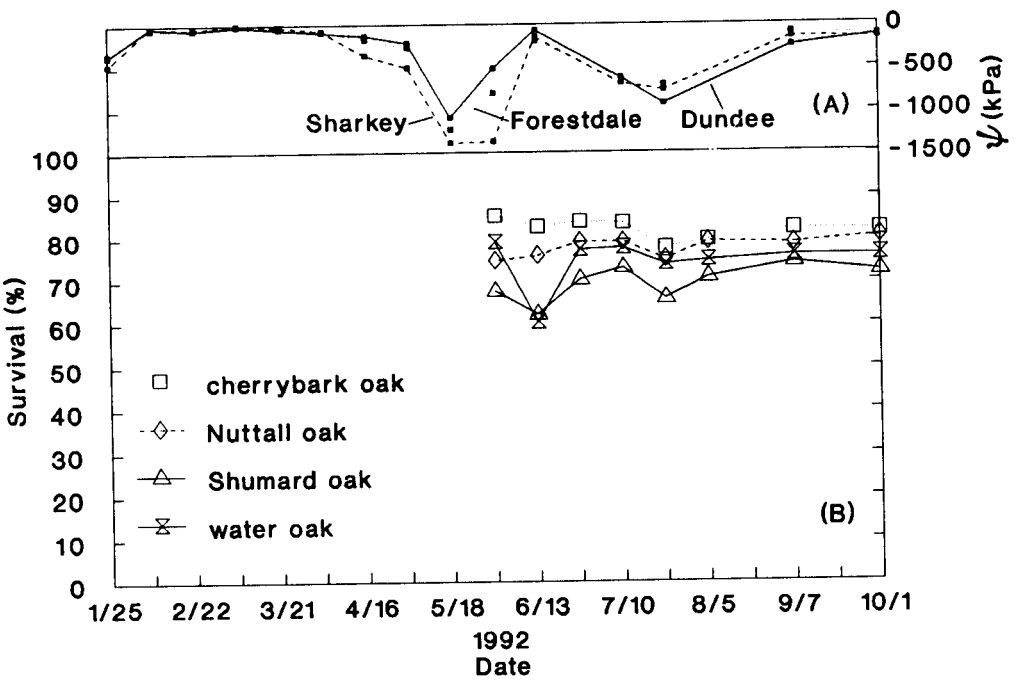

Figure 2. *The relation between soil water potential (ψ) and percent seedling survival of bottomland oak species in Lower Mississippi Valley alluvial soils.*

SUCCESSFUL REGENERATION OF QUALITY OAKS IN A RED RIVER BOTTOMLAND HARDWOOD STAND OF SOUTH CAROLINA [1]

Larry E. Nix and Angus Lafaye [2]

Abstract. Two well-stocked, mature, red river bottomland hardwood stands along the Congaree River in South Carolina were clear cut during early winter after a moderately good year of acorn production. Cherrybark, Shumard and water oak made up a significant portion of the dominant canopy of both stands (30-40% basal area). Logging conditions were relatively wet, resulting in appreciable scarification of both sites. A strong timber market facilitated near complete clear-felling and removal of all merchantable material. The scarification along with the abundant acorn crop resulted in prolific oak seedling establishment on both sites. Inventory after 3 growing seasons indicated nearly 5000 oak seedlings per acre on the dry site, nearly 2000 per acre on the wet site. After 5 growing seasons oak seedlings have declined to 1000 and 700 per acre, respectively, on the dry and wet sites. As many as 60 percent of the remaining seedlings are in a sufficiently competitive position to be in the dominant canopy at age 20 years.

Introduction

High quality oaks such as cherrybark (*Quercus pagoda* Raf.) and Shumard (*Q. shumardii*), have been disappearing from many southern bottomland forests as the rate of clearcut harvesting has increased (Johnson 1984; Nix 1989; Nix and Barry 1992). Many stands have been clearcut with the expectation of adequate oak reproduction only to result in a greatly diminished quality oak component after crown closure. The relative maturity of many stands, past high grading and lack of oak advance reproduction at harvest time have resulted in stump sprouts and seedlings of vigorous early-successional species gaining early dominance in these bottomland stands (Johnson 1984; Aust et al. 1985; Clatterbuck and Hodges 1988; Nix 1989; Nix and Barry 1992).

The importance of advance oak reproduction in successful regeneration of upland oak stands has been well-documented (Sander 1972; Watt 1979; Hannah 1987). However, it is unclear at present if advance oak reproduction is as important in bottomland oak regeneration as it is in upland oak regeneration due to the competitiveness of bottomland oak seedlings on good oak sites (Clatterbuck and Hodges 1988; Guldin and Parks 1989; Nix 1989). Recently the opportunity arose to follow the development of numerous young oak seedlings in two clearcut bottomland hardwood stands in South Carolina. As many as 5,000 freshly germinated seedlings per acre of cherrybark, Shumard, willow (*Q. phellos*) and water oak (*Q. niger*) were found at the beginning of the first growing season after harvesting the stands. These stands which had a high quality preharvest oak component were clearcut in the winter after a good acorn crop and during moderately wet site conditions, apparently resulting in the burying of thousands of acorns by the heavy skidding traffic and their successful germination. In an effort to determine the future success of these seedlings, inventories were done of their number and competitiveness and permanent transect plots were established to follow their development over the next 10 years. This paper reports the status of these seedlings after three and five years of heavy competition in the developing clearcut areas.

Methods

Two red river bottomland hardwood stands were clearcut during wet winter periods following two good acorn years in the Congaree River floodplain near Columbia, South Carolina. The stands were moderately well-stocked (70-75 ft.^{2} BA/AC), mature, even-aged (80-90 years), on good first bottom sites (SI_{50} = 95-100 for cherrybark oak) and with a 30-40 percent red oak overstory (Tables 1 and 2). One stand was judged to be a relatively "dry" site and the other a "wet" site based on appearance of standing water on color infrared aerial photographs taken

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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shortly after harvesting. The preharvest red oak component of both stands was 50+ percent cherrybark and Shumard oaks. Mature sweetgum and pine had been selectively harvested as individual trees some 10-15 years previously. There was little evidence of advance oak reproduction based on a survey of uncut portions or "control" areas left adjacent to each stand. A small pulpwood component and good local markets for the overstory species resulted in a near total clear felling and complete removal of all merchantable material from the stands. Heavy machine traffic and moderately wet conditions resulted in extensive site scarification. The two stands were harvested one year apart, the "dry" stand in 1987 and the "wet" stand in 1988. Near the end of the third and fifth growing seasons after harvest, 0.0025 acre circular plots were established at 0.5 chain intervals along N-S transects placed at 1.5 chain intervals within the stands. Over 300 plots were sampled in each of the stands during the first sampling period, about 200 during the second period. Total number and height (±0.1 ft.) of oak seedlings were recorded on each plot as were the number and heights of all competing woody species. The competitive status of each woody stem was determined by dividing the height of each by the average height of all woody stems on the plot. This competitive index (CI) was used to ascertain the status of desirable oak seedlings as compared to their woody competition in the clearcuts. Damage from deer browsing (*Odocoileus virginianus*) and mortality from vole girdling (*Microtus* spp.) was also recorded during the sampling process.

Table 1. *Preharvest inventory of a "dry" site red river bottomland hardwood stand in South Carolina.*

Species	Diameter (inch)	Trees /ac	Basal area /ac (ft²)	Volume/ac (bf Scrib.)
Sweetgum	18.1	18	31	3465
Red Oaks[1]	22.2	8	21	2771
Other[2]	19.2	9	19	1956
Total	19.2	35	71	8192

[1] Includes cherrybark, Shumard, water and willow oaks.
[2] Includes loblolly pine, white oaks, red maple, yellow poplar, hickory, elm, black gum and green ash.

Results and Discussion

Three years after harvest the stands averaged over 3000 red oak seedlings per acre that were 50 percent cherrybark or Shumard oak. The red oaks were 2.3 feet tall and had a competitive index (CI) of 0.78 (Tables 3 and 4). There were over 4500 other woody overstory and understory stems per acre that averaged 3.6 feet tall with a CI of 1.05 (Tables 3 and 4).

Table 2. *Preharvest inventory of a "wet" site red river bottomland hardwood stand in South Carolina.*

Species	Diameter (inch)	Trees /ac	Basal area /ac (ft²)	Volume/ac (bf Scrib.)
Sweetgum	17.1	14	23	2226
Red Oaks[1]	21.7	12	29	3563
Other[2]	18.8	12	21	1985
Total	19.2	38	73	7774

[1] Includes cherrybark, Shumard, water and willow oaks.
[2] Includes hickory, elm, loblolly pine, red maple, white oaks, green ash, black and tupelo gums, swamp cottonwood and sycamore.

Table 3. *Seedling inventory three years after harvest of a "dry" site red river bottomland hardwood stand in South Carolina.*

Species	No./ac	Ht.(ft.)	CI[1]
Red Oaks	4912	2.6	0.81
White Oaks	67	1.9	0.68
Other Hrwds[2]	864	3.6	1.20
Softwoods[3]	1244	4.6	1.40
Understory[4]	2536	3.6	1.10
Total Overstory	7087	3.2	1.11

[1] CI = Competition Index = seedling ht./plot ave. ht.
[2] Elm, ash, holly, hickory, sugarberry, sycamore, red maple
[3] Sweetgum, loblolly pine, black gum, yellow poplar
[4] Pawpaw, sumac, red bud, hawthorn, hornbeam, plum

Understory species in the clearcuts included pawpaw (*Asimina triloba*), sumac (*Rhus* spp.), hornbeam (*Carpinus caroliniana*), hawthorn (*Crataegus* spp.), plum (*Prunus* spp.), red bud (*Cercis canadensis*) and profuse blackberry (*Rubus* spp.) and herbaceous composites. Overstory species included elm (*Ulmus* spp.), green ash (*Fraxinus pennsylvanica*), holly (*Ilex americana*), hickory (*Carya* spp.), yellow poplar (*Liriodendron tulipifera*), sugarberry (*Celtis laevigata*), sycamore (*Platanus occidentalis*), red maple (*Acer rubrum*), sweetgum (*Liquidambar styriciflua*), loblolly pine (*Pinus taeda*), black gum (*Nyssa sylvatica*), tupelo gum (*Nyssa aquatica*), white

oak (*Q. alba*), swamp chestnut oak (*Q. michauxii*), overcup oak (*Q. lyrata*), and swamp cottonwood (*Populus heterophylla*). Oak seedling status at this time was not very favorable since stems had to average a CI of 1.00 or higher to be considered in the dominant/codominant canopy position. There also was considerable difference between the "dry" and "wet" stands, both in seedling number, species and CI, due not only to the year's difference in development, but also to the difference in site condition. The "dry" stand had nearly 3 times as many red oak, yellow poplar and pine seedlings as did the "wet" stand, but only half as many red maple, green ash and tupelo gum seedlings. Both had about the same number of competing woody overstory stems, 2-3000 per acre. At this time deer browsing and vole damage was quite extensive in the "dry" stand with nearly 30 percent of the red oak seedlings suffering heavy deer browsing in the early spring compared to less than 10 percent in the "wet" stand. Also, nearly 23 percent vole-induced mortality was found in the "dry" stand compared to 2 percent in the "wet" stand. Although no voles were trapped in either stand, the location and type of damage (girdling at the root collar) and size of teeth marks were commensurate with those of the woodland or pine vole (*Microtus pinetorum*) which is common in South Carolina. Mortality was as high as 80 percent in some localized areas with red oak seedlings comprising 90 percent of the woody stems killed. Similar vole damage was observed in upland oak stands near Vicksburg, MS several years previously (personal observation 1989).

Table 4. *Seedling inventory two years after harvest of a "wet" site red river bottomland hardwood stand in South Carolina.*

Species	No./ac	Ht.(ft.)	CI[1]
Red Oaks	1703	1.6	0.70
White Oaks	121	1.9	0.75
Other Hdwds[2]	1032	2.9	0.96
Softwoods[3]	1691	3.6	1.45
Understory[4]	1802	2.6	1.11
Total Overstory	4548	2.6	1.01

[1] CI = Competition Index = seedling ht./plot ave. ht.
[2] Elm, ash, holly, hickory, sugarberry, sycamore, red maple
[3] Sweetgum, loblolly pine, black and tupelo gums, swamp cotton-wood
[4] Pawpaw, sumac, red bud, hawthorn, hornbeam, plum

Five years after harvest red oak seedlings had decreased to about 1000 per acre, were almost 4 feet tall and had a CI of 0.86 (Tables 5 and 6). Other woody competition had dropped only slightly to 4,000 stems per acre, were 6 feet tall and had a CI of 1.14, indicating only a slight improvement in the status of desirable oak seedlings as compared to their competition (Table 7). Deer browsing and vole damage appear to have subsided at this time in the development of the clearcuts, affecting less than 5 percent of the seedlings in either case. The "wet" stand still exhibits the effects of the year's difference in age and the wetter site conditions, having fewer oak seedlings per acre that are not as tall and having a lower CI than those of the "dry" stand. However, differences have levelled off, i.e., there are not quite twice as many red oak seedlings in the "dry" stand as compared to the "wet" and the CI and height are comparable, given the one year difference in age (Table 7). The overall status of desirable red oak seedlings has improved slightly in the two stands compared to the situation at three years of age, since their CI has improved to a somewhat greater extent than that of their woody competition (Table 7). More important than these quantitative comparisons, however, is the fact that the red oak seedlings of the two stands are now into their fifth and sixth growing seasons, respectively, and average almost 5 feet in height. Generally at this stage in cherrybark and Shumard oak seedling development they will begin to put on 2-3 feet of height annually (Clatterbuck and Hodges 1988; Aust et al. 1985; Johnson and Krinard 1988; Nix 1989).

Table 5. *Seedling inventory five years after harvest of a "dry" site red river bottomland hardwood stand in South Carolina.*

Species	No./ac	Ht.(ft.)	CI[1]
Red Oaks	1114	4.2	0.88
White Oaks	15	2.9	0.73
Other Hdwds[2]	939	5.8	1.10
Softwoods[3]	1285	7.8	1.35
Understory[4]	1711	5.8	1.05
Total Overstory	3353	6.2	1.12

[1] CI = Competition Index = seedling ht./plot ave. ht.
[2] Elm, ash, holly, hickory, sugarberry, sycamore, red maple
[3] Sweetgum, loblolly pine, black gum, yellow poplar
[4] Pawpaw, sumac, red bud, hawthorn, hornbeam, plum

About sixty percent of the red oak seedlings being followed in the two stands are now even with the dominant canopy (about 7 feet height) and are exhibiting a significant increase in height growth. It is not unreasonable to expect these seedlings to make it to the dominant overstory at age 20-30 years (Johnson and Krinard 1988) as the stand canopies completely close and the faster growing woody overstory stems become the dominant vegetative cover. With 500+ red oak stems per acre in the dominant canopy, at least half of which are cherrybark and Shumard oaks, the faster-growing oaks and perhaps even the water and willow oaks will provide a significant quality oak component in the new stands as they develop in the future.

Table 6. *Seedling inventory four years after harvest of a "wet" site red river bottomland hardwood stand in South Carolina.*

Species	No./ac	Ht.(ft.)	CI[1]
Red Oaks	674	3.2	0.82
White Oaks	77	3.6	0.90
Other Hdwds[2]	1125	4.9	1.09
Softwoods[3]	1559	6.2	1.31
Understory[4]	1685	4.2	0.90
Total Overstory	3435	5.2	1.14

[1] CI = Competition Index = seedling ht./plot ave. ht.
[2] Elm, ash, holly, hickory, sugarberry, sycamore, red maple
[3] Sweetgum, loblolly pine, black and tupelo gums, swamp cottonwood
[4] Pawpaw, sumac, red bud, hawthorn, hornbeam, plum

Observations indicate that the red oak seedling distribution is concentrated along skid trails and turnaround areas and even logging decks where the machine activity effectively buried the acorns during the logging operation. Although this pattern may not be ideal, further observations will have to determine if it is detrimental to the development of the red oak component of the new stands. Since many of the red oak stems are clumped, they will strongly compete with each other reducing this valuable component rather than reducing the non-oak component as would be desired. Hopefully the skidding pattern during the extensive logging operation will prove to be an adequate acorn dispersal method as well as a good acorn "sowing" technique for future oak regeneration in bottomland hardwood stands. Whether or not such oak regeneration can effectively replace the need for advance oak reproduction in regenerating bottomland hardwood stands remains to be proven by further observations of these seedlings. The transects where oak seedlings are being monitored will be carefully monumented and hopefully the status of the seedlings and their distribution within the stands can be monitored over the next critical 10-15 years.

Acknowledgement

The authors would like to thank the Beidler family of Chicago for their cooperation and the use of their land in the conduct of this study. We also thank Jon Barry and John Thompson, graduate assistants, and Doug Benson, research forester, Clemson University, for their able assistance in collecting the data.

Table 7. *Red Oak seedling status compared to other woody stems after clearcutting two red river bottomland hardwood stands in South Carolina.*

	2-3 Years			4-5 Years		
Site	No./ac.	Ht.(ft.)	CI[1]	No./ac.	Ht.(ft.)	CI[1]
"Dry"	4912	2.6	0.81	1114	4.2	0.88
"Wet"	1703	1.6	0.70	674	3.2	0.82
Red Oaks ave.	3307	2.3	0.78	894	3.9	0.86
Other[2] ave.	4678	3.6	1.05	3698	5.8	1.14

[1] CI = competition index = seedling ht./plot ave. ht.
[2] Includes numerous woody understory, midstory, and overstory species commonly found in bottomland forests.

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ENHANCING OAK REGENERATION IN A MIXED BOTTOMLAND HARDWOOD STAND AFTER A MAJOR DISTRUBANCE [1]

W.B. Steele, D.D. Hook, M.A. Buford, and J.G. Williams [2]

Abstract. In 1989, Hurricane Hugo destroyed an 85-acre mixed bottomland hardwood stand on the Santee Experimental Forest near Huger, SC. Detailed basal area and species composition data on this stand, as well as the parent stand provided the opportunity to evaluate several silvicultural treatments for increasing the cherrybark oak (*Quercus falcata var. pagodifolia*) and shumard oak (*Quercus shumardii*) component of a bottomland hardwood stand. A study was installed on the site in 1990 which consisted of four treatments with increasing degrees of silvicultural manipulation and investment. Treatments range from no enhancement to cutting of all stems greater than 1 inch DBH, herbicide control of undesirable hardwoods, and planting of cherrybark oak seedlings. Comparison of treatments after two years suggest that control of undesirable hardwood sprouts with herbicide application and planting oak seedlings had a positive effect on the oak component. This ongoing project will monitor stand growth to observe the long-term effects of these treatments on stand composition and value.

Introduction

Bottomland hardwood ecosystems provide a wide variety of natural resource benefits including timber production, water quality enhancement, flood storage, nutrient recharge, and waterfowl habitat (Hall and Lambou 1989). Many mixed bottomland hardwood stands are dominated by oak species (Clatterbuck and Hodges 1988) and provide mast for wildlife. Cherrybark and shumard oaks are among the most valuable components of bottomland hardwood stands (Hodges and Janzen 1986, Johnson 1979) and are capable of producing quality saw logs in 60 years (Hook and Stubbs 1965).

Cherrybark and shumard oaks reproduce from seed and sprouts, (Putnam 1951) with the best sprouts stemming from the buds of younger stumps at or below ground line and from stumps less than 10 inches in diameter (Johnson 1977, Wendel 1975). Sprouts from low stumps are more acceptable because they tend to have less disease and rot (Aust et al. 1984). Dense thickets of hardwood sprouts naturally thin themselves during the early stages of stand growth. Through competition, the total number of stems is often reduced from several thousand per acre at regeneration to 1,600 - 1,800 by age 20. Of these, about 400 may develop to be commercially useful (Zahner and Myers 1984).

Herbicides are a potentially useful site preparation alternative to mechanical methods (Neary 1983) and the most effective and selective method of controlling hardwood competition is individual tree treatments (Cantrell et al. 1986). Also, underplanting cherrybark oak seedlings prior to final harvest may be beneficial where advanced regeneration is not sufficient. Seedlings may be spot planted at relatively low densities (200-500 per acre) to supplement natural regeneration and to reduce the cost of intensive treatments (Lorimer 1989). The survival of 15 to 20 carefully placed oak seedlings per acre at maturity may provide an adequate quality sawtimber component to a mixed hardwood stand (Johnson 1980).

There is a need in the South to develop effective techniques for restoring mixed bottomland hardwood wetland forests (McKevlin 1992). In addition to natural resource benefits such as wildlife habitat, flood control, and water quality enhancement, timber value can be improved by silvicultural methods that increase the composition of high value species such as cherrybark and shumard oak.

Materials and Methods

Study Site

The study site is located off Yellowjacket Road between Turkey Creek and Negro Field Creek

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Graduate Student and Professor, Clemson University, Clemson, SC; Project Leader, Southeastern Forest Experiment Station, Charleston, SC; Statistician, Clemson University, Clemson, SC.

on the Santee Experimental Forest near Huger, South Carolina. More than 80% of the stems of the 29-year old stand were uprooted or broken off by Hurricane Hugo in September, 1989. Soils of the first terrace are a humiaquepts that were farmed for rice prior to abandonment in the 1890's. The second terrace is a fluviaquents that was row cropped during the same period. About 80% of the soils are hydric and consequently about 80% of the site is considered a wetland (USACE, 1987).

The Southeastern Experiment Station has performed numerous research studies on this site since the late 1950's. It was the location for a study initiated in 1958 to assess the suitability of the seed tree method for regenerating a bottomland hardwood stand (DeBell et al. 1967). Other research studies performed on the site include: 1) development of sweetgum root sprouts (Hook et al. 1970), 2) observation of understory growth retardation under three species of oak (Hook and Stubbs 1967), and 3) early stand development (Buford, Hook, and Bunton, 1990).

Treatments

The site was divided into eight treatment blocks of 6.4 acres each. Four treatments were randomly applied to the eight blocks resulting in two replications of each treatment which are: 1) control, no treatment; 2) cut all stems greater than one inch DBH; 3) cut all stems greater than one inch DBH and spray all stumps except red oak with a chemical to inhibit sprouting; and 4) cut all stems greater than one inch DBH, spray all stumps except red oak, and plant 1,0 cherrybark seedlings at 1210 seedlings per acre on a 6 by 6 foot spacing. All trees were felled by chainsaw. A glyphosate spray mixed to a 50% solution with diesel fuel and a colorant to insure stump coverage was used on all stumps other than red oak to discourage stump sprouting. The spray was applied with a backpack sprayer with a flat nozzle immediately after the trees were felled.

Seedling Measurement

A minimum of five 4/100 acre plots per 6.4 acre block were established on the permanent plot centers used in earlier studies. All tree species taller than 4.5 feet were identified and flagged. Height and DBH of these trees were recorded as well as the stump diameter and number of sprouts per stump within these plots. In the cut-spray-plant blocks, the height of all planted seedlings were also recorded. A 1/1000 acre plot was established at 16 feet due north of each sample plot center, where sprout height, stump diameter, and number of stems were recorded for all woody stems less than 4.5 feet in height. Also, an ocular estimate of the percent cover by woody vegetation, herbaceous vegetation, and woody debris by quadrant, clockwise from north, was made on the 1/1000 acre plot. All measurements were made in the summer of 1991 and again in the summer of 1992 in order to determine one year's growth.

Results

Thirty-two tree species were found on the study site in 1992. Figure 1 shows the number of stems per acre by treatment for all tree species. The increase in number of stems from control to the cut treatment was due to stump sprouting. Treatments involving herbicide control showed a reduction in number of stems per acre by about 50%.

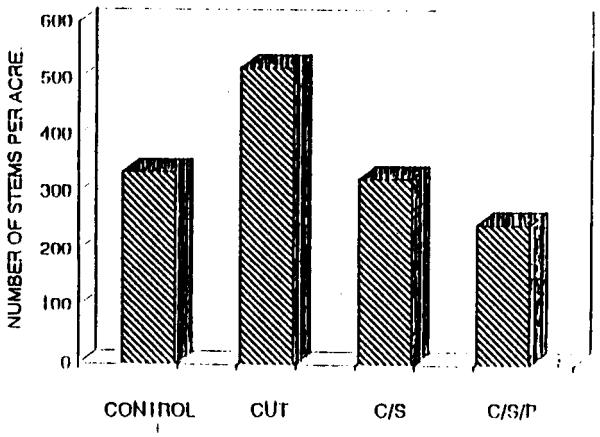

Figure 1. *Woody competition by treatment for 1992 growing season.*

The number of stems per acre and percent basal area for the six most frequently occurring species are shown in Table 1. Number of stems per acre of sweetgum (*Liquidambar styraciflua*) and ironwood (*Carpinus caroliniana*) were not statistically different by treatment. Sweetgum roots sprout prolifically and thus cannot be effectively controlled by stump application of herbicides. Ironwood stumps were of a much smaller diameter than other species and may have been overlooked by spray applicators or the spray may not have been effective on this species.

The species that comprise the majority of the basal area and stems per acre shifted from sweetgum and ironwood in treatment 1 to a more even distribution in treatment 2 and then to favoring red maple (*Acer rubra*), oak, and ash (*Fraxinus sp.*) in

Table 1. Characteristics of Six Selected Species in a Bottomland Hardwood Stand Three Years After Hurricane Hugo.

Species	Control		Cut		Cut/Spray		Cut/Spray/Plant	
	% BA*	# Stems /Acre	% BA	# Stems /Acre	% BA	# Stems /Acre	% BA	# Stems /Acre
Red maple	3	18	14	224	18	134	10	92
Ash	2	53	15	216	14	73	26	38
Red oaks	2	13	11	67	16	77	22	356**
Sweetgum	33	105	28	91	25	39	6	36
Ironwood	13	195	10	62	2	25	4	19
Elm	4	95	9	57	6	39	11	40

* BA = Basal Area

** For this treatment, planted seedlings are included in # Stems /acre, but are not included in % BA.

treatments 3 and 4 which involved herbicide application.

Duncan's Multiple Range Test showed significant ($\alpha = 0.05$) differences in stems per acre by treatment. Red maple was more abundant in treatment 2 than in the other treatments. Elm (*Ulmus sp.*) was more abundant in treatment 1 than in treatments 3 and 4. Ash was more abundant in treatment 3 than in treatment 1. Red oaks were found to be more abundant in treatments 3 and 4 than in treatment 1.

The planted cherrybark oak seedlings increased the oak component in treatment 4 by three fold. Survival of the seedlings after three years was 46%. Undoubtedly, mortality of planted oaks will continue in coming years. However, if even 20% survive, the long term impact on the oak component will still be substantial.

Conclusions

Significant differences in the number of stems per acre of red oak species between treatments indicate that, at least in the short term, the red oak component of a mixed hardwood stand can be increased by the application of herbicides to non-oak tree species and by planting red oak seedlings. Whether the initial promising effects result in an increase in mast producing trees and higher quality forest products will await future evaluations.

Acknowledgment

This project was partially supported by the USDA, Forest Service, Southeastern Forest Experiment Station.

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EFFECT OF RESIDUAL TREES ON NATURAL REGENERATION IN A TUPELO-CYPRESS SWAMP AFTER 24 YEARS [1]

Donal D. Hook, Marilyn A. Buford, William R. Harms [2]

Abstract. Experimental harvests were made in a 500 acre non-alluvial swamp on the Francis Marion National Forest in the mid 1960's to test for effects of residual trees on natural regeneration of the swamp tree species. Treatments were clear cut, leave 90, 30, and 15 trees per acre, and no cutting. All leave trees were swamp tupelo (*Nyssa sylvatica* var *biflora*), about 90 years old. First year seedling establishment of swamp tupelo varied from 12,460 seedlings per acre (s/a) with 30 leave trees per acre to 5,270 s/a with 15 leave trees per acre. However, within a few years after harvest, loblolly pine (*Pinus taeda*) seedlings became an important component of the regenerating stand and were the largest individuals on the site at age 24. Bald cypress (*Taxodium distichum*) was next in size. Swamp tupelo trees were smaller than the above species. All large loblolly pine occurred on hummocks whereas swamp tupelo occurred in the matrix of the swamp. Growth of swamp tupelo was sensitive to number of residual trees and appeared to stagnate at high densities. Pre- and post-harvesting measurements of water table levels showed that roads and harvesting had little or no affect on water table levels in the swamp. Hurricane Hugo reduced the basal area and density of loblolly pine in the treatment plots by as much as 80 %. It appears that periodic hurricanes may play an important role in reducing the stocking of loblolly pine in shallow swamps in coastal plain shallow swamps.

Introduction

A regeneration experiment was established in a 500 acre non-alluvial swamp on the Francis Marion National Forest in 1963. The swamp was composed of an even-aged stand of swamp tupelo (*Nyssa sylvatica* var *biflora*) and baldcypress (*Taxodium distichum*) that was approximately 90 years old. Bayboro series (clayey, mixed, thermic Umbric Paleaquults) cover the entire site and are listed as hydric soils by the Soil Conservation Service (1991). The stand contained 245 stems per acre that were 5 inches or greater in diameter, had 168 sq ft basal area per acre, and 24,000 bd ft per acre (Scribner rule) of saw log sized timber.

Objectives

The objective was to determine how different residual levels of swamp tupelo trees affected regeneration and subsequent growth of tree species in the swamp.

Methods

A study area containing fifteen 4.9-acre plots was laid out in the swamp during the summer of 1963. Before harvesting the entire experimental area (about 75 acres) was sprayed with 2, 4, 5-T by a mistblower mounted on a small tractor. After harvest stumps were sprayed with 2, 4, 5-T and large undesirable trees were poisoned. The five treatments were: clearcut, leave 15, 30, and 90 seed trees per acre, and a control. All leave trees were swamp tupelos and were spaced as evenly as possible within the treatment area. The treatments were arranged in three blocks. One block was located above a logging access road that was built across the swamp in the fall of 1965 and two blocks were located below the road. Five shallow wells (about 3 feet deep) were established in each plot and water table levels were recorded every two weeks from March 1964 until 1969. Block I was harvested during the dormant season of 1965-66, Block II in 1966-67, and Block III in 1967-68. The harvest was done under a regular U. S. Forest Service Contract and rubber tired skidders were used to log the area.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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In the summer of 1992, three 0.1 acre circular plots were randomly established within the central one acre area of each plot in each treatment for a total of 45 plots. The diameter of all stems 4.5 feet and taller were measured and species were recorded on each plot. Hurricane Hugo damage was documented for each stem as to whether it was leaning, bent, or broken. All blown down or broken loblolly pine stems were measured at dbh and recorded as dead in each plot.

The data was analyzed as a randomized complete block design. Regressions were also used to test for trends.

Results

The main skid trails were deeply rutted and although relatively obscure, can be seen today. Virtually no regeneration occurred in the main skid trails but all of the surrounding area regenerated quickly (after one year there were about 12,000 seedlings per acre in the leave 30 and control areas and over 5,000 seedlings per acre in the clearcut and leave 15 trees per acre; see DeBell and Auld, 1971). Analyses of water table levels among the three blocks before and after the harvest showed that there may have been slightly more water in Block I (above the road) than in Blocks II and III when the water table was above the soil surface (Figure 1). However, there were no major changes in pattern of water table responses among blocks.

A total of 35 herbaceous and woody species with individuals 4.5 feet or taller were found within the study area. After 25 years, red maple (*Acer rubrum*), swamp tupelo, baldcypress, and loblolly pine (*Pinus taeda*) were the dominant tree species in all of the regeneration plots. Basal area per acre, number of stems per acre, average basal area per tree, and average stem diameter varied by species and treatment and average basal per tree and average diameter had a species x treatment interaction for the four species (Table 1 and Figure 2).

Hurricane Hugo blew down 47 to 81 % of the loblolly pine basal area in the four treatment areas and 46 to 71 % of the stems per acre (Figure 3). Few or none of the other species were blown down by Hugo but they were bent or leaning from wind and falling trees. Red maple basal area remained essentially constant across treatments but the basal area of the other three species tended to decrease with increasing number of residual trees (Figure 2).

Table 1. *Tukey mean separation of treatment effects on the four major tree species in Bluebird Swamp 24 years after regeneration cuts.*

Species Basal Area	Species Stems per Acre	Average Basal Area	Average Diameter
RM A*	ST A	LP A	LP A
LP A	RM B	BC B	BC B
ST A B	BC C	RM B C	RM C
BC B	LP C	ST C	ST C

RM = Red Maple; LP = Loblolly Pine; ST = Swamp Tupelo; BC = Baldcypress

* Species with the same letter in the column were not significantly different at the 0.05 level.

Swamp tupelo and red maple had the highest stocking in number of stems per acre, ranging from 998 to over 2,500 stems per acre among the four treatments (Figure 2). Number of stems of red maple was very consistent across the four treatments and control (Figure 2).

Loblolly pine had the largest average diameter and basal area per tree (ba/t) on all regeneration cuts (ba/t ranged from 0.29 to 0.56 sq ft per tree among the four cuts; Figure 2). Baldcypress had the second highest average diameter and basal area per tree (ba/t ranged 0.08 to 0.18 sq ft per tree among the four cuts; Figure 2). Average diameter of swamp tupelo and red maple were much smaller than loblolly pine and baldcypress (Table 1 and Figure 2).

Only 12 species ranked among the top ten species in importance values for all treatments and control (Figure 4). Swamp tupelo, red maple, and loblolly pine were among the top 5 in importance values in the four harvest cuts whereas red maple, swamp tupelo, and fetterbush (*Leucothoe racemosa*) were the top 3 and loblolly pine was 9th in the control plots (Figure 4). Wax myrtle (*Myrica cerifera*) and fetterbush were among the top 10 in importance values in all treatments. Baldcypress ranked 5th in importance value in the clearcut and 6th in the leave 15 and 30 tree cuts, and 10th in the control. It was not among the top ten in the 90 leave tree cut.

Discussion

The establishment and rapid growth of loblolly pine was not expected and to our knowledge has not been previously reported in a swamp of this type. Also, the extremely slow growth of swamp tupelo was not expected. The species is not know for fast growth but an average diameter breast height

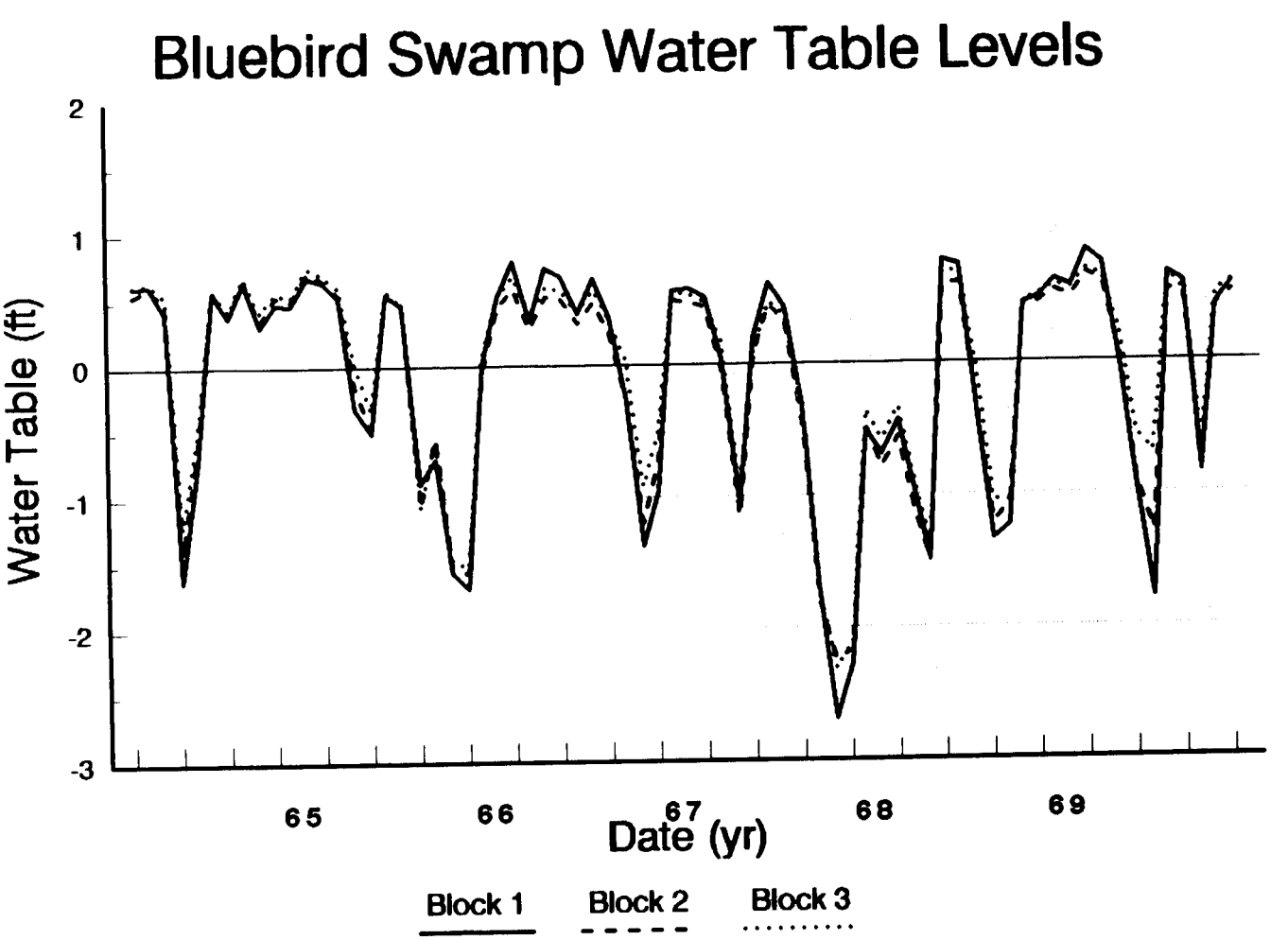

Figure 1. *Water table levels in Bluebird Swamp from March 1965 through 1969 by Block and year.*

(dbh) of less than 2 inches after 25 years was less than expected. Six years of water table data (1964-69) showed that the swamp was flooded 56 % of the time during the growing season (mid March to mid October). Also, there were about 2,800 stems per acre of the four dominant species at age 25 and swamp tupelo accounted for over 50 % of the stocking. It appears that swamp tupelo does not readily express dominance and may stagnate at these high stocking densities. A thinning study by Westvaco in a water tupelo (*Nyssa aquatica*) stand showed that stems in non-thinned stands were about 6 inches dbh and in thinned stands were about 10 inches dbh at 25 years (John Martin, personal communications).

The composition of the regenerating stands were remarkably similar despite the differences in number of leave trees. Although growth of the regeneration appeared to be impacted by the number of leave trees, the impact was less than expected. Finally, the high impact logging done in the late 1960's appeared to have had little affect on the composition, hydrology, and growth of the vegetation in this swamp. The road probably causes some minor ponding.

Initially, we thought that the deep skid trails may have caused some internal drainage of the swamp and resulted in the establishment of loblolly pine. However, close examination of the area showed that every rapidly growing loblolly pine was on a natural hummock in the swamp. No loblolly pine existed in the matrix of the swamp (i. e. loblolly pine did not exist in the areas where water stands about 0.5 feet deep during flood stage; see Figure 1). In contrast, swamp tupelo was located primarily within the matrix of the swamp floor. The hummocks function essentially as a natural bed, permitting seedling establishment above the general water level, providing limited amount of aerated root environment.

Results from controlled flooding studies have shown that the lateral roots of loblolly pine which develop under non-flooded conditions survive subsequent flooding events and contribute to the tolerance of the species to prolonged soil waterlogging (Hook et al., in prep). McKee, Hook, DeBell, and

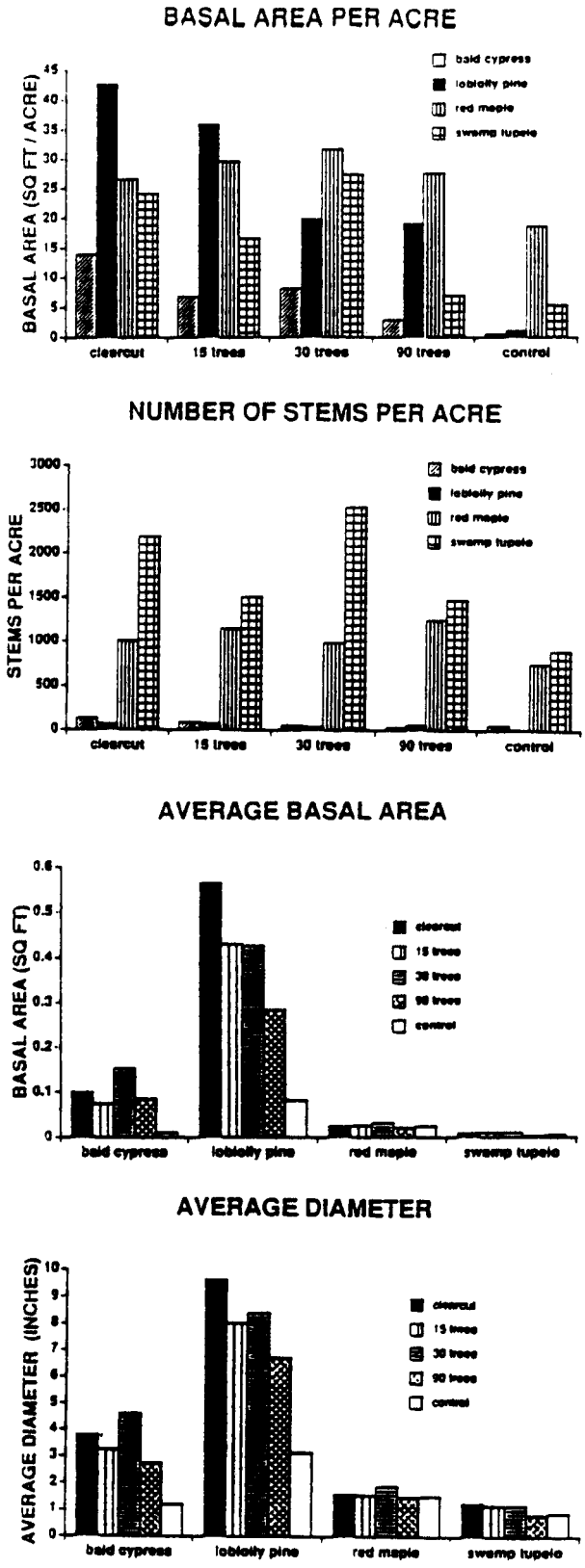

Figure 2. *Basal area per acre, number of stems per acre, average basal area per tree, and average diameter per tree for four main tree species by treatments 24 years after regeneration cuts.*

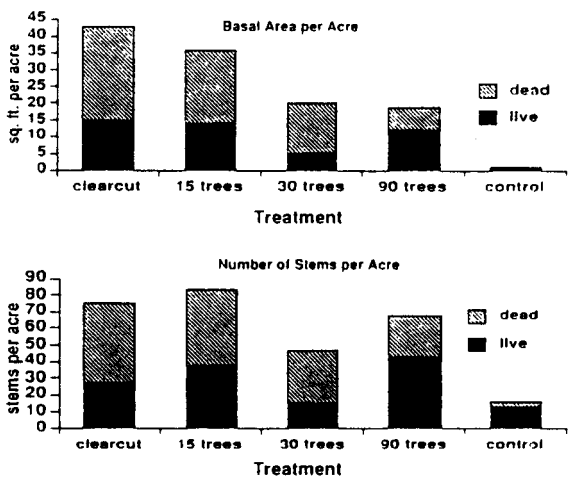

Figure 3. *Impact of Hurricane Hugo on basal area per acre and number of stems per acre for loblolly pine by treatment 24 years after regeneration cuts.*

Askew (1984) showed if sufficient phosphorus was available in the flooded soil that loblolly pine will survive and grow well in periodically waterlogged soils. Analyses of the soils in this swamp showed that soil phosphorus levels were relatively high.

If loblolly pine survives and grows so well in this swamp: Why was there little or no large loblolly pine trees in the parent stand or control plots? The answer to this is incomplete, but it appears that hurricanes probably play a major role in removing the larger loblolly pine from shallow swamps. Hook, Buford, and Williams (1991) reported that the largest and most dominant individuals suffered the most damage due to Hurricane Hugo. Gresham, Williams, and Lipscomb (1991) also reported that bald cypress and swamp tupelo suffered less than 5 % damage whereas loblolly pine suffered 47 % losses on Hobcaw Experimental Forest from Hurricane Hugo. Hooper and McAdie (in prep.) reported that the Francis Marion National Forest can expect maximum sustained winds of 91 mph every 50 years from tropical cyclones. Hence, on the average a stand over 100 years old will have been exposed to two or more hurricanes. It appears that hurricanes may remove a sufficient amount of loblolly pine from the shallow non-alluvial swamps under natural conditions so that only scattered individuals persist in mature stands.

The similarity of composition among the stands in the various treatments indicates that trees left for seed production or to moderate the environment had little or no influence on the composition of future stands on this site. However, there was a general

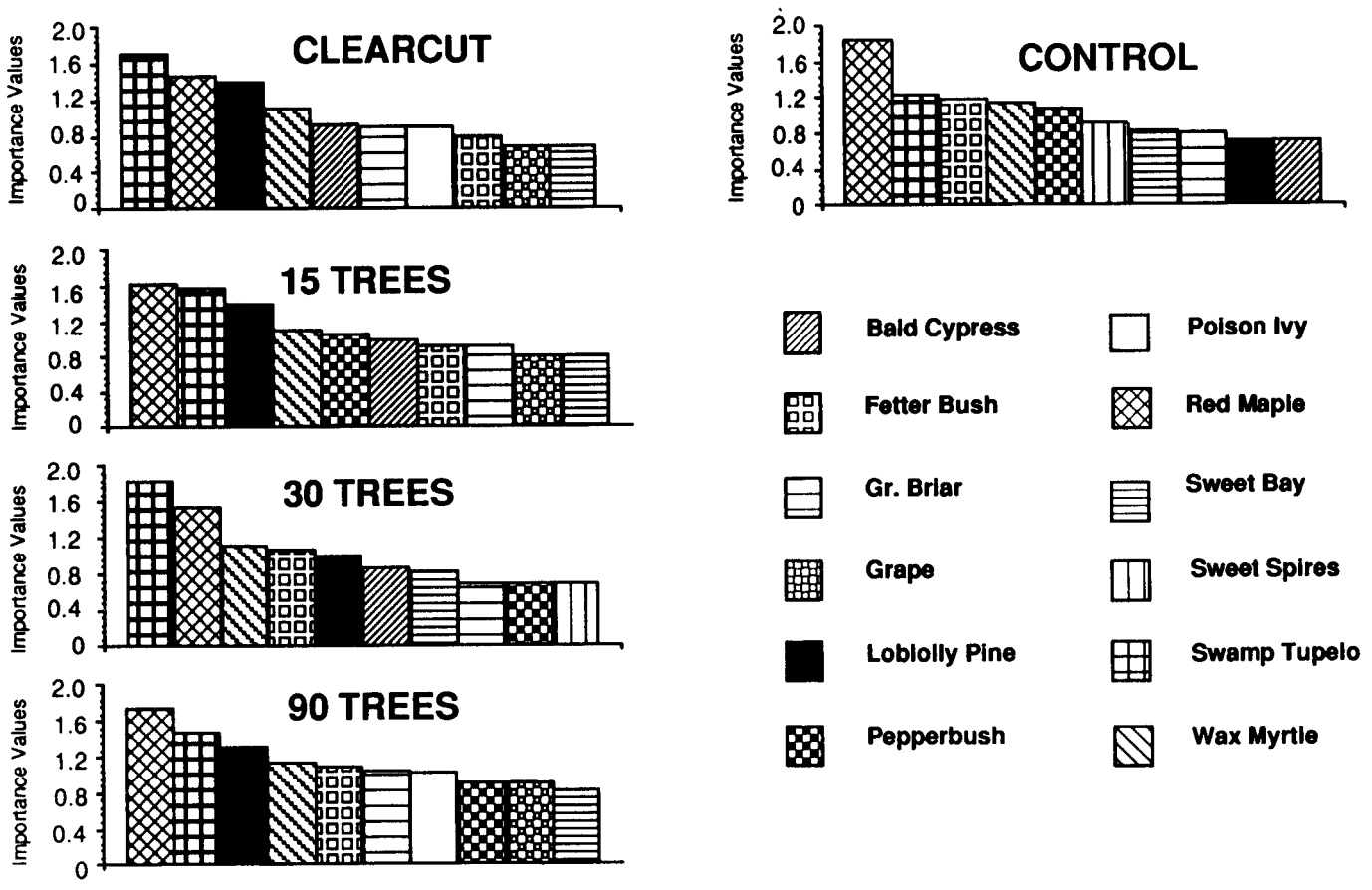

Figure 4. *Top ten species for each treatment as ranked by importance values 24 years regeneration cuts.*

trend of decreasing growth rate of the regenerating stand with increased numbers of residual trees. This trend was evident in total basal area, average basal area per tree, and average tree diameter for loblolly pine, swamp tupelo, and bald cypress but was not evident for number of stems per acre. Red maple, a more shade tolerant species, showed no change in these trends with increasing number of residual trees.

There is no convincing evidence that the residual trees had much effect on the understory species either. The composition of the ten dominant species, based on importance values, differed only slightly among the four regeneration cuts and the control. Hence, composition and stocking of the overstory and understory did not appear to be readily controlled by residual tree competition but growth of the dominant tree species in the stands appeared to be reduced by a greater number of leave trees.

Only 35 plant species (4.5 feet or taller) were found in the swamp. The lack of variation in the composition of stands in the various treatments was probably related to the hydric nature of the swamp. There is a limited menu of species, especially tree species, that can tolerate the frequent and long duration of soil waterlogging that is characteristic of this swamp. The wind damage susceptibility of other species which persist primarily on hummocks appears to play a role in maintaining the relatively simple species composition of non-alluvial swamps.

These shallow non-alluvial swamps appear to be very dynamic in nature. The presence of moving water in the swamp encourages water root development which promotes development of hummocks around most mature swamp tupelo trees (Hook, 1968). When the overstory is removed, loblolly pine has a competitive advantage on the hummocks and dominates the early stages of development in the swamp. Over time hurricanes and other natural phenomena appear to remove the pines. When the pines are blown over by wind, additional hummocks are formed by the root tip-ups. Thus, the combined actions of tupelo hummocks and pine tip-

ups create more hummocks. As a consequence of these processes, it appears, in the absence of fires, some of the shallow non-alluvial swamps in the South Carolina coastal plain may progress fairly rapidly from a swamp to a mesic pine site --perhaps within a few hundred years.

Acknowledgements

Thanks to Dave Gartner for the data analysis, Missy Huneycutt for the Figures and Beth Davis and Andrew Hulin for collecting the field data.

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PLANTABILITY OF ATLANTIC WHITE-CEDAR ROOTED CUTTINGS AND BARE-ROOT SEEDLINGS [1]

R. Phillips, W. E. Gardner, K. O. Summerville [2]

Abstract. Atlantic white-cedar has historically been an important component of swamps, fresh water bogs, wet depressions, pocosins, and stream banks in eastern North Carolina. Exploitation for durable, lightweight wood products, combined with natural regeneration failures and an absence of artificial regeneration, have reduced the species to perhaps 10 percent of its previous range--a reduction so severe that it no longer supports any substantial market sector, despite continuing high product values. Because of the species economical and ecological value, its wetland suitability, and for conservation reasons, several agencies, forest products industries, and other landowners have recently become interested in forestation of Atlantic white-cedar. Demonstration plantations were established on five sites between 1989 and 1991 using both bare-root seedlings and rooted cuttings to determine plantability of the species. Based upon three years of observation, this report covers white-cedar's apparent potential for planting, its performance on a wide range of sites, and methods to control browsing and competition.

Introduction

Atlantic white-cedar, *Chamaecyparis thyoides* (L.) B.S.P., hereafter called white-cedar, is a commercially valuable conifer which grows in fresh water bogs, pocosins, wet depressions, and along streambanks from Maine to Mississippi. In North Carolina the species occurs in several situations; (1) dense, relatively pure stands with little understory; (2) stands supporting a dense understory of loblolly bay (*Gordonia lasianthus*), shining gallberry (*Ilex coriacea*), gallberry (*Ilex glabra*), fetter-bush (*Lyonia lucida*), and red bay (*Persia borbonia*); and (3) in small stands and scattered individuals in mixed bottomland hardwood forests throughout the sandhills region. White-cedar usually occurs on sites characterized by either saturated, acidic, deep organic soils or wet sandy soils. Across its range, white-cedar is most frequently found on deep peat deposits underlain by a sandy substrate. Observations by Akerman (1923) in Virginia, and Waksman (1943) in New Jersey indicate that white-cedar may grow best under those conditions. Korstian and Brush (1931) corroborated that assessment and further concluded that as the percentage of clay and silt increased, the proportion of hardwoods increased until white-cedar apparently could no longer compete.

Most literature indicates that white-cedar is intolerant of shade (Korstian and Brush, 1931; Little, 1950). White-cedar usually fails to regenerate naturally after logging where no measures are taken to control competing vegetation. Korstian and Brush (1931) reported an absence of white-cedar seedlings in the understory of closed canopy stands. Little (1950) found that seedlings growing under closed canopy conditions survived less than three years. Current white-cedar restoration work in the Dismal Swamp imitates the natural disturbances which might have historically regenerated white-cedar. This work consists of overstory removal, site preparation, natural regeneration, and, if necessary, seedling release (Carter, 1987).

Predation by white-tail deer (*Odocoileus virginianus*), rabbits (*Sylvilagus* sp.), and meadow mice (*Reithrodontomys* sp.) can be a serious problem to successful establishment of white-cedar (Little 1950; Laderman 1989). Several plantings in North Carolina have failed because of deer browsing. To reduce browsing, mechanical barriers, such as electric fences and seedling cages, as well as repellents have been used with some success.

Only small remnants remain of white-cedar forests that once occupied a significant expanse of North Carolina's eastern coastal plain. White-cedar acreage in North Carolina may have declined by as much as 90 percent in the last two centuries (Frost, 1987). The period from 1880 to 1930 provided the most intensive exploitation, with heavy logging in swampy areas where land became worthless after the

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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timber had been removed (Lilly, 1981). This practice, combined with natural regeneration failure and an absence of artificial regeneration, drainage impacts, fire exclusion, and lack of competition control has led to the present depleted status of white-cedar in North Carolina.

In general, white-cedar has been considered so difficult to plant that natural regeneration, where possible, has remained the preferred option (Little, 1950; Laderman, 1989). Therefore, there have been only a few efforts to artificially establish the species. In North Carolina, plantings initiated in the last 20 to 25 years on the Hofmann Forest (Jones and Onslow Counties) and Bladen Lakes State Forest (Bladen County) have largely been unsuccessful or unimpressive. One planting on the Hofmann Forest was destroyed by wildfire in 1972. A second Hofmann planting had only marginal survival, and only remnant individual trees remain (personal comm. with Ed Shoaltes, 2-26-92). However, recent plantings in the 1980s by Weyerhaeuser Company and the U.S. Forest Service in eastern North Carolina reflect the growing interest in the species. This interest led to a meeting in December 1988 to discuss the status of white-cedar, and to consider initiating demonstration plantations to learn more about establishing and managing the species. The resultant project continues as a cooperative effort between North Carolina State University Extension Forestry, NC Division of Forest Resources (NCDFR), and Weyerhaeuser Company. This study was designed to test: (1) the conventional notion that white-cedar can not be successfully planted, (2) white-cedar's performance on a wide range of site conditions, (3) methods of preventing browsing, and (4) white-cedar's response to competition and subsequent release.

Materials and Methods

Demonstration plantings were installed on a range of sites, from wet mineral to deep peat soils. Previous land use on the sites ranged from cutover woodland to highly productive farmland. The demonstration sites were planted to white-cedar in 1989, 1990, and 1991. Most sites with intense competition received directed herbicide treatments for weed control to promote white-cedar survival and insure growth. Repellents and/or physical barriers were used to help prevent deer browsing. A brief description of the demonstration sites follows.

Site 1: Hofmann Forest, Onslow County, NC is a pocosin site that had been converted from natural vegetation to a loblolly pine plantation. The one-year old planted pines that survived were purposely destroyed following the white-cedar planting. Site preparation in addition to draining, included pushing and piling logging debris into windrows. The site was "bedded" by the cooperator prior to planting. The soil, a Croatan muck, is a deep organic with a low pH value (3.0-3.5). Depth of organic matter exceeds four feet with organic matter content ranging from 25 to greater than 55 percent by weight.

Site 2: Hofmann Forest, Onslow County, NC is adjacent to the site described above. With the exception of bedding, site preparation was the same as for Site 1.

Site 3: Camp Lejeune Marine Base, Onslow County, NC is cutover woodland that was originally planted to loblolly pine in 1985 following ditching and bedding, but the loblolly pine were largely killed by wildfire in 1988. The soils are either Torhunta or Onslow Series mineral soils with organic matter accumulations of 7% to 11% by weight in the upper 8 inches of the profile.

Site 4: The NCSU Agricultural Research Station in Bertie County, NC had been ditched and intensively managed for annual agricultural crops. Mineral soils, of the Johnston series, have organic matter accumulations in the upper horizon of 7% to 12% by weight. The pH values ranged from 4.3 to 4.5.

Site 5: The Bunch Tract, Chowan County, NC is cutover woodland which was site prepared by pushing logging debris into windrows. Soils, of the Roanoke series, are mineral with low pH values, and may have been affected by nearby minor agricultural drainage. The seedlings were flat planted, and competition has been mainly from woody vegetation and sedges. Organic matter ranges from 4% to 5% by weight in the top 8 inches of the soil profile.

Site 6: Monk Brothers Farm, Pitt County, NC was converted from forest to pasture about 1980. The soils, of the Rains series, are mineral with abnormally high pH values (6.5 to 7.0), probably due to intensive agricultural management. The site was bedded immediately prior to planting. Organic matter ranges from 6% to 9% by weight in the top 8 inches of the soil profile.

NCDFR-produced 1-year-old bare-root seedlings were hand-planted at each site in alternate rows on April 10-13, 1989 using spade-shaped planting bars. Containerized rooted cuttings, supplied by Weyerhaeuser Company, were planted at each site

on May 16-18, 1989 on the remaining alternate rows using round planting bars. Tree spacing in these non-replicated trials ranged from 5 to 6 feet within rows, and 8 to 12 feet between rows. Distance between rows on bedded sites were pre-determined by bed location. Seedling and cutting heights were recorded immediately after planting.

Physical barriers were installed at all sites to test the effects of deer browsing on height growth and survival. Check row plots were not caged for comparison. In most cases, 18-inch polyethylene mesh cages were used as physical barriers to deer browsing, although at Camp Lejeune, four-foot tall cages of woven wire were installed and repellents used. Herbicide applications were made on three of the sites (Chowan, Pitt, and Bertie County sites were each sprayed once during the first year (on June 23, July 3, and July 13, respectively). Arsenal[3] herbicide was applied at 4 ounces per acre in four-foot-wide bands over tree rows using a backpack sprayer. Check plots at each site were not sprayed. The Hofmann forest site did not develop enough competition the first year to warrant control, and the Camp Lejeune site was not sprayed because of policy prohibiting herbicide use.

To evaluate each plantation, height and survival were measured after the first, second, and third growing seasons. On each site, one row of seedlings and one row of cuttings adjacent to the seedling row, were selected for measurement. Total height of each tree was measured to the nearest inch, and percent survival was calculated by dividing the number of living trees in each measured row by the total number of trees planted in the row.

In the second year of the study (1990), a second cycle of planting was accomplished. Seedlings were planted April 3-5 and rooted cuttings were planted in alternate rows May 1-3, using the same methods as for the first year. Tree heights were again tallied on measurement rows immediately after planting.

On Camp Lejeune, large wire cages were again installed and chemical retardants applied. The other five sites received no mechanical barriers or chemical retardants due to the absence of any significant predation the first year.

Arsenal, at 4 ounces per acre, was tank mixed with Oust[4] at 2 ounces per acre and applied April 18 in Pitt County and April 27 in Chowan County. A later application of Arsenal at 4 ounces per acre was applied on the Bertie County site. Check plots were again left for comparison with the treated areas.

First- and second-year height and survival measurements were taken for the 1990 planting. The methods of measuring were similar to the methods used for the 1989 planting.

The third year of the study involved planting bare-root seedlings on April 9-10, 1991. All sites with the exception of Pitt County were planted. The Pitt County site was excluded from planting because of low survival and poor growth exhibited in previous years and the short supply of available seedlings. Again, initial seedling heights were measured on one full row of trees. Rooted cuttings were planted June 5-6, 1991 on alternate rows using similar materials. Heights of the cuttings were tallied on measurement rows immediately following planting. Planting was delayed because the cuttings were not considered ready for outplanting in May as in previous years.

Oust, at 3 ounces per acre, was applied April 25 to the 1991 planting site in Bertie County. Oust, a pre-emergent herbicide, was used exclusively because the weed component had not yet emerged. Thus, Arsenal, used in all previous applications, was not used. Arsenal, at 4 ounces per acre was tanked mixed with Oust at 2 ounces per acre and applied April 25 in Chowan County to the 1991 planting site.

Tall wire cages were again installed on the Camp Lejeune site, and chemical retardants were applied. As in 1990, the other five sites received no mechanical barriers or chemical retardants.

Results

1989 Planting

The sites with the most acidic soils (Hofmann Forest) support the best performing trees following three growing seasons (Table 1). Mean seedling height on the Hofmann bedded site averages 90.4 inches while seedling mean height on the non-bedded site averages 82.4 inches. The next best performing site is at Bertie County where mean seedling height is 60.2 inches after three years. Mean heights of the cuttings on the Hofmann bedded and non-bedded sites average 76.9 and 67.8 inches, respectively. These mean heights are higher than the next best performing

[3] Registered trade name for Imazapyr manufactured by the American Cyanamid Company.

[4] Registered trade name for Sulfometuron methyl manufactured by the Dupont Company.

site at Bertie County where cutting mean height is 61.8 inches.

The Camp Lejeune, Bertie County, and Chowan County sites had similar performance results. Seedling mean height averages 53.4 inches in Chowan County, 55.6 inches on Camp Lejeune, and 60.2 inches in Bertie County. Cutting mean heights were more variable than seedlings on these three sites with averages ranging from 39.4 inches at Camp Lejeune to 61.8 inches at Bertie County. The Pitt County site has been characterized by poor performance (seedling mean height 37.3 inches) after three growing seasons.

A relationship between soil pH and tree survival appears similar to that of height performance (Table 3). Percent survival is highest, exceeding 90 percent, on sites with the lowest pH. Survival on the Hofmann bedded and non-bedded sites for both seedlings and cuttings ranges from 92 to 97 percent after three years. Seedling and cutting survival on the Camp Lejeune site (soil pH 4.0) is 91 and 92 percent, respectively after three years. Most mortality on these sites occurred the first year with negligible or no mortality in the last two years. Seedling and cutting survival has been poorer on the Chowan and Bertie Counties sites compared to the Hofmann and Camp Lejeune sites.

Seedling survival after three years on the Chowan County site is 59 percent, while cutting survival is 42 percent. Seedling survival on the Bertie County site is 31 percent, while cutting survival is 40 percent. Unlike the Hofmann and Camp Lejeune sites, mortality continues on the other three sites following the initial year of establishment. The most obvious case is in Bertie County where seedling survival fell from 74 percent after two years to 31 percent after the third year. Analysis of dead seedlings from this site revealed *Phytophthora cinnamoni* root rot had been the cause of death. Poorest survival was at the Pitt County site where seedling survival was 27 percent and cutting survival only 11 percent after three years.

In general, seedling mean height has been slightly better than cuttings (Table 1). The largest differences exist on the Hofmann and Camp Lejeune sites. Seedling mean height on the Hofmann bedded site averages 90.4 inches compared to cutting mean height on the same site of 76.9 inches. On the Hofmann non-bedded site seedling mean height averages 82.4 inches compared to cutting mean height of 67.8 inches. Likewise, seedling mean height on Camp Lejeune is superior to cutting mean height (55.6 inches vs. 39.4 inches, respectively). Mean height differences between seedlings and cuttings are negligible on the remaining sites.

There were smaller differences between seedling and cutting survival. The largest difference was on the Chowan County site where seedling survival after three years was somewhat higher compared to cutting survival. Cutting survival was slightly higher than seedling survival in Bertie County.

1990 Planting

Observations after two growing seasons were made on all six plantings established on the same sites in 1990. In most respects, these results reflect similar trends to the 1989 results (Table 2). Again the Hofmann, especially the bedded site, shows superior height performance (60.7 inches) after two growing seasons. This compares to a mean seedling height of 44.1 inches on the Hofmann non-bedded site and a mean seedling height of 42.8 inches on the Bertie County site. The Camp Lejeune and Chowan County sites were similar to one another in height performance results: 29.7 inches compared to 34.8 inches, respectively. Cutting mean heights for these two sites had slightly larger differences, 23.9 versus 30.2 inches. Once again, the Pitt County site shows the poorest performance with seedling mean height averaging 14.5 inches and cutting mean height averaging 19.2 inches.

Seedling and cutting survival have both been excellent on most sites (Table 4). Similar to the 1989 planting, both seedling and cutting survival after two years exceeded 90 percent on the Hofmann and Camp Lejeune sites, with no additional mortality occurring after the first year. Seedling survival on the Bertie and Chowan County sites average 90 and 86 percent, respectively. Cutting survival on Bertie County is 87 percent compared to a lower cutting survival of 72 percent on Chowan County. The Pitt County site is an exception to these excellent survival rates where cutting survival after two years is 17 percent, and seedling survival only 7 percent.

Comparisons between seedling and cutting heights reveal somewhat similar results to the 1989 planting (Table 2 and Table 4). Seedling mean heights were slightly greater than cutting mean heights, especially on the Hofmann non-bedded site where seedling mean height was 44.1 inches compared to a cutting mean height of 32.9 inches. Mean height differences between seedlings and cuttings range from 4 to 8 inches on all other sites with the exception of

Table 1. *1989 white-cedar planting; mean heights by site after growing season year-1, year-2, and year-3 for seedlings (sdl) and cuttings (ctg) showing the relationship to soil pH.*

Site	Soil pH	Mean Height (inches) With 95% Confidence Intervals Year 1 sdl	Year 1 ctg	Year 2 sdl	Year 2 ctg	Year 3 sdl	Year 3 ctg
Hofmann, bedded	3.2	19.6 ±1.3	15.1 ±1.0	55.8 ±4.0	46.1 ±3.2	90.4 ±5.3	76.9 ±4.5
Hofmann, no beds	3.3	22.1 ±1.7	13.1 ±0.9	52.1 ±3.1	38.0 ±2.9	82.4 ±4.2	67.8 ±4.0
Camp Lejeune	4.0	17.6 ±1.2	13.1 ±0.8	34.5 ±2.4	25.1 ±1.4	55.6 ±4.3	39.4 ±2.4
Bertie Co.	4.4	14.4 ±1.1	11.6 ±0.8	30.8 ±1.9	27.1 ±2.3	60.2 ±5.0	61.8 ±6.2
Chowan Co.	4.4	11.6 ±1.0	9.3 ±0.7	28.9 ±2.7	25.4 ±2.8	53.4 ±5.6	50.7 ±5.5
Pitt Co.	7.0	10.8 ±0.7	7.8 ±0.4	19.1 ±1.1	16.7 ±1.0	37.3 ±4.3	30.0 ±7.0

he Pitt County site where cutting mean height was greater than seedling mean height (19.2 to 14.5 nches, respectively).

1991 Planting

Observations after one growing season do not eveal much difference in seedling and cutting mean otal heights among sites (Table 5). Seedling total eight on the Hofmann bedded site averages 23.3 nches. This site has shown the best performing trees n the previous two years. However, seedling mean eights on the Hofmann non-bedded (20.9 inches), Camp Lejeune (20.9 inches), Bertie County (19.6 nches), and Chowan County (18.3 inches) sites were imilar. Cutting mean heights on all sites are also comparable. Cutting mean heights range from 20.2 nches in Bertie County to 17.6 inches in Chowan County. Cutting mean heights after one year differ ittle from mean cutting heights at the time of lanting.

Seedling and cutting survival has been excellent n all sites, except for the Chowan County site (Table 5). Seedling survival on the Hofmann and Camp Lejeune sites ranged from 95 to 100 percent. Excluding the Chowan County site, cutting survival anged from 85 to 100 percent. Survival on the Chowan County site was disappointing with seedling survival averaging 62 percent and cutting survival averaging 16 percent.

Table 2. *1990 white-cedar planting; mean heights by site after growing season year-1 and year-2 for seedlings (sdl) and cuttings (ctg).*

Site	Mean Height (inches) With 95% Confidence Intervals Year 1 sdl	Year 1 ctg	Year 2 sdl	Year 2 ctg
Hofmann, bedded	28.7 ±1.9	21.9 ±1.5	60.7 ±3.6	52.9 ±4.1
Hofmann, no beds	21.9 ±1.7	17.2 ±1.4	44.1 ±3.2	32.9 ±3.0
Camp Lejeune	17.4 ±1.4	12.6 ±0.8	29.7 ±2.1	23.9 ±1.9
Bertie County	18.4 ±0.9	14.1 ±0.8	42.8 ±2.3	37.6 ±2.0
Chowan County	19.2 ±2.0	15.8 ±1.5	34.8 ±3.5	30.2 ±3.8
Pitt County	13.3 ±0.5	9.3 ±1.0	14.5 ±1.0	19.2 ±10.1

Table 3. *1989 white-cedar planting; percent survival by site for seedlings and cuttings following growing seasons year-1, year-2, and year-3.*

Site	Seedlings Percent Survival YR1	YR2	YR3	Cuttings Percent Survival YR1	YR2	YR3
Hofmann, bedded	92	92	92	97	97	97
Hofmann, no beds	95	93	93	98	95	95
Camp Lejeune	93	92	91	96	93	92
Bertie County	84	74	31	79	55	40
Chowan County	83	71	59	63	51	42
Pitt County	47	34	27	59	20	11

Table 4. *1990 white-cedar planting; percent survival by site for seedlings and cuttings following growing seasons year-1 and year-2.*

Site	Seedlings Percent Survival YR1	YR2	Cuttings Percent Survival YR1	YR2
Hofmann, bedded	100	100	90	90
Hofmann, no beds	98	98	100	100
Camp Lejeune	90	90	90	90
Bertie County	99	90	90	87
Chowan County	94	86	82	72
Pitt County	23	7	53	17

Table 5. *1991 white-cedar planting; mean heights and survival by site after growing season year-1 for seedlings and cuttings.*

Site	Mean Height (inches) Sdl	Ctg	Percent Survival Sdl	Ctg
Hofmann, bedded	23.3 ±1.9	19.2 ±1.6	100	95
Hofmann, no beds	20.9 ±1.8	17.6 ±0.8	98	100
Camp Lejeune	20.9 ±1.8	19.7 ±1.1	95	85
Bertie County	19.6 ±1.2	20.2 ±1.3	95	92
Chowan County	18.3 ±2.5	17.6 ±3.4	62	16

Discussion

Plantability

There is sufficient evidence to conclude that white-cedar can be successfully planted. This study shows that given the proper site, preparation, and care the species performs well following establishment. Survival has been excellent on those sites to which white-cedar is naturally best adapted. No significant technical problems occurred during planting of the seedlings or cuttings. The same planting tools and techniques that are used in planting southern pine were effective and there is no apparent need to develop other planting techniques. Seedlings planted in 1989 on the Hofmann site showed particular resilience in their ability to survive harsh conditions. on the day of planting, high winds, snow, and cold conditions hampered planting efforts. Many seedlings following planting were barely above water level, and many floated to the top of the water when planted and had to be re-planted. One month later a few seedlings were found lying on the ground with their roots exposed. These seedlings were subsequently re-planted. In spite of these poor conditions seedling survival on the Hofmann site remained well above 90 percent after three years.

Phytophthora cinnamoni root rot has become a problem on the Bertie County site. High soil moisture, warm soil temperatures, and poorly drained soils favor the development of Phytophthora root rot (Jones and Benson, 1990). Planting seedlings too deeply may also be a contributing factor to the development of this disease. This disease killed numerous seedlings and cuttings, many of which were initially growing vigorously. Whether or not this disease will threaten future white-cedar plantations remains to be seen.

Performance Related to Site Conditions

There is a strong correlation between tree performance and some soil physical and chemical properties. Trees planted on sites with acidic, organic soil performed better. Naturally occurring

white-cedar in North Carolina is found predominately on deep organic soils characterized by poor drainage and high acidity. Croatan mucks found on the Hofmann site are characteristic of the soils where white-cedar occurs. Tree performance at the Hofmann has exceeded that at all other sites, which may indicate white-cedar's adaptation to highly acid organic soils.

The Camp Lejeune, Chowan County, and Bertie County sites were comparable to each other, but poorer than the Hofmann site. Soils from these sites are largely mineral, but there are organic matter accumulations in the upper horizon. Soils from these sites are moderately acid, but not to the extent of the Hofmann site. Noticeably poor performance on any of these three sites may be the result of heavy woody or herbaceous competition. The Pitt County site offers a good example of white-cedar's poor performance on high pH soils. Soils on this site are typically moderately acid, however as a consequence of agricultural amendments, soil pH has been raised to approximately 7.0. We suspect that high ph values as well as intense weed and grass competition have interfered with performance.

In general, seedling performance has been slightly better than cutting performance. In the 1990 planting, the apparent. smaller differences between seedling and cutting performance is probably a factor of better quality cuttings compared to cutting quality in 1989. Cuttings planted in 1991 showed little growth (~17 inches at planting to ~20 inches after one year) following establishment. A very late planting date combined with sporadic summertime rain could be a reason for this poor growth. Also, a small root to shoot ratio could have been a contributing factor. Comparisons between seedlings and cuttings must be interpreted cautiously. Differences existed in seed sources and planting dates, and the production methodology for rooted cuttings must be considered still under development.

Deer Browsing

To date, these studies have suffered surprisingly little damage from deer browsing, in spite of large populations of deer in the study areas. Only in isolated cases has any browsing been observed. Two trees on the Hofmann site were damaged by bucks rubbing their antlers against the stem of the tree. Most tree shelters were removed during or after the first year, because the seedlings and cuttings were growing out the tops or sides of the cages. In some cases, the cages were causing physical injury and/or stunted growth. The possibility of deer browsing remains, though this threat is considerably reduced as the trees exceed approximately 6 feet in total height. Some of the reasons for the lack of browsing may include (1) other more preferred food nearby, (2) lack of any nearby edge effect (two different vegetative sites adjoining), and (3) lack of recognition of white-cedar by deer, since white-cedar may be a new food plant to them.

Herbicide Application

Although herbicide treatments were not applied as part of a replicated trial, three preliminary observations were noted; (1) the herbicide applications were effective in controlling most competition, (2) there was no apparent mortality or injury to white-cedar from herbicide treatments, and (3) Arsenal, Oust, or a combination of the two at low rates appear to be suitable herbicides for chemical release.

Multiple Branching

Many seedlings and cuttings are producing multiple stems or forks(multiple stems include more than two stems competing for apical dominance, while a fork is a tree having two stems competing for apical dominance. This phenomenon appears to be occurring on all sites, with the Hofmann site being the most prevalent. Possible reasons for this tendency may include, (1) wide tree and row spacing within the plantations, (2) accelerated growth, especially on the Hofmann site, (3) unknown genetic traits within the individual trees, and (4) silvical characteristic of the species. There has been concern that trees with this trait may produce trees of inferior wood quality because of the presence of knots. It remains to be seen whether this trait will continue to be a problem after stands experience crown closure. Cultural work on multiple-stem or forked trees may answer some questions about white cedar's response to such treatments. Presently, no cultural work has been done on trees in this study.

It should be noted that this project is largely "demonstrational" in nature. Observations have pointed to possible correlations between tree performance and some site factor (soil pH or organic matter content). As mentioned, a primary objective was to test the plantability of this species. Although, "concrete" conclusions may not be drawn from this

study, trends have been shown which may serve as a starting point for future research.

Conclusions

This study demonstrates (1) that white-cedar can be successfully established on acidic sites suitably prepared for planting; (2) that growth and survival are greater on sites characterized by deep organic, low pH soils; (3) that both seedlings and cuttings appear to have potential for artificial regeneration of white-cedar, but that seedlings may be superior; and (4) that predation from deer and other mammals may not be a serious threat to establishment in all situations. This study may direct future efforts aimed at answering questions involving white-cedar management.

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PRECOMMERCIAL THINNING OF WATER TUPELO STANDS ON THE MOBILE-TENSAW RIVER DELTA [1]

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Abstract. Three 4-year-old stands were selected for precommercial thinning. Treatment consisted of two components: (1) thinning water tupelo (*Nyssa aquatica* L.) stump sprouts and dense patches of water tupelo seedlings and (2) cutting all stems of Carolina ash (*Fraxinus caroliniana* Mill.) and willow (*Salix nigra* Marsh.) (cleaning). This approach provided a 2 by 2 factorial with two replications in each stand.

One year after treatment, the number of water tupelo seedlings was relatively unaffected by treatments. The stands were inundated from January until June, and the mortality caused by extended flooding may have overwhelmed any treatment effect.

Thinning, but not cleaning, affected growth of water tupelo stump sprouts. Depending on the stand, thinning increased 1-year diameter growth from 0.135 to 0.19 inches over unthinned plots, a 27 to 37 percent increase over the unthinned plots.

Only one permanently tagged stem died within the first year of the study; this preliminary data strongly contrasts with previous studies in which water tupelo showed very high mortality.

Introduction

Demand for hardwood pulp has increased in southern Alabama. Second-growth water tupelo-dominated stands in the Mobile-Tensaw River Delta are being harvested to fulfill the demand. Water tupelo stands tend to be more dense than other bottomland hardwood stands (Putnam and others 1960). The young post clearcut stands are also dense. Mature tupelo stands are often harvested with helicopter systems, but this method is too expensive for thinning. Ground conditions preclude the use of rubber-tired or tracked equipment for thinning. Thus, interest has arisen in conducting precommercial thinning to achieve a merchantable size (currently, 3-inch top diameter) at an earlier age, reducing rotation length as well as minimizing unsalvageable losses of growth to mortality.

Kennedy (1983) found that thinning mature water tupelo stands in the Atchafalaya Basin of Louisiana did not increase diameter growth. McGarity (1979) investigated thinning in 60-year-old muck swamp forests and found that thinning increased growth of individual trees, although the control plots had the greatest volume growth.

DeBell (1971) reported high survival for water tupelo stump sprouts 1 year after harvesting; however, 3 years later, 45 percent of the stumps with sprouts had died. Kennedy (1982) reported that mortality of young water tupelo sprout clumps was high; tupelo coppice would not comprise an important component of the mature stand. After 6 years, only 9 percent of the stumps cut in May and 18 percent of the stumps cut in November had live sprouts.

The results from the Atchatalaya Basin indicate that the high density of the 3- to 4-year-old stands in the Mobile Delta could decrease rapidly if patterns of mortality are similar. This study is intended to determine: (1) response of diameter growth of water tupelo stump sprouts to thinning; (2) whether stump-sprout thinning will improve survival of the remaining stump sprouts, and (3) whether presence of Carolina ash and willow has a detrimental effect on growth and survival of tupelo stump sprouts and seedlings.

Methods

Three areas were chosen on Scott Paper Company land on the delta of the Mobile and Tensaw Rivers in Alabama. The native tupelo stands were clearcut in 1986 and 1987, and four seasons of growth occurred before initiation of this study; all stems over 2 inches in d.b.h. were felled in the harvest operation. The areas represent good sites for water tupelo and are densely stocked with water tupelo, Carolina ash,

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[1] Paper presented at the Seventh Binnial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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baldcypress [*Taxodium distichum* (L.) Rich.], and black willow, with other species present. Before treatment, the plots had 5,000 to 10,000 stems per acre. Sprout-origin stems are larger and appear to dominate the stand, although seedlings are abundant in patches where sprouts are absent. Before treatment, the plots had 300 to 3,500 water tupelo seedlings per acre.

A 2 by 2 factorial design with two randomly selected replications at each location was used. The first factor is thinning or not thinning water tupelo. The thinning consisted of two components:

1. All water tupelo stumps were thinned to the best one or two sprouts where "best" was defined as the largest well-formed sprout that originated low on the stump. When two well-spaced sprouts of good form and low origin were present, both were left. If only one good sprout was present, that one sprout was left.

2. Water tupelo seedlings were thinned wherever they occurred in a dense patch (more than 20 per 100 ft^2, in patches of 100 ft^2 or larger); such patches were thinned so that the tallest water tupelo seedlings were left at a density of approximately one per 36 ft^2 (or a nominal 6 by 6 ft spacing).

The second factor is cleaning or not cleaning the Carolina ash and willow; all ash and willow were cut as close to the ground as possible. These factors provide four treatment combinations:

1. No thinning, no cleaning (the control).
2. No thinning, cleaning.
3. Thinning, no cleaning.
4. Thinning, cleaning.

The 0.786-acre treatment plots were in the central part of the clearcut. Three potential treatment plots were discarded as they represented intersections of pull-boat runs and were poorly stocked. The measurement plot (0.304 acre) was in the center of each treatment plot.

Small stems were counted by species, origin (sprout or seedling), and size class. Size class 1 includes stems from 3 to 4.5 ft tall. Size class 2 includes stems taller than 4.5 ft, but less than 2.5 inches in d.b.h. Size class 3 includes stems greater than 2.5 inches in d.b.h.; those stems were permanently numbered and the following attributes were recorded:
(1) d.b.h., (2) species, (3) origin, (4) number of sprouts on stump, and (5) crown class (Kraft's tree class) (Daniel and others 1979).

Additional measurements were made on up to 25 randomly selected tagged trees per plot: (1) total height, (2) height to base of the continuous live crown (ignores low solitary branches), and (3) the widest crown diameter and the diameter perpendicular to it. One year after initiation of the study, these trees were remeasured, as were up to 10 randomly selected trees that grew into size class 3.

Results and Discussion

The average number of stems per acre 1 year after treatment is presented in table 1. Individual analyses of variance were performed for each species-size class combination. Treatment effects were seldom significant at the 0.05 level; the significant effects are discussed below. Thinning did increase the number of small (size class 1) sprouts of water tupelo. Most stumps resprouted vigorously following thinning, producing numerous small sprouts. The larger tupelo sprouts (size class 3) were reduced by thinning; however, this effect was significant only for location 2. The second location had the greatest density of tupelo stumps. Cleaning also increased the number of small sprouts of other species. Most of the willow and Carolina ash produced many sprouts after they were cut. Although cleaning did not reduce the number of sprouts, it did reduce the average size of the sprouts. Cleaning did reduce the number of seedlings of other species; however, the effect was only significant at location 3, which had the most willow stems of the three locations. Willow were primarily of seedling origin--the Carolina ash were primarily of sprout origin.

The number of stems within a species-size class was highly variable, and thus significant effects were rare. We supplemented our initial analyses with models predicting number of water tupelo seedlings and diameter growth of water tupelo sprouts. Emphasis on water tupelo reflects the value of tupelo compared with the other species.

Equation 1 represents the conceptual form for an equation to predict number of water tupelo seedlings:

$$N_{1991} = A + B*N_{1990} \quad (1)$$

where N_{1991} is the number of tupelo seedlings per plot in 1991, N_{1990} is the number of tupelo seedlings in 1990, and A and B are linear functions of dummy variables for treatments and locations and interactions among those variables. Thus B can be considered to

Table 1. *Average number of stems per acre for four treatment combinations one year after treatment, averaged across all locations.*

Class[1]	Treatment			
	Control	Clean	Thin	Clean & Thin
Tupelo-1 (sp)	2	26	440	410
Tupelo-2 (sp)	1,101	1,334	1,910	2,355
Tupelo-3 (sp)	387	390	207	228
Tupelo-1 (sd)	463	260	390	400
Tupelo-2,3 (sd)	749	354	317	355
Cypress-1,2 (sp)	123	94	195	77
Cypress-3 (sp)	43	41	40	14
Cypress-1 (sd)	61	81	89	38
Cypress-2 (sd)	128	135	114	43
Cypress-3 (sd)	1	1	0	1
Other[2]-1 (sp)	13	841	93	771
Other-2 (sp)	2,011	1,260	2,469	2,153
Other-3 (sp)	3	1	7	1
Other-1 (sd)	39	24	73	43
Other-2 (sd)	308	46	563	67
Other-3 (sd)	15	0	17	0
Total	5,447	4,888	6,924	6,956

[1] Class is specified by species, size, and whether sprout (sp) or seed (sd) origin. Size class 1 represents stems from 3 to 4.5 ft tall. Size class 2 represents stems over 4.5 ft tall but less than 2.5 inches in d.b.h. Size class 3 represents stems 2.5 inches in d.b.h. and larger.

[2] Other represents all species other than water tupelo and baldcypress.

be survival and A can be considered to be ingrowth. Nonsignificant terms were deleted from the equation, and the final equation was:

$$N_{1991} = -2318.4*L_1*Thin + 2537.7*L_1*Thin*Clean + N_{1990}*(0.686 + 11.3*L_1*Thin - 11.7*L_1*Thin*Clean) \quad (2)$$

where L_1 is a dummy variable signifying location one, Thin is a dummy variable representing thinned stands, and Clean is a dummy variable for cleaned stands. The adjusted R^2 value is 0.94, and the standard error of the estimate is 86.5 trees. For all plots except thinned plots on location one, the equation simplifies to $N_{1991} = 0.686*N_{1990}$--the other terms drop out because the dummy variables equal 0. The significance of the other terms of equation 2 is suspect. A few plots at location one have very high influence. The number of tupelo seedlings was not related strongly to the treatments. Although the areas flood annually during the winter, the water level remained high until June of 1991; this is much later than usual. Duration of the floodwater may have caused relatively high mortality and overshadowed the effects of the treatments.

Diameter growth of tupelo stump sprouts was modeled by a quadratic function of initial diameter where the effects of treatments and location could enter as constants or as interactions with initial diameter or diameter squared. After eliminating nonsignificant terms, the final model became:

$$\text{Diameter Growth} = 0.190*Thin - 0.055*Thin*L_1 + 0.32523*D_0 - 0.0521*D_02 + 0.023*D_0^2*L_2 - 10.005*D_0^2*L_2*Clean \quad (3)$$

where D_0 is the initial diameter and L_2 represents location 2. Other variables are consistent with preceding equations. The adjusted R2 value for equation 3 is 0.92; the standard error of the estimate is 0.193 inches. Diameter growth is greater at location two than at locations one and three; the magnitude of the difference increases with increasing diameter. The effect of thinning at locations two and three is an increase in diameter growth of 0.19 inches. The effect of thinning at location one is an increase of 0.135 inches. Although these increases are modest,

they represent only the effect of thinning the first year after treatment. The increase corresponds to a 27 to 37 percent increase in diameter growth over unthinned plots, depending on the location.

Figure 1 is a graph of predicted diameter growth versus initial diameter. Locations one and three show diameter growth curves that are very flat across the range of diameters. The curves for location two represent a more likely trend--diameter growth increases with increasing initial diameter. The slight negative effect of cleaning on diameter growth at location two represents the influence of a few trees that happened to grow slowly rather than any real negative impact.

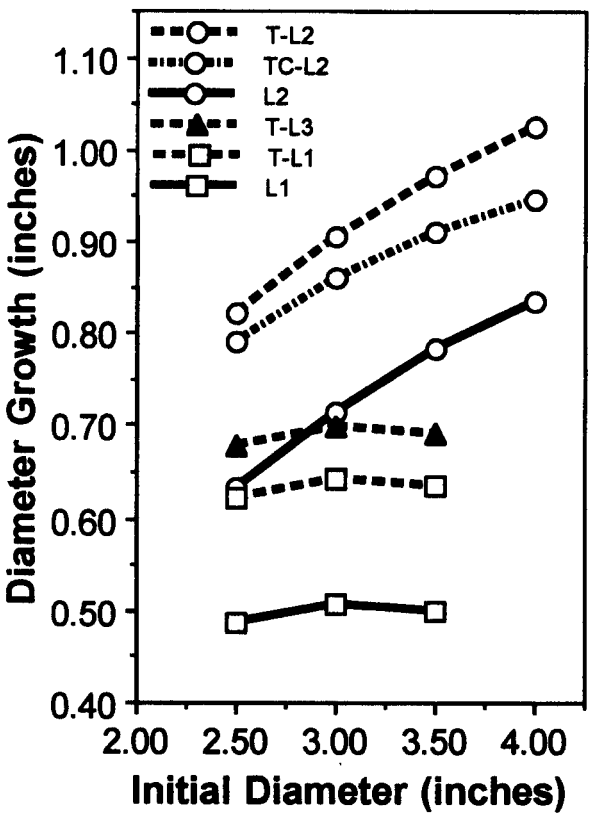

Figure 1. *Diameter growth curves for different treatments and locations. T-L2 indicates thinned plots on location two. TC-L2 indicates thinned and cleaned plots at location two. L2 indicates control plots at location two. T-L3 indicates thinned plots at location three. T-L1 indicates thinned plots at location one. L1 indicates control plots at location one or three.*

Although we placed high importance on investigating mortality rates, this investigation will be delayed until future measurements are made. Of all the tagged stems, only one stem died. That individual was inadvertently broken off during measurement. Although this result is preliminary, the low mortality in this study contrasts greatly with the very high mortality found in previous studies of coppice tupelo (DeBell 1971, Kennedy 1982). We attribute at least part of the difference to characteristics of the Mobile-Tensaw River Delta--no major drainage projects that altered wetland processes there.

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DEVELOPMENT OF ADVANCED CHERRYBARK OAK REPRODUCTION FOLLOWING MIDSTORY AND UNDERSTORY COMPETITION CONTROL AND SEEDLING CLIPPING: 4-YEAR RESULTS [1]

Brian R. Lockhart, John D. Hodges, James M. Guldin [2]

Abstract. Development of advanced cherrybark oak reproduction (*Quercus pagoda* Raf.) following midstory and understory vegetation control and seedling clipping was evaluated on three bottomland hardwood sites. After four growing seasons, released seedlings had greater heights than non-released seedlings; 58, 81, and 68 cm compared to 37, 47, and 65 cm, respectively, for the River Road, Keaton Tower Road, and Dummy Line Road sites (the Dummy Line Road site data reflects only three growing seasons) on the Noxubee National Wildlife Refuge. Released-clipped seedlings had the greatest height and root-collar diameter growth among the four treatments (release/no release and clipping/no clipping treatment combinations) except for the Keaton Tower Road site after the third growing season where released-intact seedlings had the greatest height growth. Patterns in height development indicate that releasing advanced cherrybark oak reproduction is necessary to increase seedling growth and vigor, but clipping seedlings, in addition to release, may not be necessary.

Introduction

Numerous problems have been reported in attempts to naturally regenerate oak stands. For example, Beck (1970) reported less than one foot in height growth of three-year-old northern red oak seedlings (*Quercus rubra* L.) two years after release and only 2.4 feet after six years. Janzen and Hodges (1987) reported less than one foot in height growth of advanced bottomland red oak reproduction, primarily water oak (*Q. nigra* L.), willow oak (*Q. phellos* L.), and cherrybark oak (*Q. pagoda* Raf.), three years after release from competing midstory and understory vegetation. Finally, Graney (1989) reported less than one foot in height growth of Ozark upland advanced oak reproduction five years after midstory competition control. These reports represent a few of many attempts to naturally regenerate oak stands. So far, results have been mixed with far too many regeneration failures occurring to have reliable regeneration prescriptions.

Artificial regeneration techniques, such as planting and direct seedling, are viable options to regenerate oak stands. But these techniques have usually been cost prohibitive to most landowners, although recent cost-sharing programs such as the Conservation Reserve Program have made these options more attractive (Kennedy 1990). Therefore, problems in naturally regenerating oaks stands, especially southern bottomland oaks, can be summarized into three main problem areas.

The first problem area involves an insufficient number and/or size of advanced oak reproduction, i.e., reproduction that is present underneath a forest canopy (Smith 1986). Proposed desirable stocking densities have ranged from as many as 400-435 seedlings/acre (Arend and Scholz 1969) to as few as 45-60 seedlings/acre (Oliver 1978, Clatterbuck and Hodges 1985). These stocking values were dependent upon site, seedling size, and anticipated stand development patterns. At present, a height of 4.5 feet has been proposed as the minimum acceptable size for advanced bottomland red oak seedlings (Hodges and Janzen 1987).

A second problem area is the slow height growth response to release as stated with the above examples. Oak seedlings which exhibit this slow height growth are simply not able to compete against sprouts of less-desirable species. Several foresters consider this slow response to release a more serious problem than inadequate stocking (Hodges and Janzen 1987). One key to increasing seedling height growth is to increase the light levels reaching these seedlings. But regulation of light levels alone will not always ensure rapid height growth. A technique proposed to partially alleviate this slow growth response is to clip

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992. Paper approved for publication by the Arkansas Agriculture Experiment Station.

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oak seedlings at the time of release. Subsequent sprouts usually have greater rates of height growth, appear more responsive to release, and are presumably more competitive against less-desirable species (Bundy et al. 1991, Lockhart 1992).

The third problem area involves a lack of consideration in the biological requirements for seedlings of the genus *Quercus*. There is currently an inadequate understanding of the field conditions needed for adequate seedling establishment and subsequent growth (Hodges and Janzen 1987, Crow 1988).

Because of these problem areas, especially the slow response of oak seedlings to release, a study was conducted involving advanced cherrybark oak reproduction. The objective of this study was to determine if clipping cherrybark oak seedlings, combined with midstory and understory competition control, is a feasible silvicultural technique for enhancing the growth and development of advanced oak reproduction. Information gained from this study may help in the understanding of the early growth patterns of advanced oak seedlings.

Materials and Methods

Study Location

Three study sites, each containing advanced cherrybark oak reproduction, were located on the Noxubee National Wildlife Refuge in east-central Mississippi.

Site 1, or River Road, was located on a terrace along the Noxubee River. Soils were composed of Stough fine sandy loam (coarse-loamy, siliceous, thermic Aquic Fragiudults). Stand composition was old-field mixed pine and hardwood consisting of loblolly pine (*Pinus taeda* L.), water oak, and sweetgum (*Liquidambar styraciflua* L.) in the overstory and sweetgum, oaks, hornbeam (*Carpinus caroliniana* Walt.), hophornbeam (*Ostrya virginiana* Mill. K. Koch) and red maple (*Acer rubrum* L.) in the middle and lower canopy positions. Overstory stand age was approximately 48 years. Site index, base age 50 years, for cherrybark oak was 83 (USDA 1973). The River Road site is inundated only during periods of extremely high water.

Site 2, or Keaton Tower Road, was located within a horseshoe bend adjacent to the Noxubee River. Soils were composed of Ochlockonee loam (coarse-loamy, siliceous, acid, thermic Typic Udifluvents). Stand composition was mixed bottomland hardwood consisting of cherrybark oak, Shumard oak (*Q. shumardii* Nutt.), water oak, pignut hickory (*Carya glabra* (Mill.) Sweet) and American beech (*Fagus grandifolia* Ehrh.) in the overstory. Species occupying the middle and lower strata included hornbeam, hophornbeam, hickory, pawpaw (*Asimina triloba* (L.) Dunal) and flowering dogwood (*Cornus florida* L.). Overstory stand age was approximately 80 years. Site index for cherrybark oak was 98. The Keaton Tower Road site is subjected to severe annual flooding.

Site 3, or Dummy Line Road, was located adjacent to Loakafoma Creek. Soils were composed of the Urbo series. Stand composition was old-field mixed pine and hardwood consisting of loblolly pine, cherrybark oak, and sweetgum in the overstory, and sweetgum, oaks, green ash (*Fraxinus pennsylvanica* Marsh.), red maple, hornbeam, and hophornbeam in the middle and lower canopy positions. Site index for cherrybark oak was approximately 100. The Dummy Line Road site is subjected to annual inundation for short periods of time.

Study Design

A 2x2 factorial arrangement in a split-plot design with two replications per site was established in February, 1989, for the River Road and Keaton Tower Road sites and February, 1990, for the Dummy Line Road Site. Individual plot size was variable, but averaged about 0.25 acres.

Within each plot, 30-70 cherrybark oak seedlings, averaging 25-60 cm in height depending on site, were flagged for treatment and future measurements. Treatments consisted of midstory and understory removal or no removal at the whole-plot level and seedling clipping or no clipping at the subplot level. All stems, excluding cherrybark oak seedlings, in the midstory and understory, including those in the intermediate or overtopped crown classes (Smith 1986), were removed. Immediately after each stem was cut, Tordon 101R® was applied to the stump using a mist-spray bottle. Seedling clipping consisted of severing approximately one-half of the cherrybark oak seedlings per plot at 2.5 cm above the groundline using a hand-held shear. Seedling ages were not determined due to the difficulties in determining such ages (Tryon et al. 1980) and the destructive sampling required.

Seedling Measurements

Cherrybark oak seedling measurements were conducted at the end of the 1989, 1990, 1991, and

1992 growing seasons. Measurements included: (1) survival, as indicated by detectable growth, (2) total height in centimeters as measured from groundline to base of terminal bud, and (3) root-collar diameter in millimeters. Root-collar diameter was measured at groundline in 1989. Two root-collar diameter measurements, perpendicular to each other at three cm above groundline, were taken in 1990, 1991, and 1992. Root-collar diameter of clipped seedlings was measured at the base of the sprout stem in 1989 and three cm above the base in 1990, 1991, and 1992. The change in height of root-collar diameter measurements was necessary to avoid the variation (due to taper) associated with groundline measurements. A simple linear regression was developed to relate 1989 measurements to the other years.[3]

Results and Discussion

Survival

Seedling survival patterns, as indicated by detectable growth, appeared different between sites. Released seedlings had greater survival than non-released seedlings on the River Road site (Figure 1). Released-intact seedlings had the greatest survivalt (95%) while non-released clipped seedlings had the lowest survival (54%) after four growing seasons. Survival was >90% after two years and >80% after four years for all but the non-released clipped seedlings. Lower survival of clipped seedlings, especially non-released clipped seedlings, after one growing season was due primarily to clipped seedlings not sprouting. Continued decreases in the survival of non-released clipped seedlings was probably due to depletion of stored food reserves under conditions of low light. A slight increase in the survival of released-intact seedlings after the 1992 growing season was due to the finding of seedlings lost in 1991. Lost seedlings were not included in survival calculations.

Released seedlings on the Keaton Tower Road site also had the greatest, though somewhat disappointing, survival than non-released seedlings (Figure 2). After four years, survival was 69 and 66%, respectively, for released-clipped and released-intact seedlings. The low survival, especially at theend of the first growing season, was due primarily to severe flooding that occurred on at least four occasions during the growing season. In general, oak seedlings begin to perish if inundated for more than 1-2 days when fully leafed (Broadfoot and Williston 1973). Low survival for clipped seedlings, as depicted by the 21% survival for non-released clipped seedlings, was further hampered by siltation of seedling stumps. No buried stumps were observed to sprout. Some seedlings also perished due to a portion of the bank collapsing along the Noxubee River.

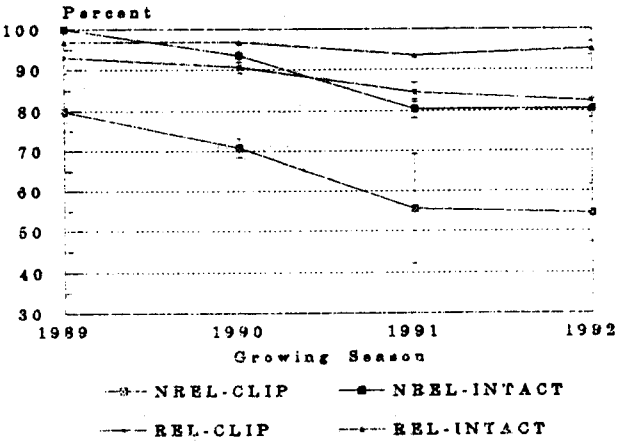

Figure 1. *Survival of advanced cherrybark oak reproduction, River Road site. Vertical bars represent standard errors.*

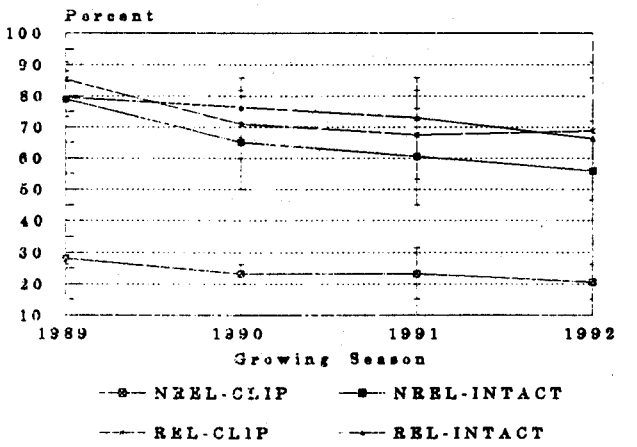

Figure 2. *Survival of advanced cherrybark oak reproduction, Keaton Tower Road site. Vertical bars represent standard errors.*

Seedling survival on the Dummy Line Road site was greater for intact seedlings than clipped seedlings after three growing seasons (Figure 3). Survival was greatest for released-clipped seedlings (98%) and lowest for non-released clipped seedlings (85%). Overall, greater survival occurred on the

[3] $RCD_{3cm} = 0.846333*RCD_{groundline}$, ($r^2 = 0.99$, n = 45), where RCD is root-collar diameter in millimeters.

Dummy Line Road site compared to the River Road and Keaton Tower Road sites. This greater survival was due, in part, to greater survival of clipped seedlings. Furthermore, seedlings on the Dummy Line Road site, on the average, were much larger seedlings than on the other two sites, possibly indicating a better-established root system.

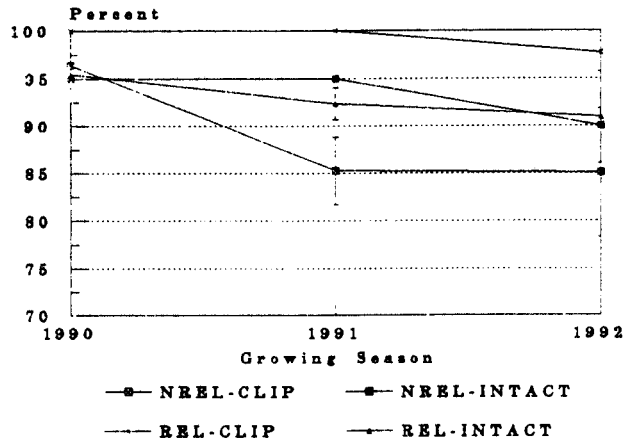

Figure 3. *Survival of advanced cherrybark oak reproduction, Dummy Line Road site. Vertical bars represent standard errors.*

In summarizing seedling survival: (1) intact seedlings generally had greater survival than clipped seedlings, especially if seedlings were released, (2) lowest survival occurred with non-released clipped seedlings on all three sites, and (3) seedling survival was greater on the Dummy Line Road site compared to the other two sites, due probably to their larger initial seedling sizes.

Height Development

Released-intact seedlings had the greatest height after four years on the River Road site at 63 cm (Table 1). Non-released intact seedlings grew only 10 cm after four years. Furthermore, these seedlings have grown only one cm in the last two growing seasons. Clipped seedlings, regardless of midstory and understory treatments, grew an average of near 20 cm the first year after clipping. Thereafter, non-released clipped seedling grew little, averaging only 11 cm over the last three years. On the other hand, released-clipped seedlings showed near linear growth, averaging 13 cm/year over four years. Of particular interest, released-clipped seedlings pass non-released intact seedlings during the fourth growing season after treatment.

Released-intact seedlings also had the greatest height on the Keaton Tower Road site after four years at 100 cm (Table 1). Non-released intact seedlings showed small but steady increases in height, averaging about 6 cm/year, while non-released clipped seedlings grew about 10 cm/year over the four-year period. As expected, released-clipped seedlings had rapid early height growth with an average of over 22 cm/year after each of the first two growing seasons after treatment. These seedlings had slowed to about 8 cm of height growth over the last two years, similar to non-released intact seedlings. One reason for these slower rates of height growth was due to beaver damage. Although the rate of height growth of individual resprouts was high, the net effect was a temporary decrease in total height, thus affecting average height development. Of particular interest, released-clipped seedlings, similar to those on the River Road site, passed non-released intact seedlings during the second growing season after treatment.

Intact seedlings had a greater average height than clipped seedlings after three years, 83 cm compared to 49 cm, respectively on the Dummy Line Road site (Table 1). Little difference appeared to occurred in height growth between released and non-released intact seedlings. Non-released intact seedlings had the greatest initial height at 68 cm and were still the tallest seedlings after three years at 86 cm. Non-released and released-clipped seedlings had similar rates of height growth after two years. Afterwards, release-clipped seedlings had a greater rate of height growth during the 1992 growing season, growing an average of 54 cm over the past three years.

In summarizing height development: (1) released-intact seedlings had the greatest height on the River Road and Keaton Tower Road sites after four growing seasons, (2) non-released intact seedlings grew an average of <30 cm (<1 foot) after four years while non-released clipped seedlings had greater height growth, but averaged only about 30-45 cm (1-1.5 feet) after four years, (3) released-intact seedlings grew surprisingly well, growing an average of 30-75 cm (about 1-2.5 feet), depending on site, and (4) released-clipped seedlings grew an average of about 60 cm (2 feet), passing non-released intact seedlings on two sites but not released-intact seedlings.

Table 1. *Height development and cumulative relative height growth (RHT) of advanced cherrybark oak reproduction on the Noxubee National Wildlife Refuge. Numbers in parentheses represent standard errors.*

Site and Treatment	Initial Height	1989 Height	1989 RHT	1990 Height	1990 RHT	1991 Height	1991 RHT	1992 Height	1992 RHT
River Road									
Nrel-Clip[1]	41.2 (6.0)	16.9 (1.2)	41	21.8 (1.0)	53	22.0 (0.4)	53	27.9 (1.7)	68
Nrel-Intact	36.8 (4.5)	41.6 (3.4)	13	45.8 (3.4)	24	46.5 (2.9)	26	46.9 (0.6)	27
Rel-Clip	35.6 (0.8)	18.8 (2.2)	53	33.1 (5.3)	93	41.8 (5.0)	117	52.5 (6.2)	147
Rel-Intact	33.4 (0.0)	40.8 (4.1)	22	49.3 (3.9)	48	53.6 (7.0)	60	63.2 (12.0)	89
Keaton Tower Rd.									
Nrel-Clip	20.2 (0.3)	11.6 (0.0)	57	17.4 (1.4)	86	29.2 (2.6)	145	37.8 (7.2)	187
Nrel-Intact	23.2 (1.0)	30.8 (3.5)	33	39.1 (7.6)	69	49.7 (8.3)	114	55.9 (6.4)	141
Rel-Clip	27.0 (4.3)	21.8 (3.2)	81	44.2 (7.7)	164	55.1 (11.9)	204	60.9 (12.8)	226
Rel-Intact	27.2 (8.5)	35.8 (6.6)	32	49.2 (7.6)	81	77.7 (11.1)	186	100.4 (27.1)	269
Dummy Line Rd.									
Nrel-Clip	68.8 (8.9)	--	--	26.9 (0.7)	39	38.2 (1.2)	56	44.1 (1.1)	64
Nrel-Intact	68.1 (9.6)	--	--	74.7 (11.9)	10	80.2 (12.3)	18	85.9 (13.1)	26
Rel-Clip	52.7 (25.0)	--	--	26.2 (4.9)	50	41.8 (7.7)	79	53.8 (10.0)	102
Rel-Intact	57.5 (23.8)	--	--	64.3 (24.6)	12	72.2 (22.9)	26	81.2 (22.7)	41

[1] Explanation of treatment terms: Nrel = non-released, no midstory or understory vegetation removal; Rel = released, midstory and understory vegetation removed; Clip = clipped advanced cherrybark oak reproduction; Intact = advanced cherrybark oak reproduction was not clipped.

Relative Height Growth

Another way to represent seedling height development is relative height growth, in which height growth is expressed as a percentage of pre-treatment seedling height. Intact seedlings that have 100% relative height growth have doubled their pre-treatment height. By comparison, clipped seedlings that reach this point have matched their pre-treatment seedling height.

As expected, non-released intact seedlings on the River Road site had grown only about one-quarter of their pre-treatment height with little cumulative relative height growth over the last two years (Table 1). Non-released clipped seedlings grew almost one-third of their pre-treatment height in two growing seasons, but little thereafter. On the other hand, released-intact seedlings grew a steady 20-25% over each of the four growing seasons, while released-clipped seedlings grew over half of their pre-treatment height after the first growing season. These seedlings grew to near their pre-treatment height after two growing seasons and passed this height during the third year. After four years, these seedlings have grown about 1.5 times their pre-treatment height.

Non-released intact seedlings on the Keaton Tower Road site grew surprisingly well, doubling their seedling height in three years, and grew an average of 1.5 times their pre-treatment height after four years (Table 1). Non-released clipped seedlings also did well, doubling their pre-treatment height in four years. Two possible reasons for non-released seedlings doing well on the Keaton Tower Road site include: (1) due to high mortality, only the very best non-released seedlings, and probably the most vigorous, survived, and (2) two large overstory trees on one non-released plot died during the 1989 growing season, allowing substantial amounts of sunlight to reach some "non-released" seedlings. Released-intact seedlings nearly doubled in height after two growing seasons, similar to non-released intact seedlings. These seedlings grew nearly 200% during the last two years, amounting to 2.5 times their pre-treatment height over the four-year period. Released-clipped seedlings grew 1.5 times their pre-treatment height after two years, thereafter increasing in relative height growth but at a decreasing rate. These seedlings would probably have had better fourth-year results if not for beaver damage.

Non-released intact seedlings on the Dummy Line Road site grew only an average of about 25% of pre-treatment height after three years while non-released clipped seedlings grew an average of about 65% of pre-treatment height during the same period (Table 1). These results were similar to the River Road site, but actual growth was greater on the Dummy Line Road site due to larger seedling sizes. Released-clipped seedlings, as with both the River Road and Keaton Tower Road sites, had the greatest relative height growth after three years. These seedlings had reached their pre-treatment height

during this time. Finally, released-intact seedlings grew an average of about 41% of their pre-treatment height after three years.

In summarizing relative height growth: (1) non-released seedlings generally had the lowest percentages of relative height growth, (2) released-clipped seedlings had the greatest relative height growth after three growing seasons on all three sites, (3) released-clipped seedlings passed their initial heights during the second or third growing season after treatment, and (4) released-intact seedlings had variable patterns of relative height growth, ranging from low on the Dummy Line Road site to excellent on the Keaton Tower Road site.

Root-Collar Diameter Development

Released-intact seedlings had the largest root-collar diameter after four years on the River Road site at 6.26 mm, having grown 3.11 mm over the study period (Table 2). Clipped seedlings, regardless of midstory and understory treatment, had rapid early root-collar diameter growth of 1.50 and 1.99 mm, respectively, for non-released and released seedlings after one growing season. Root-collar diameter development of non-released clipped seedlings slowed thereafter, averaging only 0.92 mm over the last three years. Released-clipped seedlings have maintained near linear growth of 0.74 mm/year over the last three growing seasons. Non-released intact seedlings grew little, with an actual net reduction of 0.04 mm from 1989 to 1992. As with height development, released-clipped seedling root-collar diameter passed that of non-released intact seedlings during the 1991 growing season.

Released-intact seedlings also had the largest root-collar diameter on the Keaton Tower Road site at 8.03 mm (Table 2). This value represented a near three-fold increase from pre-treatment root-collar diameter with an average of 1.77 mm/year in growth. Released-clipped seedlings had rapid early root-collar diameter development, averaging 1.86 mm/year during the first two growing seasons after treatment. Growth slowed to an average of only 0.21 mm during the 1991 growing season, again due probably to beaver damage, before increasing to an average of 5.36 mm after the 1992 growing season. Non-released clipped seedlings maintained a slow but steady increase in root-collar diameter, averaging 0.49 mm/year during the four-year study period. Finally, non-released clipped seedlings had the lowest root-collar diameter throughout the study period, averaging 2.27 mm after the 1989 growing season, but only 0.76 mm over the following three years.

Patterns of root-collar diameter development on the Dummy Line Road site were similar to patterns of height development. Intact seedlings had greater average root-collar diameters than clipped seedlings after three years, 6.85 mm compared to 4.22 mm, respectively. Non-released intact seedlings had the largest initial root-collar diameter at 5.10 mm, but grew only 0.30 mm/year after treatment installation. Released-intact seedlings, after growing only 0.47 mm after the 1990 growing season, grew an average of 1.49 mm the last two years. These seedlings passed non-released intact seedlings during the 1991 growing season. Released and non-released clipped seedlings had very similar patterns of root-collar diameter development compared to their respective height development patterns. These seedlings had rapid early root-collar diameter growth of 2.53 and 2.18 mm, respectively, for released and non-released seedlings. Thereafter, non-released clipped seedlings slowed to 0.70 mm/year over the last two years, while released-clipped seedlings grew 1.17 mm/year during the same time period.

In summarizing root-collar diameter development: (1) released intact seedlings had the largest root-collar diameters after four years, (2) root-collar diameter growth was lowest for non-released intact seedlings, (3) released-clipped seedlings had the greatest root-collar diameter growth, passing non-released intact seedlings after two growing seasons on the River Road and Keaton Tower Road sites, and (4) non-released clipped seedlings had similar first-year root-collar diameters to released-clipped seedlings, but growth slowed thereafter. These patterns of root-collar diameter development were, in essence, similar to the patterns in height development.

Conclusions

Controlling competing midstory and understory vegetation resulted in greater, though not impressive, height and root-collar diameter growth of advanced cherrybark oak reproduction. Also, clipping cherrybark oak seedlings, combined with midstory and understory competition control, resulted in the greatest seedling height growth, but not enough to pass released-intact seedlings after four years. Based on these results, two-to-four more years of study are needed before more definite statements can be made concerning the silvicultural value of midstory and understory vegetation control and seedling clipping on

Table 2. *Root-collar diameter (RCD) development of advanced cherrybark oak reproduction on the Noxubee National Wildlife Refuge. Numbers in parentheses represent standard errors.*

Site and Treatment	Initial RCD	1989 RCD	1990 RCD	1991 RCD	1992 RCD
River Road					
Nrel-Clip[1]	3.41 (0.35)	1.50 (0.15)	1.77 (0.19)	2.14 (0.08)	2.42 (0.18)
Nrel-Intact	3.75 (0.72)	3.46 (0.19)	3.41 (0.20)	3.90 (0.13)	3.71 (0.03)
Rel-Clip	3.10 (0.11)	1.99 (0.20)	3.04 (0.43)	4.23 (0.56)	4.81 (0.54)
Rel-Intact	3.15 (0.14)	4.32 (0.59)	4.50 (0.54)	5.25 (0.62)	6.26 (1.25)
Keaton Tower Road					
Nrel-Clip	2.27 (0.05)	1.51 (0.04)	1.90 (0.17)	2.35 (0.19)	3.03 (0.36)
Nrel-Intact	2.48 (0.17)	3.04 (0.29)	3.33 (0.57)	4.08 (0.70)	4.43 (0.17)
Rel-Clip	2.75 (0.40)	2.26 (0.27)	3.72 (0.69)	3.93 (1.17)	5.36 (1.19)
Rel-Intact	2.72 (0.31)	3.68 (0.44)	4.79 (1.05)	6.26 (0.97)	8.03 (1.73)
Dummy Line Road					
Nrel-Clip	5.55 (0.03)	--	2.18 (0.10)	2.94 (0.10)	3.57 (0.08)
Nrel-Intact	5.10 (0.28)	--	5.26 (0.36)	5.47 (0.35)	6.01 (0.44)
Rel-Clip	4.14 (1.66)	--	2.53 (0.64)	3.94 (0.83)	4.87 (1.02)
Rel-Intact	4.24 (1.59)	--	4.71 (1.66)	5.98 (1.84)	7.68 (2.25)

[1]Explanation of treatment terms: Nrel = non-released, no midstory or understory vegetation removal; Rel = released, midstory and understory vegetation removed; Clip = clipped advanced cherrybark oak reproduction; Intact = advanced cherrybark oak reproduction was not clipped.

increasing the growth and development of advanced cherrybark oak reproduction.

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THE INFLUENCE OF MIDSTORY-UNDERSTORY CONTROL TREATMENTS ON REGENERATION OF RED OAK SPECIES FOLLOWING CLEARCUTTING [1]

Robert T. Deen, John D. Hodges, and Greg C. Janzen [2]

Abstract. Seven years after midstory-understory control enhanced growth of desirable stems, i.e., oaks (*Quercus* spp.), was observed. Desirable stems clipped and released and desirable stems released only had significantly greater height and root collar size than desirable stems in control plots. Average annual height growth was significantly greater in the clipped plus release plots vs. the release only and the control plots. Height growth response for oaks was delayed for 3 years in the release only plots. The treatment plots were clearcut with all woody vegetation cut to the ground. Two years following clearcutting, coppice oak stems in the clip plus release plots and the release only plots were significantly taller than coppice stems in the control plots. No significant difference existed between treatments for root collar size.

Introduction

Regeneration of oaks has been a difficult ilvicultural task in many instances. Oak regeneration ailures are widespread across eastern North America lue to various circumstances. One reason for lack of ak regeneration success is the inability of oaks to ecome firmly established beneath the overstory prior o harvest. This inability is due, in some instances, o a dense layer of midstory-understory vegetation that ffectively reduces the amount of light reaching the orest floor. This lack of light retards development of ak seedlings which in turn reduces food reserves vital or continued growth and survival.

Efforts to obtain oak seedlings and/or enhance development of oak seedlings in place have been practiced using the shelterwood method (Loftis 1983, Sander and Clark 1971). Results have been inconsistent and it is apparent that alterations to the classical shelterwood method are required. Use of the classical shelterwood has favored the growth of faster-growing intolerant species, i. e., yellow poplar (*Liriodendron tulipifera* L.), over that of oak. Loftis (1983) suggests using a series of lighter cuts that will restrict development of faster-growing, intolerant species and favor oak.

Cherrybark oak (*Quercus pagoda* Raf.), and it is believed other bottomland red oak species as well, grows best under light intensities of approximately 50% shade (Hodges and Janzen 1987) and will grow fairly well even under higher shade levels.

In many southern bottomland hardwood stands mismanagement through diameter-limit cutting or selective harvest has created a dense layer of midstory vegetation. Where a dense midstory is present overstory removal by itself may not sufficiently increase light levels to the forest floor. Removal of the midstory - understory layer of vegetation is necessary to increase light levels reaching the forest floor allowing oak regeneration present to respond. It is well-known that large advance regeneration is critical for successfully obtaining oak regeneration (Loftis 1990, Sander 1972). Johnson (1980) developed a guide to predict hardwood regeneration potential in southern bottomland hardwoods based on the size and numbers of advance regeneration present and the size of severed trees. The highest potential is given to advance regeneration $\geq$ 3 feet tall and trees 2.0 - 10.0 inches dbh. Seedlings $\leq$ 1.0 foot tall are valued the least and chances for their becoming a major contributor to the newly developing stand is low at best (Johnson and Deen 1993). Studies in other geographical regions show that small oak seedlings simply cannot compete with faster-growing, intolerant species following release and will be lost as the stand develops in time (Beck 1970, McQuilkin 1975, Sander 1972).

Another factor of importance is the length of time oak seedlings will persist beneath the overstory. This will determine the timing of treatments necessary to open up the stand and increase light levels enabling oak seedlings present to develop to a size suitable for regeneration. Studies have shown that mortality is

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high over time for oak seedlings germinating *underneath the overstory* (Beck 1970, Johnson 1975) and oak seedlings should be released within approximately 10 years.

Preharvest herbicide use can control a dense midstory-understory, enhance growth, and increase the proportion of seedling-origin desirable stems present (Janzen and Hodges 1985, 1987, Loftis 1983). Once oak advance regeneration reaches a size considered adequate for regeneration purposes, clearcutting is the desired regeneration method (Hodges 1987, Kellison et al. 1981).

This paper updates an earlier study of the response of oak stems to preharvest herbicide control of a dense midstory-understory (Janzen and Hodges 1987) and summarizes stand development 2 years after a complete clearcut.

Methods

The stand used for this study was located within the floodplain of Loakfoama Creek on the Noxubee National Wildlife Refuge in Winston County, Mississippi. The stand contained adequate advance oak regeneration with water (*Quercus nigra* L.) and willow oak (*Quercus phellos* L.) being the primary oak species. The overstory was composed of mainly water oak, willow oak, and hickory (*Carya* spp.) while the midstory consisted of hickory and other less desirable, shade-tolerant species. Sweetgum (*Liquidambar styraciflua* L.) and green ash (*Fraxinus pennsylvanica* Marsh.) as well as many undesirable species were present in the lower story with the oaks. Age of the overstory at the time the study was installed was 100 years. Site index (base age 50) for water and willow oak is 100 feet (Baker and Broadfoot 1979).

Nine 1/5-acre plots were installed with six plots randomly selected for treatment of mid- and understory vegetation. Control plots were located apart from the treatment plots so as to avoid any edge effects. Treatments were assigned as follows:

(1) Inject only. All trees greater than 1.0 inch dbh that were undesirable species and did not contain at least one number three factory grade sawlog (USDA Forest Service 1981) were injected with glyphosate. Desirable species were left intact.

(2) Inject/Clip. Inject/Clip plots combined injection as above plus clipping of the desirable stems to the ground. Undesirable stems too small to be injected but three feet in height or taller were clipped and stump sprayed with glyphosate. Desirable stems that did not contain at least one number three factor grade sawlog were cut to determine if a mor vigorous sprout could be obtained.

(3) Control. Control plots received n herbicidal treatment; midstory and understor remained intact.

Injection and cutting plus stump spraying o undesirable stems was done in the fall of 1983 Cutting of desirable stems was done in the winter o 1983-84. Clearcutting of the major plots took place in the late summer-early fall of 1990 with all woody vegetation cut back to the ground to stimulate sprouting of oak advance regeneration.

Each major plot contained two 1/100-acre circular subplots which were used to monitor changes in the number of stems of advance regeneration following midstory-understory control and after clearcutting. Growth response of individual oaks was measured on fifteen randomly located oaks within each major plot. These trees served as center of a 1/2-meter radius subplot in which all trees were flagged and measured for height and root collar by species. Following clearcutting, only the red oak species present in each of the fifteen randomly located plots were measured for height and root collar diameter. After clearcutting, root collar was measured at groundline and, if necessary, at the point of attachment to the parent stump. Data were analyzed using ANOVA and significance was indicated at the 0.05 level by the F-test.

Results and Discussion

Seven years after midstory-understory control, oak advance regeneration had responded favorably to increased light and coppicing (Table 1). Oak stems in the inject only and inject/clip treatments were significantly taller than oak stems in the control based on flagged tree data. Oak stems in the control had gained little in height growth.

A high proportion of the oak advance reproduction lacked apical dominance (flat-topped) at the time the study was initiated. Coppicing of these stems has produced a vigorous terminal leader capable of immediate response to treatment (Table 2). Average annual height growth of coppice oak stems in the inject/clip treatment was greater than in the inject only and control treatments for all but the last year following treatment. Sprout-origin oak stems in the inject/clip treatment regrew to their average original height prior to treatment 3 years after midstory control (Janzen and Hodges 1987). Oak advance

regeneration in the inject only treatment also responded immediately to release but this response was short-lived. As can be seen (Table 2), height increment of the inject only oak stems slowed in years 2 - 4 following treatment. Beginning with year 5, annual height increment of oak stems in the inject only treatment was much more favorable. The delay in height growth response was probably related to the condition of the seedlings as indicated by the flat-topped growth form. Oak stems in the control fluctuated yearly in height growth increment.

Table 1. *Average heights for red oak[1] stems after 7 years of midstory-understory control and 2 years after clearcutting on the Noxubee National Wildlife Refuge, Winston County, MS.*

Treatment	Pretrt	7 Yrs	Clearcut 2 Yrs
	----------Height (cm)----------		
Inject	48.5a[2]	91.8a	123.5a
Inject/Clip	42.2a	116.4a	123.9a
Control	31.3a	39.7b	84.2b

[1] Red oak species includes the following: cherrybark oak, water oak, and willow oak.
[2] Values followed by the same letter indicates no statistical difference at the 0.05 level.

Table 2. *Average annual height increments for red oak[1] species following 7 years of midstory-understory control on the Noxubee National Wildlife Refuge, Winston Co., MS.*

Year Following Treatment	Treatment		
	Inject/Clip	Inject	Control
	----Annual Height Increment (cm)-----		
1	21.4	15.5	3.5
2	8.3	3.4	−10.9
3	13.8	3.6	0.2
4	22.0	3.5	−0.7
5	16.5	9.4	5.1
6	23.3	16.6	−1.7
7	8.1	10.4	4.2

[1] Red oak species includes the following: cherrybark oak, water oak, and willow oak.

It is important to note that following clearcutting, 80 - 99% of all oak stems present were of sprout origin.

Two years following clearcutting, coppice oak stems in the inject only and inject/clip treatments were significantly taller than coppice oak stems in the control based on flagged trees (Table 1). The average heights of coppice oak stems in all 3 treatments 2 years after clearcutting exceeded the average heights of oak stems in each corresponding treatment prior to clearcutting. The coppice oak stems in the control treatment more than doubled in height following clearcutting. Coppice oak stems in the inject only and inject/clip treatments were only slightly taller following clearcutting as compared to before clearcutting. However, the oak advance regeneration in the inject only and the inject/clip treatments were much taller than oak advance regeneration in the control before clearcutting (Table 1). Therefore, height growth response of coppice oak stems in the inject only and the inject/clip treatments following clearcutting has been considerable, i.e., averaging approximately 62 cm of height growth per year.

Response of oak advance reproduction in root collar diameter has been similar to height growth response based on flagged tree data (Table 3). At time of treatment oak stems in the control were slightly larger than oak stems in the inject only and inject/clip treatments. Seven years after treatment oak stems in the inject only and inject/clip treatments were significantly larger than in the control. The larger root collars for the inject only and inject/clip treatments indicates a larger root system on average for oak stems in these 2 treatments as compared to the control. The larger root system should be significant, biologically, in growth response and, possibly, survivability following clearcutting.

Table 3. Average root collar diameter for red oak species[1] following 7 years of midstory-understory control and 2 years after clearcutting on the Noxubee National Wildlife Refuge, Winston Co., MS.

Treatment	Pretrt	7 Yrs	Clearcut 2 Yrs
	-----Root Collar Diameter (mm)-----		
Inject	4.5a[2]	7.6a	13.3a
Inject/Clip	4.5a	9.8a	12.0a
Control	5.9a	4.4b	10.5a

[1] Red oak species includes the following: cherrybark oak, water oak, and willow oak.
[2] Values followed by the same letter indicates no statistical difference at the 0.05 level.

Root collar diameter was not significantly different among coppice oak stems in the 3 treatments following clearcutting based on flagged tree data (Table 3). Coppice oak regeneration in the control doubled in root collar size following clearcutting while coppice oak regeneration in the inject only and inject/clip treatments showed modest increases in root collar diameter.

The combination of increasing light and *production of oak* sprouts by inject/clipping has been instrumental in increasing the numbers of oak stems per acre by height classes compared to the inject only and control treatments based on the 1/100-acre plots (Table 4). As mentioned previously, the clipping of oak stems has produced a vigorous sprout able to take advantage of favorable light conditions, and, in combination with an already-established root system providing water and nutrients, is capable of rapid initial height growth. The rapid increase in height growth of sprout-origin oak stems provides a competitive advantage over that of newly-germinated oak seedlings and small, flat-topped oak advance reproduction. This competitive ability should enable coppice oak stems to compete more equitably with other forms of regeneration of both intolerant and tolerant species.

Data obtained from the flagged oaks indicated that the control treatment had the lowest survival rates for oak of the three treatments after 7 years of midstory-understory control (Table 5). Oak stems in the control treatments were also the smallest of the 3 treatments (Tables 1 & 3). The lower survival rate for oak stems in the control is probably due to the low light conditions found under the overstory resulting in low food production. Conversely, the higher survival rates of the inject/clip and inject only treatments are probably due to increased light that allows for greater food production. The coppicing of stems in the inject/clip treatment does not appear to have played a role in increasing survivability of oak stems over the 7 year study period.

Two years following clearcutting oak stems in the inject/clip treatment exhibited higher rates of survival than either the inject only or the control treatments. A possible reason for the increased survivability of oak stems in the inject/clip treatment may be due to the sprout-origin nature of these stems. Coppice regeneration from clipping results in the development of a larger oak stem compared to the inject only and control treatments (Table 1 & 3). These larger oak stems seem better able to withstand the rigors of harvesting compared to small oak seedlings and advance regeneration (Johnson and Deen 1993). Also, the larger food reserves in these oak stems enable vigorous sprouts to be produced that are better able to compete with other forms of regeneration.

Table 4. Increase in the number of red oak[1] stems per acre by height classes following 7 years of midstory-understory control on the Noxubee National Wildlife Refuge, Winston County, MS.

Treatment	Height Classes (cm) 0 - 50	50 - 100	101 - 150	>150
Inj/Clip	−5383 (7350)[2]	+567 (683)	+367 (150)	+800 (250)
Inject	+1883 (4917)	+ 67 (583)	+ 33 (100)	+200 (100)
Control	−3817 (5683)	− 17 (417)	+ 17 (50)	+ 33 (50)

[1] Red oak species includes the following: cherrybark oak, water oak, and willow oak.
[2] Number in parenthesis is the original number of stems per acre by height class before treatment.

Summary

Increasing light to the forest floor by controlling the midstory-understory vegetation has resulted in increased growth of oak advance regeneration. Clipping in conjunction with increasing light levels has further enhanced growth of oak advance regeneration. Heights and root collar diameters of oak stems in the inject only and inject/clip treatments are significantly greater than in the control. It is obvious that after 7 years of midstory-understory control oak advance regeneration in the inject only and inject/clip treatments are of a size desirable for regeneration through clearcutting.

Two years after clearcutting, oak sprouts in the inject only and inject/clip treatments are significantly taller than those in the control. Oak stems in all 3 treatments appear to have responded favorably to clearcutting and occupy a dominant position in the newly regenerated stand. Even though coppicing of oak stems in the inject/clip treatments does not appear to have been a major factor in increasing the rate of survival in the midstory-understory control, coppicing has resulted in a large stem better able to survive the rigors of harvest cutting.

Table 5. *Percent survival for red oak[1] species following 7 years of midstory-understory control and 2 years after clearcutting on the Noxubee National Wildlife Refuge, Winston Co., MS.*

Treatment	Mid-Understory Control 7 Yrs	Clearcut 2 Yrs
	--------Survival (%)-------	
Inject	63.4	59.0
Inject/Clip	56.2	79.0
Control	42.1	60.0

[1] Red oak species includes the following: cherrybark oak, water oak, and willow oak.

Acknowledgements

Contribution No. PS - 8186 of the Mississippi Agricultural and Foresry Experiment Station. Authors thank Jim Tisdale and George Chastain of the Noxubee National Wildlife Refuge, Mississippi for their cooperation.

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DEVELOPMENT AND EVALUATION OF A PRACTICAL DECISION-MAKING MODEL FOR SOUTHERN BOTTOMLAND HARDWOOD STANDS [1]

Thomas M. Manuel, John D. Hodges, Keith L. Belli, and Robert L. Johnson [2]

Abstract. A model was developed to aid southern hardwood foresters in separating stands which need regeneration from those which should be managed with the existing trees. The model assigned index values to stands based solely on sample tree characteristics. Threshold values were determined between manageable and unmanageable stands for three sets of management objectives. Indices above a threshold value indicated high management potential, while indices below a threshold value indicated low management potential. Thirteen stands were modelled and the model's decisions were tested against the recommendations of expert foresters for each set of management objectives. Agreement between the model and experts ranged from 76% to 85%, depending upon the management objective tested. A computer program was developed to make data input easier for future users of the model.

Introduction

The initial decision in the management of any forest stand is to determine whether it has the quality, vigor, and stocking to be managed or whether it should be regenerated. This decision is easily made by most foresters when applied to pine stands. When applied to hardwood stands, however, this fundamental decision is often poorly made due to insufficient training of foresters in hardwood silviculture as well as a lack of quantitative hardwood management guidelines. In the near future the demand for hardwood timber is expected to increase dramatically while the supply of quality hardwood growing stock is expected to decrease continually (U.S. For. Serv. 1988). Thus, the need for expert-level decision-making in southern hardwood management is more evident now than ever before.

The objective of the research reported here was to develop and evaluate a practical decision-making model for southern bottomland hardwoods to simulate the initial decision made by an "expert" in hardwood silviculture to either "manage" or "regenerate" a given stand. Several years ago, the need for such a model was realized by Robert L. Johnson, former Project Leader of the USDA Forest Service, Southern Hardwoods Laboratory, and John D. Hodges of Mississippi State University. Through numerous discussions they were able to identify and quantify the mental criteria which they systematically employed when making the "manage" or "regenerate" decision for hardwood stands. Johnson and Hodges gave their ideas to researchers at Mississippi State University who, through extensive modification and testing, developed a system that effectively mimicked expert-level decisions for the management or regeneration of southern hardwood stands. This system has been converted to the model which is the subject of this paper.

Methods

Study Areas

Several bottomland hardwood stands were modelled during the course of the study, all of which were in river bottoms in east-central Mississippi. These areas were selected to cover a wide range of age classes, stocking levels, stand qualities, and species compositions, thereby allowing the model to be tested across various situations common to minor river bottoms in the South.

Within each stand a single, fairly uniform, circular plot was chosen for the modelling of a certain forest condition. Whenever possible 1.00-acre plots were modelled. In a few instances, however, plot size was restricted to .0.25 or 0.50 acres to avoid overlapping timber types within a plot. Only trees 5.1 inches or greater in diameter at breast-height (DBH) were evaluated for inclusion in the model. In an attempt to keep the model practical the variables were

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tallied in a fashion easily incorporable into a standard timber cruise.

Tree Groups

The trees on each plot were categorized by their management potential into three broad groups: growing stock, poles, and cutting stock and culls. The growing stock group consisted of trees 12-inches DBH and larger that were merchantable or potentially merchantable. Growing stock were tallied by diameter (2-inch classes), tree class (preferred or reserve, derived from Putnam, et al. 1960), crown class (Smith 1986), grade of butt log (U.S. For. Serv. 1981), vigor (Hodges, et al. unpublished), merchantable height (1/2-log increments), and species.

Trees in the 6, 8, and 10-inch diameter classes were placed in the pole group. Due to extreme subjectivity in predicting their future grade, merchantability, and canopy position, poles were treated differently within the model from the growing stock. Poles of desirable or acceptable species that had a terminal leader present, were not flat-topped, had at least medium vigor, no apparent rot, and the potential to produce quality sawtimber were recorded for input into the model and only their DBH and species were recorded. Those poles that were lacking in any of the above characteristics were not recorded and had no impact on the modelling decision.

The cutting stock/cull group consisted of trees 12 inches DBH and larger that were merchantable, but were in the cutting stock tree class (Putnam, et al. 1960), or were unmerchantable culls due to poor form, grade, or non-acceptable species preference class. Species, DBH, and merchantable height were tallied for cutting stock trees but only the species and DBH were tallied for culls.

Decision Model

The decision-making model developed through this study consisted of three components: 1) variable ownership objectives 2) a series of mathematical functions, and 3) a threshold value for each set of objectives that separated manageable stands from those needing regeneration.

Three sets of management objectives were used to test the flexibility of user input. The main objective in all three sets of objectives was sawtimber production. The objectives differed in terms of whether or not a maximum allowable diameter was imposed and whether or not sweetgum (*Liquidambar styraciflua* L.) poles were acceptable. Specifically, the objectives were as follows:

Ownership Objective 1

a) 26-inch maximum allowable DBH
b) all sweetgum were acceptable

Ownership Objective 2

a) 26-inch maximum allowable DBH
b) sweetgum less than 12 inches were not acceptable

Ownership Objective 3

a) No maximum DBH restriction
b) sweetgum less than 12 inches were not acceptable

A series of mathematical functions condensed the decision-making variables used by expert hardwood foresters into a single stand index value. A stand's index was based on its stocking level and the quality and vigor of its trees. The model combined these characteristics in such a way that the stands were indexed from zero to over 100. A stand index near zero was indicative of a condition for which no option other than regeneration existed. Alternatively, an index near 100 represented a stand well qualified for continued management. For a detailed description of these functions, see Manuel et al. (1993).

During the course of the study, threshold values between management and regeneration were determined by comparing the stand index values generated by the model against the decisions of a panel of three hardwood silviculture researchers. This panel reviewed the stand conditions represented by each study plot for each objective and individually indicated whether each stand should be regenerated or managed within the next ten years. Those stands which were invariably given high stand index values by the model (65 to 100+ points) were consistently regarded as manageable by the panel. Similarly, those stands which were always given low index values (0 to 30 points) by the model were deemed to be in need of regeneration by the silviculturists. It was within the mid-range in terms of index values (30 to 65 points) that threshold values were set for each ownership objective to separate those stands in need of regeneration from those which did not.

As stand index values decreased from 65 to 30 points, there was a point at which the majority of the panel members no longer recommended management,

but rather recommended regeneration of a given stand. For each objective, the threshold value was set between the value of the stand with the lowest index that the majority of the panel recommended management, and the value of the stand with the highest index that the panel decided to regenerate. Based on the decisions of the preliminary panel of silviculturists, the threshold value between management and regeneration was determined to be 50, 35, and 44 index points for Objectives 1, 2, and 3, respectively.

After the threshold values were established by the decisions of the first panel, an independent panel of 10 to 12 professional hardwood foresters reviewed each of 13 study plots and made the requisite "manage" or "regenerate" decision for each stand within the next ten years, for each set of objectives. The only regeneration system they were allowed to consider was a clearcut. Their decisions were used as the criteria for testing the model's "recommendations".

Results and Discussion

Management Objective 1

The model indicated that seven of thirteen stands had indices above the threshold and were thus manageable under the first set of objectives. The majority of experts also considered these stands manageable. Furthermore, the experts were in complete agreement to manage those four stands which the model considered most manageable (i.e. had the highest stand indices).

The model placed six stand indices below the threshold value for Management Objective 1 and the majority of experts agreed to regenerate four of these stands. However, the experts were evenly split in their decisions regarding the remaining two stands. The model ranked these stands well below the threshold. As in the manageable case, however, those stands placed on the far end of the regenerate scale by the model were definitely in need of regeneration according to the experts.

Overall, for Management Objective 1, 126 out of 148 expert decisions were in agreement with the model. Therefore, the model was considered approximately 85 percent accurate, when using the first objective. Because the experts were almost entirely in agreement with the model for those stands placed at both extremes of the index scale, the model is unlikely to "recommend" poor decisions to its users for this objective.

Management Objective 2

The model placed six of thirteen stands in the manage range and the other seven in the regenerate range for the second set of objectives. For all but one of the stands which the model indicated as manageable, the majority of the experts were in agreement to manage. The experts were largely in agreement with the model on all other stands which needed regenerating under this set of objectives.

Overall, for Management Objective 2, the experts agreed 124 out of 148 times with the model which gave the model 84 percent accuracy. As with the first objective, those stand indices farthest from the threshold had the strongest agreement with the experts. Therefore, it is likely that the model will not recommend incorrect actions on very manageable or very unmanageable stands when using this set of objectives.

Management Objective 3

For the third set of objectives, the model placed six stands in the manage category and seven in the regenerate category. A majority of experts were in agreement with the model for all but one of the six stands above the threshold and the seven stands below the threshold for the third objective. The experts agreed with the model 83 percent and 71 percent for management and regeneration, respectively.

Across all stand conditions modelled, 113 of 148 expert decisions were in agreement with the model's results for Management Objective 3. Thus, the model was considered 76 percent accurate with this objective. This was the lowest for the three sets of objectives tested. The fact that the experts had more split decisions on this objective than the others indicated that even expert foresters have difficulty in determining biological maturity. As with the other objectives, the stands for which there was little question among the experts to regenerate or manage were properly assessed by the model.

All Objectives

For the thirteen stands reviewed by experts with three sets of objectives per stand, a total of 444 decisions were made. Of these the experts agreed with the model 363 times. Therefore, the model was found to be approximately 82 percent accurate across the wide range of conditions encountered on the modelled stands. To the model's credit, most of the disagreement with the experts was on stands which

could arguably be managed or regenerated within the next ten years. On stands with very high or very low management potential, on the other hand, the model and experts were very consistent in their decisions.

The Computerized Model

Following development and evaluation of the model it was converted into a stand-alone, executable program for IBM-compatible personal computers. The program, named "HARDWOOD", was written to enable future users of the model to easily input data and read direct, easily-interpreted results. Plot-by-plot data may be entered into HARDWOOD and the results are presented as plot index values, an overall stand index, a decision of "manage" or "regenerate" (relative to the selected management objective), and a 95% confidence interval about the stand index value.

Summary and Conclusions

Through the course of this study, a decision-making model was developed for determining whether or not southern bottomland hardwood stands should be managed with the trees present or regenerated within the next cutting cycle. The model was driven by three components that described the potential contribution of each tree to the stocking of the stand, modified by quality and tree class. The sum of the individual tree values was used to assign a numerical index to the stand. Threshold indices for management or regeneration were identified for each of three sets of management objectives.

Decisions by the model were evaluated against those of a panel of experienced hardwood foresters. Eighty-two percent of the experts' decisions were in agreement with the model, which was most accurate when assessing stands with very high or very low management potentials.

Following development and subsequent testing of the model's results, a computer program was written to make the model easier to use. The program is still in need of slight refinement, but should soon be ready for distribution through the Mississippi State University School of Forest Resources. It is the hope of the authors that this program will be used by practicing foresters to enhance their decision-making skills in southern hardwood stands. Although the decision of whether to manage or regenerate a given stand may seem simple, it is nonetheless a preliminary decision which must be made before any further silvicultural decisions can be made. Furthermore, there are many foresters who lack sufficient knowledge of hardwood silvics to correctly make this basic decision. The model can serve as a training tool for inexperienced foresters and as a decision model for management of hardwood stands.

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Wetlands: Harvesting Impacts

Moderator:

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National Council of the Paper Industry
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FIELD TOUR PREVIEW POSTER PRESENTATION: INFLUENCES OF TIMBER HARVESTING ON WETLAND FUNCTIONS IN LOW ORDER, BLACKWATER FLOODPLAIN SYSTEMS [1]

B.G. Lockaby, R.H. Jones, F. Thornton, R.G. Clawson, D. Brown, A.J. Griffin, and S. Lloyd [2]

Abstract. Increased demand for hardwoods has intensified harvesting activity on wetland sites that, a decade ago, were ignored as a potential source of fiber. An example of these site types include narrow floodplains of low-order blackwater streams which may be occupied by deciduous stands that have developed on organic soils. Due to uncertainty regarding potential influences of harvesting activity on productivity and environmental quality functions in these systems, a multi-disciplinary study was installed to evaluate harvest effects. Two types of harvests (aerial and ground-based) were compared in terms of their impact on regeneration, decomposition, mineralization of N and P, water quality, denitrification, and faunal and microbial populations (i.e. amphibians and blue-green algae) which may serve as bio-indicators of disturbance. Processes associated with each response variable were compared among plots representing (1) undisturbed conditions, (2) ground-based systems, (3) aerial harvesting. Results have been summarized through one growing season following harvests.

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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EFFECTS OF SKIDDER COMPACTION AND RUTTING ON SOIL PHYSICAL PROPERTIES AND WATER TABLES IN A SOUTH CAROLINA WETLAND [1]

W. M. Aust, M. D. Tippett, J. A. Burger, W. H. McKee, Jr. [2]

Abstract. Six wet pine flats were salvage-logged following Hurricane Hugo in the fall of 1989. High soil moisture conditions during the salvage operations resulted in soil compaction and deep rutting (puddling) within primary skid trails. Two studies were established to assess the effects of rubber-tired skidder trafficking on soil physical properties and water tables. One study addressed sites that had been compacted, the other study addressed sites that had been rutted (puddled). Each study consisted of three sites (blocks) from which plots were sampled in trafficked and nontrafficked areas. Effects of trafficking on soil properties and water tables were tested by comparing trafficked and nontrafficked plots. Soil compaction resulted in an increase in soil bulk density and a decrease in soil porosity (macro-, micro-, and total), depth to the water table, and saturated hydraulic conductivity. Rutting resulted in an increase in bulk density and a decrease in the depth to the water table, depth of reducing conditions, soil porosity, and saturated hydraulic conductivity. Both compaction and rutting decreased the amount and time of soil aeration by reducing internal water movement. Reduced water and air flow could reduce site productivity.

Introduction

Forest harvesting operations on wet sites have the potential to compact and puddle a site, and these disturbances may result in reduced site productivity (Hatchell et al. 1970, Lockaby and Vidrine 1984, Wert and Thomas 1981, Murphy 1983). Compaction and rutting (puddling) occur at different levels of soil moisture (Greacen and Sands 1980) and the two disturbances may have different effects on soil physical properties. An understanding of the conditions necessary for rutting and compaction and the consequences of each can help the forest land manager avoid, minimize, or mitigate potential problems associated with each.

Numerous investigations have revealed that forest machine trafficking may have little effect on drier soils, yet, moist soils are readily compacted (Greene et al. 1983; Koger et al. 1984; King 1979; Campbell et al. 1973; Hatchell et al. 1970; Lockaby and Vidrine 1984; Wert and Thomas 1981; Murphy 1993). Compaction usually occurs when a soil is at or near field capacity. When a soil is near field capacity cohesive forces of the soil are reduced and the soil's ability to support heavy loads is reduced (Akram and Kemper 1979).

Deep rutting (puddling) generally accompanies forest harvesting operations on very wet to saturated sites. A soil near saturation has very low shear strength and shear failure may occur when a load is applied. Under these conditions soil moisture has reached the liquid limit and flows when trafficked. The liquid nature of the saturated soil results in soil churning and physical displacement, as opposed to compaction (Burger 1989), and results in the destruction of soil aggregates (Sharma and DeDatta 1986). The changes in soil physical properties resulting from compaction versus rutting could cause different hydrologic responses on wetland sites. Therefore, the objective of this research was to determine and contrast the effects of soil compaction and deep soil rutting (puddling) on soil physical properties and hydrologic characteristics.

Methods and Procedures

The study sites were located in the Coastal Plain region of South Carolina on the Wambaw District of the Francis Marion National Forest. The original forest stand was longleaf (Pinus palustris) and loblolly pine (Pinus taeda) and site indices were approximately 90 feet (base age 50 years). All study sites had been salvaged logged under wet soil conditions in response to Hurricane Hugo and had obvious primary skid trails. Overall, the salvage logging operations were similar to commercial

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Assistant Professor, Graduate Research Assistant, and Professor, Virginia Polytech. Instit. and State Univ., Blacksburg, and Soil Scientist, U.S. Forest Service, Wetland Research Center, Charleston, SC.

clearcutting operations. Dominant soil series included Bethera (clayey, mixed, thermic Typic Paleaquults), Rains (fine-loamy, siliceous, thermic Typic Paleaquults), Lynchburg (fine-loamy, siliceous, thermic Arenic Paleaquults), and Goldsboro (fine-loamy, siliceous, thermic, Aquic Paleudults). Topography was nearly level (1-2 % slope).

Three sites with compacted primary skid trails and three sites with rutted skid trails were located. The three compacted sites were moderately well to poorly drained. Soils consisted of loamy sands to loam surface horizons overlying sandy clay loam subsoils. Compacted study sites were identified as having no evidence of churning and soil displacement. A typical skid trail on this type of site consisted of a depressed area, without deep ruts or displaced soil.

The three rutted and puddled sites were somewhat poorly to poorly drained. Soil surface horizons ranged from sandy loam to loam; subsurface horizons ranged from sandy clay loam to clay. Soil displacement, in the form of berms, was evident along all primary skid trails on these sites. Skid trails on these areas were deeply rutted and soil was deposited on either side of the rut.

Soil compaction and rutting were assessed by two parallel studies, each consisting of a completely randomized block design with three blocks. Treatments consisted of nontrafficked and trafficked (primary skid trails) areas. Four measurement plots were established on each block (Figure 1). Each measurement plot measured 80 feet (along the skid trail) by 20 feet and four 20 foot transect lines were randomly established across each plot to measure the disturbance profile (Figure 2).

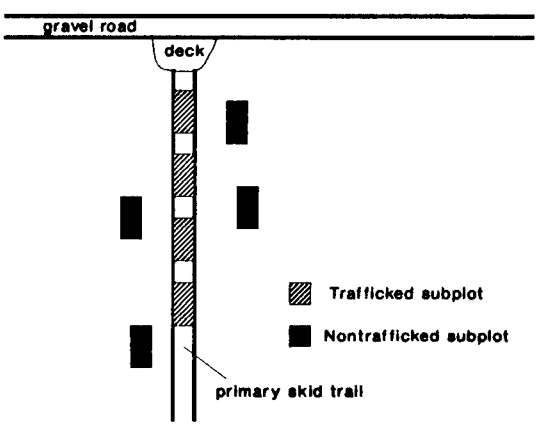

Figure 1. *Example of the layout of 1 site (block).*

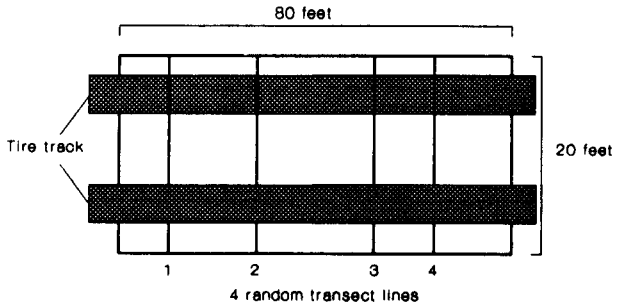

Figure 2. *Example of the layout of 1 trafficked subplot.*

The following measurements were taken along each transect line. Soil surface profiles were taken from a leveled line at 6-inch intervals. Each point was classified as tire track, berm, or between tracks within the trafficked subplots. The control plots were all classified as nontrafficked. Soil core samples (4-inch depth) were taken from areas of each disturbance class, and these samples were subsequently analyzed for saturated hydraulic conductivity (constant head method, Klute and Dirksen 1986), soil pore space (total, macro, micro-) (Danielson and Sutherland 1986) , and bulk density (Blake and Hartge 1986). Augered water table wells and steel rods were installed in the tire track, between the tire tracks, and in the nontrafficked control areas. The auger hole wells were used to monitor water tables (biweekly) (Faulkner et al. 1989) and the steel rods were used to obtain a measure of the average depth of reduced conditions (biweekly) (McKee et al. 1978, Hook et al. 1987).

Results and Discussion

An examination of the rutted (puddled) skid trails revealed that on an average 80- by 20-ft. plot 53% was berm, 43% was within the rutted tire track and 4% was in the unbermed trail center where logs were dragged. The rutted tire track exposed the denser and less fertile subsurface soil and the berm areas were a mixture of mixed a composite of surface and subsurface soil material. The central area of the disturbance where logs had been dragged was not compacted; however, surface soil had been removed.

The shallowest ruts were over 10 inches deep, and average rut depth approached 16 inches. Ruts of this depth may not be filled in by common site preparation disks and may require bedding or dozing in extreme cases.

Rut profiles of compacted sites soils revealed a more uniform and less severe disturbance than the rutted sites. Compacted skid trails had no distinct berms and soil removal by dragged logs was not as evident. The compacted trails consisted of depressions ranging from 2 to 8 inches deep. In these areas, soil was actually compressed instead of being displaced. Approximately 85 % of the compacted trails was in the tire track and 15% was located in the log-drag zone.

Soil bulk densities of the trafficked and nontrafficked areas were compared for both the rutting and compaction studies. Rutting significantly (alpha = 0.05) increased the soil bulk density within the actual tire track, but did not increase the bulk density between the tracks (Figure 3). Mean bulk density of the nontrafficked control area, between the tire track, and in the tire track were 1.04, 1.03, and 1.39 Mg/m3, respectively. Within the compacted sites, trafficking significantly (alpha = 0.05) increased bulk density within both the tire track and in between the tire tracks compared to the non-trafficked control area. However, within the compacted sites, bulk density values at less than 1.2 Mg/m3 were still below the critical values at which root growth becomes limiting. The tire track bulk density within the rutted tire track was approaching 1.4 Mg/m3, a value which may be limiting to root growth, but this higher value is probably a reflection of the inherent density of the subsoil that made up the bottom of the track rather than being a function of rutting disturbance.

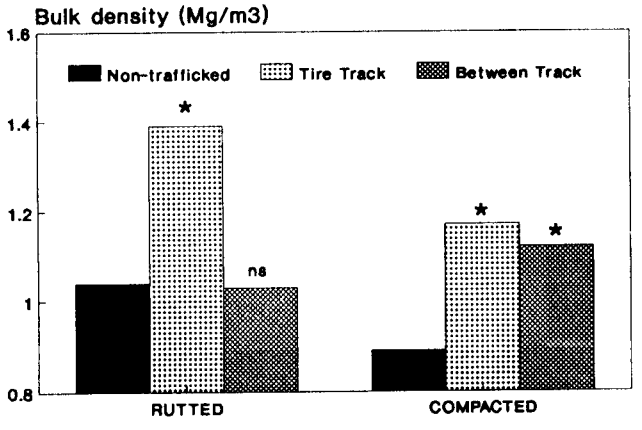

Figure 3. *Average bulk density of rutted and compacted sites.*

Micropore space refers to pores smaller than 0.06 mm in diameter which retain water against the force of gravity. Macropores are larger than 0.06mm and drain under gravitational force and fill with air. Pore space (total, micropore, and macropore) was reduced by both types of disturbance, rutting and compaction (Figure 4). As a soil is trafficked under moist or wet conditions, the macropores collapse. The reduction of macropore space means that these already-wet sites now retain more water than before, reducing aerated pore space well below 10%.

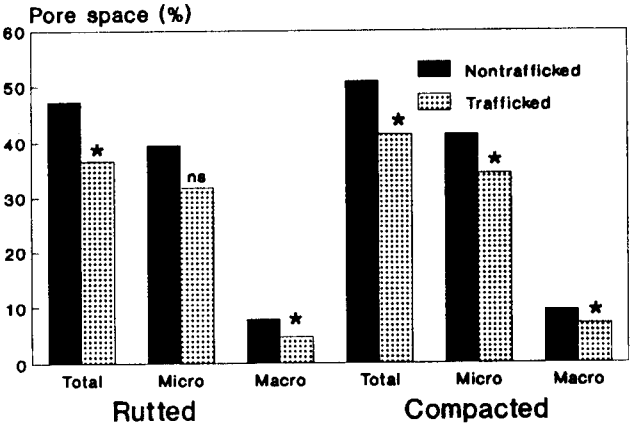

Figure 4. *Average porosity of rutted and compacted sites.*

Saturated hydraulic conductivity (Ks) was initially low on the rutted sites, below 10 cm/hr (Figure 5). This lower average Ks value partially explains why these rutted sites were wetter and also why they were originally more subject to rutting and puddling. Following trafficking, the rutted sites had Ks values below 1 cm/hr, an extremely slow rate. Ks values within the compacted sites responded similarly to trafficking. These sites initially had higher Ks values (2X) than the rutted sites, but trafficking reduced Ks values to below 3 cm/hr (Figure 5).

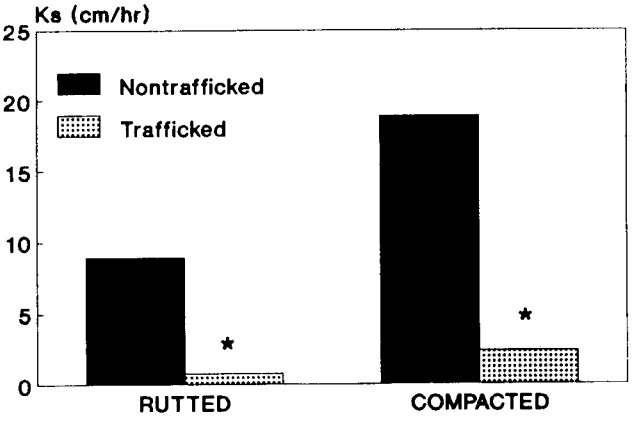

Figure 5. *Average saturated hydraulic conductivity of rutted and compacted sites.*

This dramatic reduction of Ks means that the sites will drain more slowly and less thoroughly. The water tables of the compacted sites reflected the

slower drainage (Figure 6). The water table of the nontrafficked plots was used as a normalized control value; all water tables were corrected for elevational differences. Compaction of the moderaly well-drained (MWD) site resulted in a large increase in the relative water table level (Figure 6). Water tables were 35-45 cm higher on the somewhat poorly drained compacted sites, and the poorly drained (PD) site was least affected, having increased by only 5-10 cm.

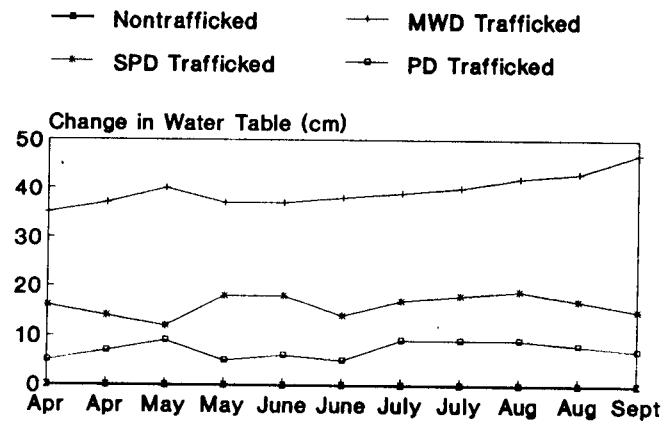

Figure 6. *Relative response of water table to compaction.*

Water table levels of the rutted (puddled) blocks responded similarly to disturbance. The relative water table change was greatest on the somewhat poorly drained site, while only small changes occurred on sites that were poorly drained (Figure 7).

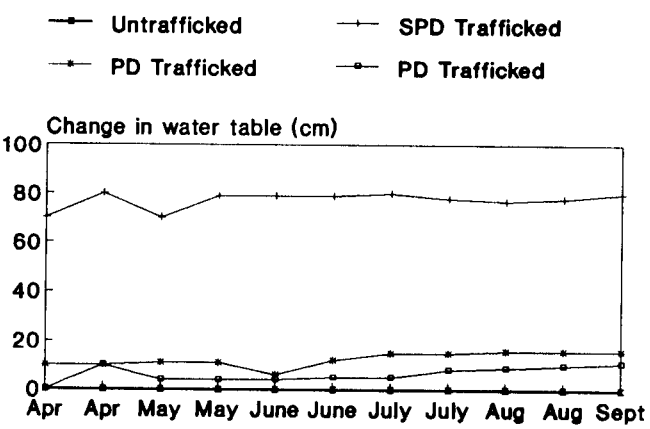

Figure 7. *Relative response of water table to rutting.*

The increases in the relative depth of the water tables within the compacted and rutted areas implies that soil aeration will not be as great within the skid trail as in nontrafficked areas. The depth of rust on steel rods was used as an indication of the relative oxidation-reduction status of the soil. Overall, rust occurred closer to the soil surface in the trafficked areas than in the nontrafficked areas (Figures 8 and 9). This was more pronounced in the rutted (puddled) areas than in the compacted areas, especially during early and late summer.

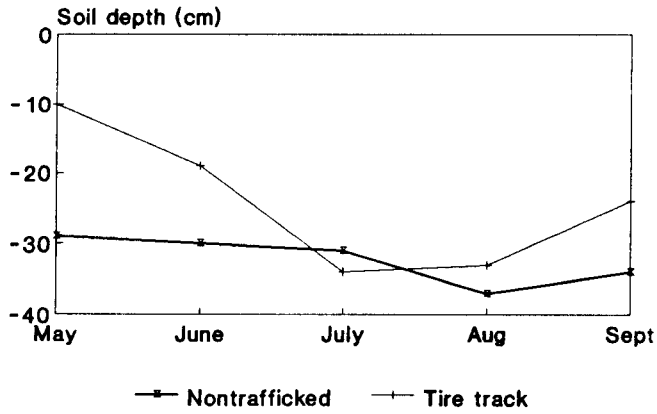

Figure 8. *Effect of rutting on depth of rust on steel rods.*

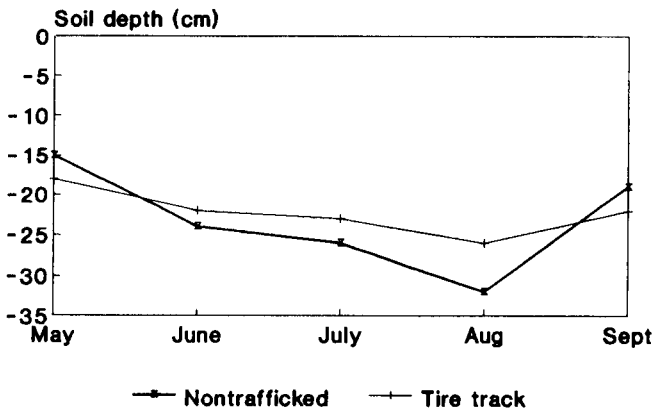

Figure 9. *Effect of compaction on depth of rust on steel rods.*

Conclusions

Visually, the rutted areas appeared to be more highly disturbed than the compacted areas, and measurements of soil physical and hydrologic properties verified this. Neither compaction nor rutting had an important effect on soil bulk density as density affects root exploitation of the soil volume. The compacted area bulk density values were relatively low, even after trafficking, due to the high sand and organic matter content of these surface soils. Macropore space values were initially low on all sites and trafficking further accentuated the problem, resulting in decreased saturated water flow (Ks), increased water table levels, and decreased soil aeration. The decreases were greatest in the areas which initially had the best drainage. This suggests

that trafficking on better-drained sites under moist or wet conditions may result in more serious change than sites having poorer natural drainage. Upland studies of the effects of trafficking on tree growth have tended to concentrate on problems associated with soil strength. On these wet sites, the more serious consequences of rutting or compaction are reduced air and water movement. The reduction in aeration can have serious effects on tree growth and the decreased drainage may reduce the opportunity for silvicultural operations. Site preparation and fertilization are possible but uncertain solutions. The effects of these and other ameliorative techniques should be evaluated. In any case, avoidance of the disturbances is the preferred solution.

Acknowledgements

This project was conducted and supported by the U.S. Forest Service and the Department of Forestry, Virginia Tech.

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TIRE PERFORMANCE AS A FUNCTION OF WIDTH AND NUMBER OF PASSES ON SOIL BULK DENSITY AND POROSITY IN A MINOR STREAM BOTTOM [1]

W.M. Aust, T.W. Reisinger, B.J. Stokes, and J.A. Burger [2]

Abstract. The use of wide skidder tires offers a possible mechanism for reducing site impacts of mechanized harvesting operations in wetlands. A minor stream bottom in southern Alabama was selected as a study site for the evaluation of the soil impact associated with seven different skidder-tire sizes, ranging from 28-inch-wide singles to 43-inch-wide duals. Four levels of trafficking were evaluated for each tire size: 0, 1, 3, and 7 passes. Each tire size and traffic level were replicated twice. Soil disturbance was quantified by measuring soil bulk density, soil porosity, and saturated hydraulic conductivity. Overall, when starting soil moisture was accounted for (covariate analysis), no clear advantages were gained by using wider tires on this site with soil moisture contents near saturation. However, disturbance level increased proportionately with level of trafficking.

Introduction

Skidders equipped with wide tires are more operationally productive on wet sites. The use of wide tires can also be used under some conditions to avoid or minimize site damage. Most studies addressing this issue have been conducted on upland sites. Few studies have compared soil impacts associated with different tire sizes on wetland sites.

Burger et al. (1989) compared the effects of skidder harvesting as affected by tire size and number of passes on a wetland site in Georgia. Three tire sizes (28-, 34-, and 44-inch-wide tires were used for 0, 1, 3, 9, and 27 passes in the same skid trail. Their study detected no benefit from using the wider tires relative to impacts on soil physical properties. The major benefit of wide tires based on their study was that more passes could be made before severe rutting occurred. Aust et al. (1991) evaluated two tire widths and three levels of trafficking for skidders operating on wet organic soils in Alabama and concluded that wider tire widths offered marginal advantages for reducing site impacts. The purpose of this project was to compare the effects of an even broader range of tire widths on soil physical properties when mineral soils were trafficked under saturated conditions.

Methods and Procedures

The study site was located in southwestern Alabama (Butler County) in a mixed pine - bottomland hardwood stand on the floodplain of the Pigeon River. Soils were classified as Bethera series (clayey, mixed, thermic, Typic Paleaquults). This site was poorly drained and is typical of Coastal Plain minor stream bottoms, having a sandy loam surface horizon overlying a finer-textured subsoil (clay loam).

Seven tire widths and 4 levels of passes composed the study treatments. Tire widths evaluated included:

1) 28-inch-wide single tires,
2) 43-inch-wide single tires with 12 (low) PSI of air pressure,
3) 43-inch-wide single tires with 25 (high) PSI of air pressure,
4) 50-inch-wide single tires,
5) 28-inch-wide/23-inch-wide dual (51-inches) tires,
6) 30.5-inch-wide dual (61-inches) tires, and
7) 43-inch-wide dual (86-inches) tires.

Originally a 68-inch-wide tire was included in the study but the soils found on replications of this tire had significantly lower plastic limits. Therefore it was eliminated from the analysis because the tire effect was confounded by soil type. The 28-inch-wide

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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tire would normally be used only on drier sites, but, was included in this study for contrast. The dual 43-inch-wide tires are not used operationally, but were also included to obtain a broad spectrum in tire width.

Traffic levels included 0, 1, 3, and 7 passes. A pass consisted of one loaded trip through a sampling station; the same load (i.e. 2 pine log lengths) was pulled for all trips. All tires were mounted on the same Franklin 170 cable skidder. All treatments were applied under saturated to near saturated soil conditions; volumetric water contents taken immediately prior to treatment application averaged 44.0 %.

The two replications and 7 tire sizes required 14 treatment plots. Sixteen treatment plots were located and tire-width treatments were randomly assigned. Each treatment plot was 22.5 feet wide and bounded by a post positioned at either end. Prior to trafficking, undisturbed soil (0 pass) measurements were collected. An aluminum I-beam was mounted from the posts and leveled. Soil-surface profile measurements were then taken from the I-beam. Five soil-core stations were established along the I-beam. At each soil-core station, 2-inch diameter x 2-inch long soil cores were taken at 0-2, 4-6, and 8-10 inch soil depths.

Data for 1, 3, and 7 passes were collected in the following manner: the I-beam gate was opened and the loaded skidder was driven through for the appropriate number of passes. The I-beam was repositioned at the same level and soil surface profiles were measured. Soil disturbance categories were established that included outside berms, inside berms, tire track (inside and outside for duals), and the log-pull area located between the tire tracks. Soil cores were taken at the 0-2 inch soil depth in the soil disturbance areas which were present. The data reported in this preliminary paper include only those from the tire track samples.

Approximately 1000 soil cores were taken for the study. Each core was used to determine saturated hydraulic conductivity (Klute and Dirksen 1986), soil total pore space and macropore space (Blake and Hartge 1986), and bulk density (Danielson and Sutherland 1986). Soil from cores corresponding to a replication, tire width, pass, and soil depth were combined and these composite samples were used for soil particle size analysis and Atterburg limits.

The study was analyzed as a split-block design (Steele and Torrie 1980) with tire-width forming the main treatment and traffic level (passes) forming the split treatment. Pretreatment (0 passes) measurements and of volumetric soil water contents were included as covariates when found to be significant ($p < 0.15$).

Results

A summary of the results of the covariate analyses is presented in Table 1. Several parameters were originally included as covariates, but only those covariates having p-values less than or equal to 0.15 were retained in the ANOVA. After the analyses were completed, tire widths and traffic level means were separated via a Fisher's Mean Separation Test (alpha = 0.10 for tire width, 0.15 for traffic level). These tests were used to generate the data presented in Figures 1-6.

Pretreatment bulk density values averaged 1.03 Mg/m3, with a 95% C.I. of 1.01 to 1.06 Mg/m3. Soil bulk density values were altered by tire width and traffic level, but there was no significant interaction (Table 1). The mean soil bulk density resulting from trafficking by the various tires ranged from 0.89 to 1.36 Mg/m3. There was a complicated trend relating the width of the single or dual tires to bulk density values (Figure 1). The narrowest tire (28-inches) had the highest mean bulk density as expected.

Table 1. *Summary of covariate analysis of variance.*

Treatment	Parameter	P-value
Tire width	bulk density[1]	0.052
	total pore space[2]	0.050
	macropore space[3]	0.189
	hydraulic conductivity[4]	0.385
Traffic level	bulk density[1]	0.069
	total pore space[2]	0.069
	macropore space[3]	0.057
	hydraulic conductivity[4]	0.710
Tire X Pass	bulk density[1]	0.353
	total pore space[2]	0.190
	macropore space[3]	0.564
	hydraulic conductivity[4]	0.290

[1] Pretreatment bulk densities used as covariate.
[2] Pretreatment total pore space used as covariate.
[3] Pretreatment macropore space and volumetric water content used as covariate.
[4] Pretreatment saturated hydraulic conductivity used as covariate.

The 43-inch wide tire with only 12 PSI of air pressure, performed as well as using a dual 43-inch wide tire combination, and both had lower bulk density values than the single 43-inch wide tire using

25 PSI of air pressure. Both of the intermediate-width dual combinations (28-23 duals and 30.5 duals) resulted in intermediate values of bulk density following trafficking. Overall, bulk density values were lowest for the ultra wide 43-inch-wide duals and the high floatation 50-inch wide tire and were highest for the narrow 28-inch-wide tires. Although there were some small differences in bulk density caused by different tires, there was no trend with increasing tire width. Bulk densities fell within a narrow range with a low average value. This low average value was a level that should have little or no adverse effect on plant growth. The results are consistent with the fact that bulk density is buffered against change when soils are very wet.

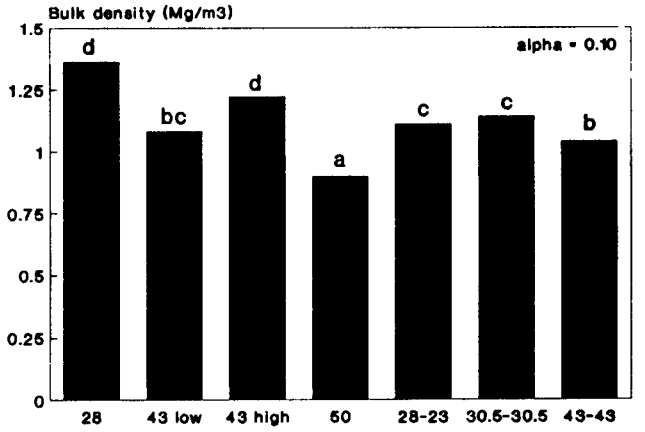

Figure 1. *Average soil bulk density values by tire width.*

Soil bulk density increased with increasing levels of traffic. After one pass, soil bulk density values averaged 1.06 Mg/m3 and were significantly lower than those found after three or seven passes (1.12 and 1.18 Mg/m3, respectively) (Figure 2). The small overall change in bulk density shows again that very wet soils are not easily compacted and that soil compaction as measured by bulk density is not a manifestation of site disturbance on very wet sites.

Pretreatment total pore space averaged 60.9 % with a 95% C.I. of 60.0 to 61.8 %. Total pore space was significantly affected by tire width and traffic level but there was no significant interaction between tire width and traffic level (Table 1). Mean adjusted total porosity values following treatments ranged from 50 to 67 %. The highest total porosity was maintained by the 50-inch-wide tires, the tires which caused the least compaction (Figure 3). The lowest total porosity values following treatment occurred where the 28-inch-wide tires were used (Figure 3). Again, the use of lower air pressure in the 43-inch-wide tire appeared beneficial. Also, the intermediate-width duals (28-23 and 30.5 duals) resulted in intermediate values of total pore space (Figure 3).

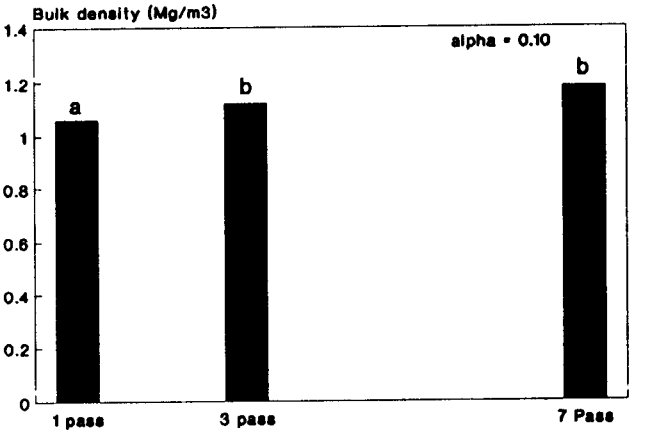

Figure 2. *Average soil bulk density values by traffic level.*

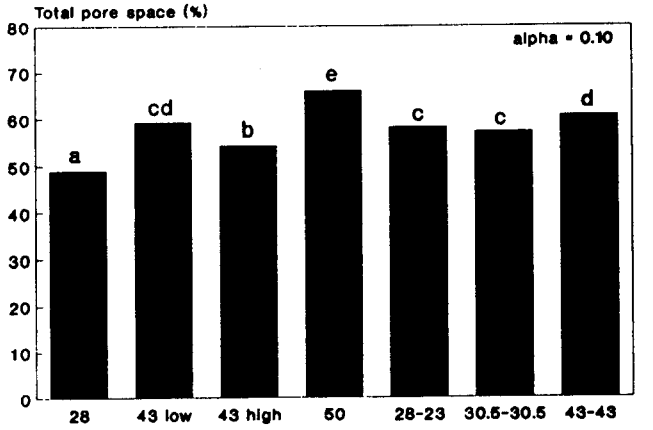

Figure 3. *Average total pore space by tire width.*

Not surprisingly, increased traffic levels resulted in decreased total pore space (Figure 4). The highest total pore space was found following 1 pass and lowest total pore spaced occurred after the highest level of trafficking (7 passes). The 3 pass traffic level had intermediate values. Like bulk density, absolute change in total pre space was small.

Prior to treatment, macropore space averaged 19.2%. Mean macropore space values after treatment ranged from 16 to 23 % and were not significantly affected by tire width (Figure 5). Increasing traffic levels decreases macropore space (Table 1). Both 3 and 7 passes had significantly lower macropore space than 1 pass (Figure 6).

Saturated hydraulic conductivity values were low prior to trafficking. Pretreatment hydraulic conductivities averaged 6.2 cm/hr and the 95 % CI ranged from 4.3 to 8.1 cm/hr) and were not significantly affected by either traffic level or tire

width (Table 1, Figures 7 and 8). Often there is a good correlation between decreases in macropore space and decreases in saturated hydraulic conductivity; however, these soils already had low Ks values. On sites which already have low Ks (i.e., 3-8 cm/hr) values, operation of heavy equipment will have little further impact on internal water movement. Areas having higher rates of internal water movement are more subject to skidding impacts (i.e., well- to somewhat poorly drained sites logged when wet).

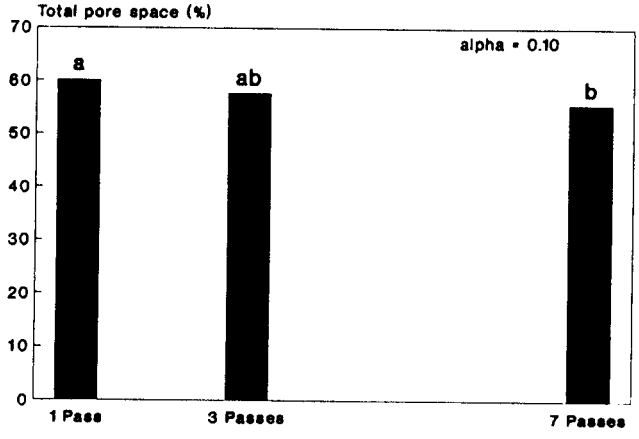

Figure 4. *Average total pore space by traffic level.*

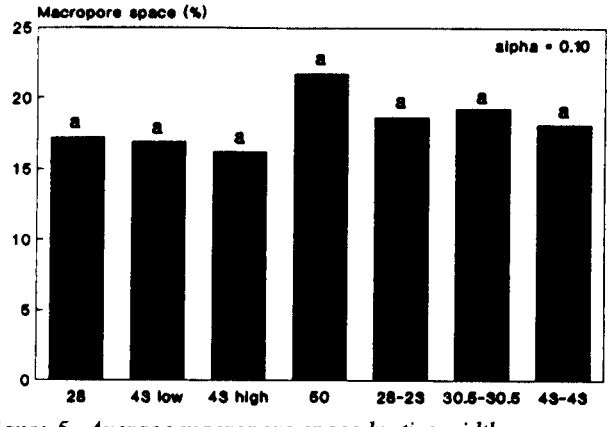

Figure 5. *Average macropore space by tire width.*

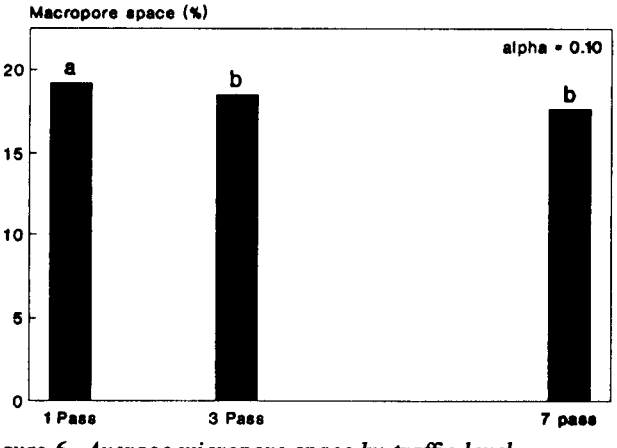

Figure 6. *Average micropore space by traffic level.*

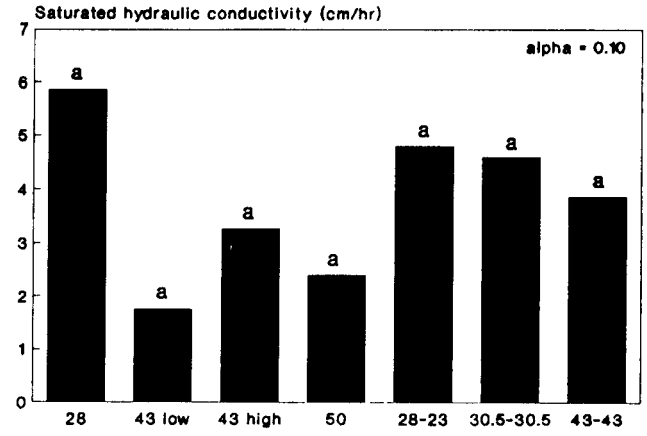

Figure 7. *Average saturated hydraulic conductivity by tire width.*

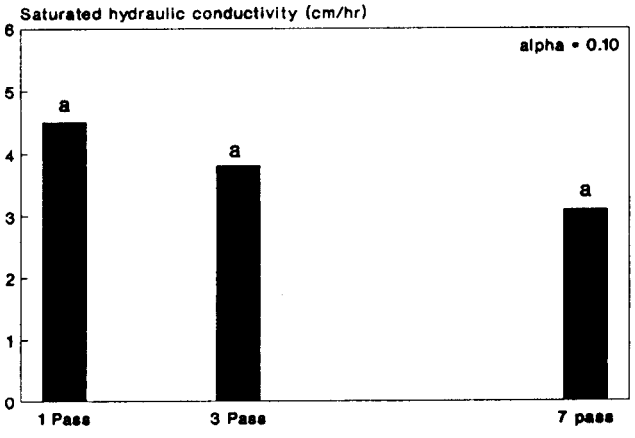

Figure 8. *Average saturated hydraulic conductivity by traffic level.*

Discussion

Conditions on this study site were typical of normal wet-weather harvesting conditions. The soil was saturated, but there was little water actually standing on the soil surface. The one-pass traffic level was similar to that of a normal tertiary skid trail, the 3-pass level was approaching the level of soil displacement associated with a primary skid trail, and the 7-pass traffic level was the maximum number of passes that could be made without bogging down or getting the machine stuck.

The results provide a mixed picture of the effectiveness of using wide tires to minimize site impact. The dual 43-inch-wide tires were effective in minimizing soil compaction and porosity losses, yet, the use of this dual combination is probably not practical due to restricted maneuverability. The total width of the tires and machine was over 19 feet. The 50-inch-wide tires had the least effect on soil bulk density and total pore space, but did not maintain

macropore space any better than some of the other tires tested. The intermediate-width dual tires had intermediate impacts on soil properties. Because the tread of the 28-inch/23-inch-wide and 30.5-inch wide duals is more aggressive than the tread found on the high flotation tires of similar width, the dual configurations did not prevent soil compaction as effectively. However, the duals are far less expensive and are far more flexible for a range of operating conditions. Perhaps, a smaller tire with a less aggressive tread might be used more effectively in a dual configuration. The 43-inch-wide tire was operated at two air pressures, 12 and 25 PSI. The lower air pressure seemed to have some operating advantages over the higher air pressure and may offer some advantages with other types of tires. However, the manufacturers specifications and warranties usually specify higher air pressures.

As expected, increasing traffic levels resulted in increased levels of soil disturbance. The 1 pass traffic level had soil bulk density, total porosity, and macroporosity values near the pretreatment level, but, after 3 passes, significant disturbances had occurred. The 7-pass level clearly resulted in soil impacts which were undesirable. These types of skid trails are often site prepared, yet, the ameliorative affect of site preparation on deeply rutted skid trails has not been adequately studied and its effectiveness is uncertain.

Overall, the findings agree with those of Burger et al. (1989) and Aust et al. (1991). Both of these studies compared the effects of tire size and traffic level on soil physical properties and concluded that tire size was a less important factor than was traffic level. The use of wider and wider skidder tires will not prove to be a universal panacea for preventing site degradation. Wide tires do improve logging production and reduce soil surface disturbance compared to narrow tires, but the wider tires do not eliminate the need for good planning and site assessments prior to harvesting.

Acknowledgements

This cooperative project involved support and assistance from a large number of organizations, including the U. S. Forest Service, Union Camp Corporation, International Paper Company, Franklin Equipment, Webco Tire and Wheel, Firestone, Price Logging, Rubber Applicators, and Virginia Polytechnic Institute and State University.

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THE RESPONSE OF SOIL PHYSICAL AND CHEMICAL PROPERTIES AND WATER QUALITY TO TIMBER HARVEST AND SOIL DISTRUBANCE: PRELIMINARY RESULTS [1]

Donna M. Perison, Russ Lea, and Robert Kellison [2]

Abstract. Bottomland areas provide unique transitional environments between riverine and upland systems. Bottomland hardwoods were ranked first as a national research priority based on distribution, degree of developmental pressure, and gaps in functional data (Clairain 1981). The objective of this research was to quantify the relative impact of skidder and helicopter harvesting on wetland functions such as: 1) water quality, 2) sediment retention, 3) carbon export, and 4) nutrient removal and transformation. Experimental parameters were selected as indices of wetland functions. Five replications of a randomized complete block design (with some restrictions on randomization) of three treatments: 1) control, 2) helicopter forwarding, and 3) skidder forwarding, were established along preharvest environmental gradients defined by geostatistical analyses. Pretreatment site variability was factored out to ensure that treatment differences were being tested rather than artifacts of the original site condition. Mean annual sedimentation rates for the helicopter treatment were slightly higher but not significantly different from the control treatment. Water table elevations were significantly lower in the control stand. Decomposition rates were significanty lower in the control treatment as compared to the harvest treatment. Under conditions of less inundation, decomposition in the skidder ruts was consistently higher than the helicopter and out of the skidder rut samples. This difference diminished with increased inundation.

Introduction

Activities in bottomland hardwoods have come under increased scrutiny. The interest and concern for the wetland resource is being manifested through federal legislation and policy. The National Wetlands Policy Forum recognized timber production as a value of botomland hardwoods and challenged groups with wood production interests in bottomlands to conduct research to refine silvicultural management practices to allow income generation while preventing significant loss of wetland function (The Conservation Foundation 1988). Section 208 of the Federal Water Pollution Control Act Ammendments (P.L. 92-500) also calls for the implementation of best management practices in forested wetlands to control nonpoint sources of pollution. Legislative measures are developing despite the fact that there is insufficient quantitative documentation of the particulars of wetland processes. Even less information exists concerning the amount of impact these systems can withstand and still maintain their ecosystem function. An understanding of the impact of logging disturbance on wetland function is key to the development of effective best management practices. The research on water and soil quality documented in this paper, in conjunction with two concurrent projects concerning vegetative productivity and wildlife habitat, also documented in this proceedings, will: 1) contribute to a better understanding of how blackwater wetlands function and respond to disturbance, and 2) provide a foundation for the refinement of silvicultural best management practices in forested wetlands.

Methods

The study site is located in the Middle Coastal Plain, in Orangeburg County, at the junction of the South Fork Edisto River and the Little River near Norway, South Carolina. The site may be classified as a broadleaved deciduous, palustrine wetland (Cowardin 1979) with surface water or saturated soil conditions present for extended periods, especially early in the growing season. Soils are classified in the Lumbee series, a member of the fine-loamy over sandy or sandy-skeletal, silicaceous, thermic family of Typic Ochraquults (DeFrancesco 1988). The site is representative of blackwater swamps in the Carolinas that have timber management potential.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Graduate Research Assistant, Associate Dean Research, and Director, North Carolina State University, Raleigh.

Five replications of a randomized complete block design with three treatments (control, helicopter forwarding, skidder forwarding) were established along environmental gradients (Gomez and Gomez 1984) defined by geostatistical procedures (Burgess and Webster 1980 a,b, Gaston et al. 1990). It was necessary to locate the control treatments about 100 m from the other treatments to ensure that they were upstream from the planned disturbance and functioning as a continuous, undisturbed stand. As determined from the preharvest gradient analyses, the control and harvest treatments sample similar environmental contours. Sampled treatment plots were 0.89 acres in size. Trees were chainsaw felled in late January, 1991, and lifted out by helicopter in mid-April, 1991. Due to flooded conditions the skidder harvest was simulated in mid-November, 1991.

Sedimentation rates, water table elevation and decompositon rates were measured as indices of wetland functions such as: 1)water quality, 2) sediment retention, 3) carbon export, and 4)nutrient removal and transformation. System recovery will be monitored for two growing seasons after treatment installation, with sampling to be completed in Fall, 1993

Sedimentation rates were measured with sedimentation bars (National Council of the Paper Industry for Air and Stream Improvement 1986). The bars consisted of a 2 inch washer welded to a 2.5 foot long 1/4 inch rebar. The washer was placed flush with the surface at ten locations across each plot. The depth of sediment was measured at two points on each washer, after one year, to calculate an average annual sedimentation rate for each treatment.

Soil Burial Test Fabric (British Standards Institute) was used to document relative differences in decomposition rates across the treatments (Latter and Walton 1988, Mader 1990). In July, and again in August, 80 cotton strips (12 x 50 cm) were incubated in the soil for 14 days. Twenty strips per treatment were installed in the helicopter and control treatments (4/plot). Sampling in the skidder treatment was stratified with 20 strips (4/plot) located in the ruts and 20 strips (4/plot) located out of the ruts. In addition to the treatment strips, 30 strips were installed and immediately removed to serve as field controls. These control strips represented the initial condition of the fabric, controlling the effect of insertion and degradation in storage after inoculation. After exposure, the strips were cut and frayed to 12 x 3 cm test strips corresponding to 0 cm (soil surface), 5, 10, 15, 20 25, and 30 cm depths. Tensile strengths of the test strips were determined on a Monsato Tensometer 10 at the College of Textiles, North Carolina State University. Percent loss of tensile strength in the treatment test strips from the tensile strength of the field control strips was calculated and reported.

Results and Discussion

The mean annual sedimentation rate for the helicopter treatment (0.8 inches per year), was slightly higher but not significantly different from the control treatment (0.7 inches per year). Mean annual sedimentation rates are not available for the skidder treatment this year due to the fact that the skidder was only established in November of 1991. Sedimentation rates on the helicopter treatment were probably slightly higher than the control treatment due to the increased filterability caused by the vegetative regrowth and the woody debris. These results paralleled results obtained on a study conducted on the Tensaw River near Mobile, Alabama (Aust 1990). These preliminary results indicate that the ability of the system to provide enhanced water quality by the filtering of water born sediments has not been negatively impacted by helicopter logging.

Water table elevations were significantly higher in the skidder plots as compared to the undisturbed plots in a July sampling. In an August sampling, the water table elevation was significantly higher in the helicopter and skidder treatments as compared to the control. The skidder treatment exhibited the highest water table elevations. The helicopter and skidder treatments were not significantly different from each other in either sampling (Figures 1 and 2). The lower water tables in the undisturbed forest are attributable to the greater amount of evapotranspiration occurring in the forest canopy as compared to the clear-cut vegetation The higher water table elevations exhibited by the skidder treatment may be attributed to decreased saturated hydraulic conductivity of the soil (resulting in pooling), or to less transpiring herbaceous vegetation. Tests of soil saturated hydraulic conductivity will be conducted and the water table will be measured during the dormant season when the trees in the undisturbed stand are without their leaves to test these hypotheses.

Decomposition rates were lower in the undisturbed area than in the harvest area due to lower temperatures under the forest canopy.

Decomposition rates were highest at a depth of 5 cm then decreased with depth (Figures 3 and 4). Under conditions of increased length of flooding, the differences in decomposition rates between the helicopter treatment, within skidder ruts, and outside of the skidder ruts, were diminished. This was indicated in data from the July testing of the soil burial fabric where the cloth was inundated for 10 days of the 14 day incubation period (Figure 3). However, when the flood period decreased (i.e. the soil surface was exposed to direct sunlight for longer periods), decomposition rates in the skidder ruts were higher than the other areas probably due to heightened temperatures in the ruts resulting from less shading vegetation. This effect can be seen in the August sampling for the burial fabric where the cloth was inundated for only 7 days during the 14 day incubation period (Figure 4). Soil and surface water samples are being analyzed for carbon and other nutrients to document the changes and recovery of nutrient processes resulting from timber harvest.

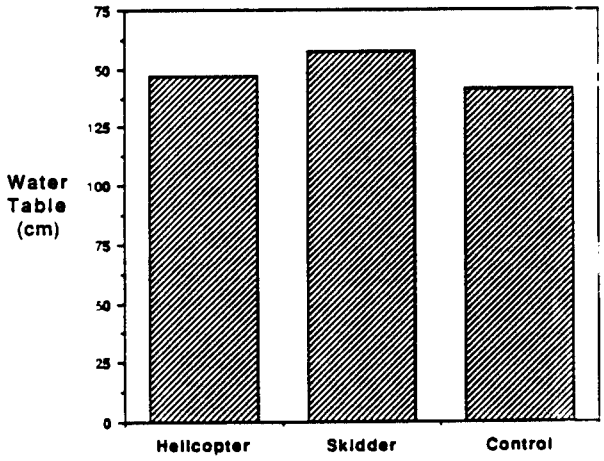

Figure 1. *Water table elevation - July sampling.*

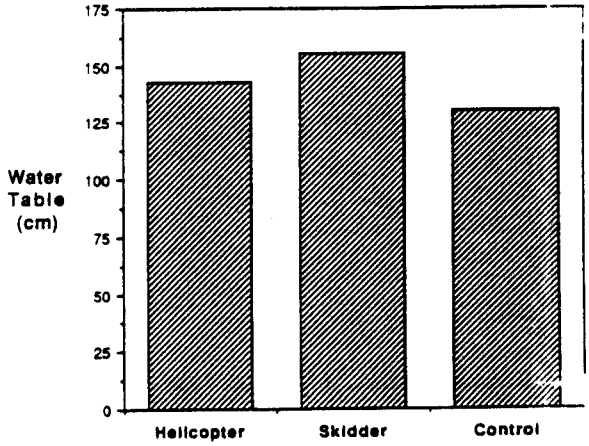

Figure 2. *Water table elevation - August sampling.*

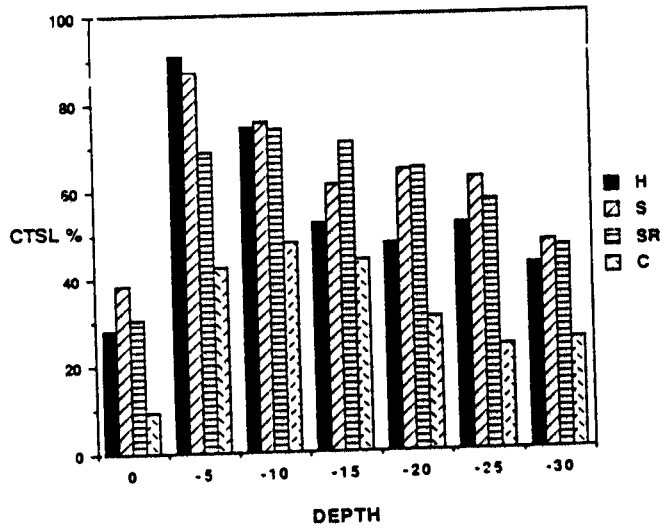

Figure 3. *Cellulose decomposition - July 1992 (CTSL% = percent cellulose tensile strength loss, H = helicopter, S = skidder out of rut, SR = skidder in rut, C = control).*

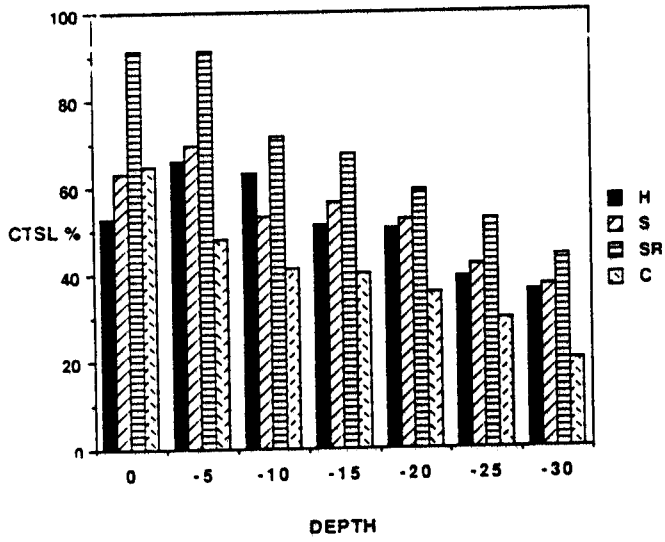

Figure 4. *Cellulose decomposition - August 1992 (CTSL% = percent cellulose tensile strength loss, H = helicopter, S = skidder out of rut, SR = skidder in rut, C = control).*

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THE IMPACTS OF TIMBER HARVEST AND SOIL DISTURBANCE ON THE VEGETATION IN A BLACKWATER SWAMP [1]

Christina Pavel and Robert Kellison [2]

Abstract. The objective of this study is to analyze the response of the vegetation in a blackwater swamp to the environmental conditions created by a harvest operation. This response is quantified by a measure of the plant biomass on the study site. Biomass is defined as the dry weight of plant material present on a given area and is expressed as g/m^2. This is a valued measure of a disturbance event because it has been interpreted as an indicator of the relative soil fertility and nutrient uptake on a site (Mader 1990). Five replications of a randomized complete block design were installed with three treatments: Control, Helicopter forwarding, Skidder forwarding. Vegetation was divided into four strata to facilitate measurement: Herbaceous, Understory, Midstory, and Overstory. Biomass was obtained from the oven-dry weight of the vegetation in the herbaceous layer and from regression equations for the vegetation in the three remaining strata.

Introduction

The information presented in this paper are the preliminary results and analysis of data collected during the summer of 1992. Complete analysis of the data and any interacting effects of the site has not yet been completed.

Methods

The methods will follow those outlined by Mader (1990) in order to reduce the variability resulting from differences in sampling methods and procedures (de la Cruz 1979). This will allow for a reliable comparison of biomass results with similar studies in bottomland hardwood forests.

Herbaceous Stratum

This stratum is defined as all herbaceous vegetation, and woody plants less than 1m tall. Vegetation was sampled on 1x1 m^2 clip plots in the control treatment and 1x0.5 m^2 plots on the helicopter and skidder treatments. All stems originating in the plot were clipped at the soil surface. The clip plots were randomly located on each of the 5 treatment replications. Sample size was determined from previously collected herbaceous biomass (May 1992) and a desired accuracy of 90%. Forty clip plots were sampled on the helicopter and control treatments. Vegetation in the skidder treatment was sampled both in and out of the skidder tire ruts. The skidder ruts sampled for the in-rut plots were systematically located on each skidder treatment replication. The plots for the out-of-rut samples were randomly located on each of the skidder replications with the stipulation that the plot location was not in a rut. Forty plots were sampled as out-of-rut, 25 plots were sampled as in-rut plots. Percent cover was visually estimated at each clip plot location and classified into quartiles. The data for this stratum was collected in August 1992. Vegetation was separated according to species and oven dried at 70°C. Biomass was recorded as the weight of the dried vegetation in grams.

Understory Stratum

Vegetation in this stratum is defined as all woody saplings and shrubs greater than 1m in height, with a diameter less than 1.6 in. Vegetation was sampled on 5x5 m^2 permanent plots on the three treatments. Diameter was measured on all stems originating within the plot at 16 in (40 cm)above the base of trees and 1.2 in (3 cm) above the base of shrubs. The tallest stem of each species on each sample plot was recorded. Stem origin was recorded as a seedling or sprout. Sample size was determined from preliminary data (summer 1990) and a desired accuracy of 90%. Twenty-five sample plots were systematically installed on each of the treatments. Existing regression equations will be used to predict biomass from stem diameters. In addition, biomass regression equations will be developed on site for five species. This stratum was measured in June 1992.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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Stems were harvested for the regression equation in September 1992.

Midstory Stratum

Midstory vegetation includes all woody plants with a dbh greater than 1.6 in (4 cm)but less than 7.9 in (20 cm). Vegetation was sampled on permanent 0.01 ac circular plots in the control treatment only. Diameter was measured at breast height. Total height was also measured. The sample size was determined from preliminary data (summer 1990) and the area of the treatment plot (0.9 ac). Existing regression equations will be used to predict biomass from the diameters. Sampling was completed in July 1992.

Overstory Stratum

The overstory is defined as all vegetation with a dbh greater than 7.9 in (20 cm). The overstory was only sampled on the control treatment. Permanent points marked the center of the variable-radius circular plots. A BAF 20 prism was used in order to provide between 8 and 12 trees per sample point. Total height and diameter at breast height were measured on the permanently marked trees. Regression equations from the literature will be utilized to determine the biomass of this stratum (Messina et al. 1983, Clark et al. 1985). Sampling was completed in July 1992.

Results

Results to date are preliminary and include information on the density and number of different species in each stratum. Biomass data is available for the herbaceous stratum, however, this information is not yet complete for the remaining strata.

Herbaceous

Fifty-eight different species were sampled on the site. There were 44 species in the helicopter treatment, 31 and 25 in the skidder and control treatments respectively. The most commonly occurring species were red maple (*Acer rubrum*), smartweed (*Polygonum* sp.), baby tears (*Micranthemum* sp.), and red ludwigia (*Ludwigia repens*). Red maple, green ash (*Fraxinus pennsylvanicum*), and oak (*Quercus* sp.) were the woody species with the greatest frequency of occurrence. Biomass measurements are reported in table 1. Table 2 shows the change in mean biomass from the first to the fifth replication. The elevation of the first replication is approximately 1m greater than the elevation of the fifth replication.

Understory

Fifteen different species were measured. There were 12 in the helicopter treatment, 8 in the skidder and 10 in the control treatments. The dominant species in terms of frequency of occurrence are red maple, water tupelo (*Nyssa aquatica*), and blackgum (*Nyssa sylvatica* var. biflora). In the helicopter plots, 82% of the stems were sprouts, 18% seedlings. The skidder plots were 73% sprouts, 23% seedlings, and the control was 54% and 46% sprouts and seedlings respectively. The percent of stems recorded as sprouts for the entire site was 74%. Preliminary on-site regression equations have been formulated for three species.

Sweetbay (*Magnolia virginiana*):
$Y = -150.83 + 217.85*(\text{diameter})$ $R^2 = 0.90$

Quercus sp:
$Y = -61.39 + 172.38*(\text{diameter})$ $R^2 = 0.90$

Blackgum:
$Y = 188.09 + 44.99*(\text{diameter})$ $R^2 = 0.95$

These equations are preliminary and are currently only valid for this site. Similar equations will be developed for sweetgum (*Liquidambar styraciflua*) and green ash.

Midstory

There were 7 species sampled in the midstory. The dominant trees in terms of frequency of occurrence were blackgum and musclewood (*Carpinus caroliniana*). The average number of trees per acre (t/ac) is 344.

Overstory

Nine species were sampled in the overstory. The species with the greatest frequency of occurrence were water tupelo, water oak *Quercus nigra*), blackgum and red maple. The average basal area pre acre (BA/ac) is 196 ft^2 with a range of 120 to 320 ft^2/ac. The average number of trees per acre (t/ac) is 205 with a range of 71 to 435 t/ac.

Discussion

The greatest amount of herbaceous biomass was measured on the skidder treatment, followed by the helicopter and control treatments (Table 1). The

number of different species measured, as reported above, was greatest on the helicopter treatment, followed by the skidder and the control treatments. These differences in biomass and species composition may be due to the decrease in elevation across the site from the first replication to the fifth (Table 2). In order to account for this effect, the treatment blocks, in addition to the preliminary biomass data which was collected in the summer of 1990, will be utilized in the final analysis to determine if the differences due to the treatments are significant.

Table 1. *Summary of preliminary herbaceous biomass (g/m^2) results on three different treatments in a blackwater swamp. Sampling was completed in August 1992.*

	Biomass (g/m^2)		
Treatment	Mean	Minimum	Maximum
Helicopter	161	17	269
Skidder	196	13	609
Control	2	0.4	4

Table 2. *Mean herbaceous biomass for three treatments on each of five replicated blocks. Sampling was completed in August 1992.*

	Biomass (g/m2)				
Treatment	Block1	Block2	Block3	Block4	Block5
Helicopter	269	225	155	138	17
Skidder					
IN	165	44	13	22	74
OUT	218	435	609	66	64
TOTAL*	192	240	311	44	69
Control	14	19	121	34	59

*Total is the mean biomass on each block for the entire plot both in and out of the skidder tire rut.

The helicopter treatment plots had the greatest percent of understory stems which were sprouts, as reported above, followed by the skidder and the control treatment plots. The percent of understory stems recorded as seedlings was greatest for the control treatment, as reported above, followed by the skidder and helicopter treatment plots. These stems represent the next-generation forest on this site. The sprouts on the helicopter and skidder plots originate from the severed stems of the previous stand. These sprouts have a competitive advantage over the seedlings on these plots due to their well established root systems. Consideration of the effect of site on these results will continue as described above.

The density information for the midstory and overstory strata will be used along with the calculated biomass as an index of the biomass which was removed from the harvested plots. These strata will also be analyzed in terms of the change in biomass, density and species composition with plot location and elevation across the replications. There was a total of five commonly occurring species. Blackgum was a commonly occurring tree species in both the midstory and overstory.

Conclusion

The amount of herbaceous vegetation on both the helicopter and skidder plots is greater than the herbaceous vegetation on the control treatment plots.

The number of different species is greater on both the helicopter and skidder treatment plots than on the control treatment plots.

The significance of the differences between the number of species and the biomass accumulation on the helicopter and skidder treatments has not yet been determined.

The helicopter treatment plots had the greatest percent of understory stems as sprouts. The average percent sprout for the entire site was 74%. The percent sprouts was greatest on the harvested plots (helicopter and skidder) than on the control treatment plots. The percent of understory stems recorded as seedlings was greatest for the control treatment.

The biomass equations created from understory stems are only valid for this site.

The midstory and overstory strata had a total of five commonly occurring tree species.

Only preliminary conclusions may be drawn from the data at this time. Further analysis will be done to account for any block effect in the treatment design. Data collection on the site continues for information such as the amount(%) of each skidder plot that is a tire rut, and the volume of those ruts will be valuable information in assessing the impact on the vegetation.

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EFFECT OF TIMBER HARVEST ON THE HERPETOFAUNA COMMUNITY OF A BOTTOMLAND HARDWOOD ECOSYSTEM: PRELIMINARY RESULTS [1]

Joseph P. Phelps and Richard A. Lancia [2]

Abstract. Increasing recognition of the importance of bottomland hardwood ecosystems, both as natural systems and as sources of wood products, along with the concern that amphibian populations worldwide may be declining, led to the establishment of this study to document the impact of timber harvest on the herpetofauna community diversity of such a site. In addition to harvest and control treatments, treatments comparing the impact of skidder and helicopter logging were established. Reptiles and amphibians were collected using coverboards to simulate ground refugia, PVC pipes to simulate arboreal treefrog habitat, and the more established method of drift fences with pitfall traps. A total of 2880 captures, representing 26 species, were made from the three methods combined. The data indicate that beta diversity is probably increased by the presence of the clearcut. Differences in diversity between treatments within the clearcut are less clear. The results presented here are based on the first of two seasons of data collection. Eventually, a correlative model will be developed to predict diversity based on vegetative cover, site inundation, woody debris, and litter depth. All of these are significant to habitat and affected by logging.

Introduction

Bottomland hardwood forests have been recognized in many studies (Brinson et al. 1981, Clark and Benforado 1981, Harris and Gosselink 1986) as valuable ecosystems in terms of such functions as floodwater retention, water quality protection, sediment retention, timber production, and wildlife habitat. Careful management will be required to realize all of these benefits, and to abate the rapid loss of these systems (Turner et al. 1981).

Although wildlife is often considered in forest management, amphibians and reptiles are rarely considered. This is despite their importance and abundance in nearly all ecosystems (Burton and Likens 1975, Pough et al. 1987). Amphibians alone comprise about 30 percent of all vertebrate species in the United States and Canada (Clawson et al. 1984) and their importance can be much greater in the south, with amphibians comprising 45 percent of all vertebrate species in Florida (Vickers et al. 1985).

The activities involved in timber harvesting affect amphibians and reptiles (herpetofauna) through alteration of forest floor and arboreal microhabitats. An attempt should be made to devise timber harvest strategies that minimize the impact on herpetofaunal communities. This is especially a concern in light of recent evidence that many populations of amphibians worldwide have been decreasing at an alarming rate (Blaustein and Wake 1990). While the causes of most of the declines are as yet mysteries, logging has been postulated as a potential factor (Wake 1991).

The results presented here represent the data collected in the first of two planned field seasons. The study attempts to document the impact of timber harvest on the herpetofaunal community, as expressed by the Shannon Index. Aside from a comparison of diversity between the clearcut (approximately 25 acres) and the control, diversity differences, if any, between areas logged by skidder and helicopter will also be documented. Once all the data are collected, a model will be developed to predict diversity based on factors that are believed to be important to habitat, and affected by logging operations. These include amount of coarse woody debris (Harmon et al. 1986, Tucker et al. 1990), water levels and site inundation (which relate to rutting on the site), vegetative cover (Clawson et al. 1984), and litter depth (DeGraaf and Yamasaki 1992).

Methods

The study site is located on the South Fork of the Edisto River near Norway, South Carolina. The timber on the site was removed with a biological clearcut in January of 1991. A randomized complete

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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block design was established with three treatments and five blocks. The treatments are skidder removal of timber, helicopter removal, and a control area (where no timber was cut- the control area was last logged approximately 45 years ago). The placement of the plots is under the restriction that the control plots must be upstream of the harvested area and in a continuous stand.

Trapping was carried out continually from 29 May to 13 August 1992. Three types of traps were used. Nine arrays of drift fences with pitfall traps (Gibbons and Semlitsch 1981) were constructed on the site, three arrays each along the long axes of the clearcut, control forest, and the edge of the two. Each array consists of two lengths of aluminum flashing (50 feet by 2 feet) placed perpindicular to each other. The pitfall traps are 5 gallon plastic buckets placed three to each side of each fence. The fences were believed to have too large an effective trapping radius to accurately sample the small (0.9 acre) treatment plots, so they were arranged and analyzed with a completely random design in mind. The three treatments of this part of the experiment are clearcut, edge, and control. Forty-five coverboards (artificial shelters) (DeGraaf and Yamasaki 1992, Tucker et al. 1990, Fitch 1992) were placed on the site, three to each treatment plot. Each board was about 1.5 feet by 4 feet in size. Five foot lengths of poly-vinyl chloride (PVC) pipe were used to simulate arboreal habitat for capturing treefrogs. If successful, this method will be the first developed to capture treefrogs. Four pipes were placed on each treatment plot, two each of 1 inch and 2 inch diameter. The pipes captured only one species with any regularity, and only two species were captured at all. Because of this, the only comparison made with the pipe data dealt with the relative abundance of the common species among treatments and between pipe sizes. The analysis was a split plot, with pipe size as the split plot factor.

Each animal captured was released immediately. Diversity (Shannon's Index: H) was calculated for each drift fence array and for the coverboards of each treatment plot based on the proportion of captures of each species. The assumption that relative capture frequency is proportional to relative abundance is probably not valid. However, since the traps and procedures used in the different treatments are identical, relative measures of diversity should be valid. In order to compare among species in terms of abundance, capture-recapture experiments may be done for some species. As the data are currently applicable, only relative abundances of one species among treatments can be compared.

Results and Discussion

The drift fences accounted for about 85 percent of all the captures (2450 captures) and trapped a total of 20 species. Seven species were captured exclusively by drift fences. The drift fence captures were predominantly made by the edge fences. Coverboards accounted for 155 captures and 19 species. The number of coverboard captures was distributed fairly evenly among all three treatments. Six species were exclusive to coverboards, so a total of 26 species were captured in the two types of traps combined (Table 1). By using both trapping methods, we increased the knowledge gained about the site significantly. Because of the different habits of the diverse species present in the forest, a variety of types of traps was helpful in at least detecting the presence of six or seven species. Large snakes such as cottonmouths (*Agkistrodon piscivorus*) and water snakes (*Nerodia spp.*) are able to get over fences or out of buckets, and terrestrial turtles such as eastern box turtles (*Terrapene carolina*) are not susceptible to falling into pitfalls (Gibbons and Semlitsch 1981). Similarly, coverboards do not seem to be effective at trapping large turtles, and the animals found under them will depend on the time of day and other factors (Fitch 1992). Treefrogs are not sampled often by either of these methods. Three species known to occur on the site were never trapped [brown water snake (*Nerodia taxispilota*), greenish rat snake (*Elaphe obsoleta*), and mud snake (*Farancia abacura*)].

The diversities of the drift fences were calculated for each of the three treatments. The edge fences had the greatest species richness (15 species) but the lowest diversity, which was due to heavy captures of two toad species (*Bufo terrestris* and *B. quercicus*). The highest diversity among the drift fences was in the control (H=1.326). The skidder plot coverboards accounted for the highest richness (12 species) and the highest diversity (H=2.189) (Table 2). Analyses of variance for the diversities of drift fence treatments and coverboard treatments showed no difference at the 5 percent alpha level. A 5 percent t-test showed that the combined drift fence diversity (1.128) was significantly lower than the combined coverboard diversity (2.374).

The treefrog pipes allowed for 278 captures of green treefrogs (*Hyla cinerea*). Most of these (199)

Table 1. *Total herpetofauna captures by trap type and treatment, South Fork Edisto River, South Carolina, 1992.*

	Drift Fences	Coverboards	PVC pipes		
			1"	2"	Total
Clearcut	732	---	---	---	---
Edge	1232	---	---	---	---
Control	485	---	---	---	---
Skidder	---	46	17	50	67
Helicopter	---	55	106	95	201
Control	---	53	5	9	14
TOTAL	2449 (20 spp.)	154 (19 spp.)			282 (2 spp.)

Table 2. *Herpetofauna species richness and diversity for drift fences and coverboards by treatment, South Fork Edisto River, South Carolina, 1992. Diversity expressed as Shannon's Index (H) with variance in parentheses.*

	Drift Fences		Coverboards	
	Richness	Diversity	Richness	Diversity
Clearcut	12	1.135 (.0019)		
Edge	15	0.981 (.0026)		
Control	14	1.326 (.0028)		
TOTAL	20	1.128 (.000624)		
Skidder			12	2.189 (.0103)
Helicopter			9	1.587 (.0189)
Control			9	1.756 (.0148)
TOTAL			19	2.374 (.00698)

were on helicopter plots. An analysis of variance showed no significant difference in captures between the 1 inch and 2 inch pipes. There was a treatment effect at the 5 percent level of confidence. Toe clipping of individuals showed that once a frog occupied a particular pipe, it tended to stay there for many days, even though each frog was evicted each time it was found in a pipe.

Although the diversity measurements for drift fences and coverboards did not differ significantly among treatments, the number of species that were observed in the clearcut but not the control (5 species) and vice versa (6 species) suggests that the clearcut does have significant effects on herpetofauna habitat. The result of the clearcut seems to be that the beta-diversity of the area is increased. That is, although the diversity of the clearcut taken alone (its alpha-diversity) is not significantly higher than an adjacent undisturbed forest, the diversity of the area taken as a whole is higher with the clearcut than it would be in an uninterrupted block of forest. To verify this concept, it would be helpful to have two large areas of bottomland, one which was uninterrupted forest, and one which was a mosaic of clearcuts and forested land. Under the circumstances, there seems to be enough evidence to at least suggest that small clearcuts may increase beta-diversity.

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IMPACT OF HARVESTING ACTIVITIES ON OAK SEEDLING ESTABLISHMENT IN A BOTTOMLAND HARDWOOD FOREST [1]

Jon E. Barry and Lawrence E. Nix [2]

Abstract. Oak (*Quercus* L. spp.) seedling establishment was studied in relation to two levels of harvesting activity. Twenty-four 1.6-acre plots in the Congaree River bottoms of South Carolina were logged during December 1991. Three treatments harvested either no basal area, 20 ft^2/ac, or 40 ft^2/ac basal area from each of the 24 plots by cutting and skidding poor quality and nonmerchantable trees. Seedling counts within 0.0025 acre plots showed that more new oak seedlings and fewer residual oak seedlings were present in the 20 ft^2/ac and 40 ft^2/ac plots than in the control plots six months after harvest. The control plots averaged 282 new and 222 residual oak seedlings/ac; the 20 ft^2/ac harvest treatment averaged 1,321 new and 25 residual oak seedlings/ac; and the 40 ft^2/ac harvest treatment averaged 993 new and 139 residual oak seedlings/ac. These treatments may prove useful in establishing oak seedlings prior to final harvests.

Introduction

Bottomland forests in the Southeast are usually dominated by hardwoods with oaks as an important stand component. Historically, the Congaree River flood plain in South Carolina has supported this type of forest. However, very few oak seedlings and saplings currently exist in the understory of this bottomland forest; and regeneration of the oaks has been sporadic at best. Oak regeneration in upland stands is thought to require advanced oak reproduction or seedlings and saplings in a competitive state prior to overstory removal (Loftis 1983).

Acorns are a necessary part of oak seedling production; however, acorn production can range widely. Several factors can influence the production of acorns and the establishment of new oak seedlings. Among them are variations in weather (Goodrum et al. 1971), stage of tree development (Downs and McQuilkin 1944, Goodrum et al. 1971), incomplete acorn development (Burns et al. 1954, Tryon and Carvell 1962), insect infestations (Downs and McQuilkin 1944, Beck 1977), consumption by wildlife (Cypert and Webster 1948, Goodrum et al. 1971, Wood and Roark 1980), and removal by floods (Aust et al. 1985).

Successful establishment of new oak seedlings in several stands in the Congaree River bottoms after harvests during the winter of 1987-88 suggested that proper timing of the harvest and the accompanying soil disturbance might bury acorns and encourage establishment of oak reproduction in bottomland stands after good seed years.

With new oak seedling establishment as a goal, an experiment was designed to test whether a properly timed intermediate harvest of midstory and defective overstory trees could be used to establish new oak seedlings after a good acorn crop. This experiment was intended to demonstrate a method to establish new oak seedlings either as part of a final harvest or as a preharvest pool of advanced oak regeneration.

Materials and Methods

Two stands were selected in the Congaree River bottoms approximately three miles southeast of Columbia, South Carolina, and approximately one-half mile apart. An inventory of stand one was done with prism samples during the summer of 1991, and an inventory of stand two was done with 1/10th acre fixed radius plots during the fall of 1991.

During September 1991, 0.0001 acre seed traps were installed in both stands on two-chain grids to monitor acorn production. One seed trap was placed at every other point on the grid, and the species of oaks above each seed trap were recorded. Thirty-eight seed traps were placed in stand one and forty-two seed traps in stand two. Seed traps were checked and emptied every two weeks from early October until late November. Acorns from each seed trap were counted and the mean number from each

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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collection period totaled per stand. Acorns were floated-tested in water to determine a percentage of filled acorns (Baldwin 1932). These data were used to estimate acorn production for the two stands for 1991.

During the fall of 1991, these two stands were divided into a total of twenty-five 1.6-acre plots, 10 plots in stand one and 15 plots in stand two. Three harvest level treatments were assigned to the plots by random drawing. Basal area/ac removed from each plot was used as the measure of harvest level and stand disturbance. Eight plots were assigned to the control (0 ft^2/ac removed) group and the high harvest level (40 ft^2/ac removed) group and nine plots to the low harvest level (20 ft^2/ac removed) group. Skid trails were laid out so that each plot could be entered from one side without crossing another plot. During late November and early December 1991, the plots were marked for harvesting, individual tree diameters were recorded, and a running basal area/ac maintained on a pocket calculator. Trees were added to or removed from the tally as needed to adjust the basal area for removal to the desired value.

Harvesting was done between 12 and 19 December 1991, by a commercial logging crew. Equipment drivers were instructed to enter plots only from skid trails and to not drive across flagged plot boundaries. Trees were directionally felled with a small feller machine, limbed in place with chain saws, and dragged to the logging deck with a rubber tired skidder.

During June 1992, the numbers of new oak seedlings and residual oak seedlings less than 4.5 feet tall occurring under the crowns of oak trees in each plot were determined. Oaks which appeared to have only one season of growth were classified as new oak seedlings while oaks which appeared to have grown for two or more seasons were classified as residual oak seedlings. Three dominant or codominant oaks were selected from each plot: willow (*Q. phellos* L.), cherrybark (*Q. pagoda* Raf.), and swamp chestnut (*Q. michauxii* Nutt.). Substitutions were made as required. Four 0.0025 acre samples were taken under the crown of each tree. In each sample, the number of new oak seedlings and number of residual oak seedlings less than 4.5 feet tall were counted per species. Since sampling was restricted to plots under oak tree crowns, seedling means were adjusted by the mean percent basal area of the oak component of the two stands.

The logarithms of the oak seedling counts were examined using a Statistical Analysis System general linear models procedure (α=0.05) (SAS Institute 1985) to determine whether there were statistically significant differences in logarithms of numbers of new oak seedlings and residual oak seedlings between the three treatments. Stand and treatment were tested as main effects, and the interaction was tested using partial (type III) sums of squares. A Duncan's New Multiple Range test was used to identify significantly different means.

Results and Discussion

The two stands were similar in stocking (basal area/ac) and oak component (Table 1). Thirty-five percent of the basal area of stand one was oak, roughly 9% white oaks and 26% red oaks; and 33% of stand two was oak, roughly 17% white oak and 16% red oak.

Table 1. *Preharvest basal areas for trees greater than four inches dbh in two bottomland hardwood stands in South Carolina.*

Species	Stand 1	Stand 2
	----------(ft^2/ac)----------	
Oaks	42.28	40.84
Misc.	79.94	81.54
Total	119.63	122.38

Both stands produced an above average number of sound acorns during the fall of 1991 (Table 2). Acorn collections from nearby stands during 1990 and 1991, and observations by local hunters indicated that the 1991 acorn crop was larger than normal.

Table 2. *Preharvest acorn collections during the fall of 1991 from two bottomland hardwood stands in South Carolina.*

	Acorns/ac	% Filled
Stand 1	129,737[a]	63.9
Stand 2	76,190[b]	65.9

[a] Excluding 263 overcup oak acorns
[b] Excluding 952 overcup oak acorns

Downs (1944) reported a mean of 16,770 acorns/ac during a seven year period from an oak stand on the Bent Creek Experimental Forest near Asheville, North Carolina, while Beck (1977), also at Bent Creek, reported a mean of about 43,000 acorns/ac for a twelve year period with an exceptional crop of about 147,000 acorns/ac. The mean crop

sizes from the Congaree River bottoms were larger than the mean crop sizes of both Downs (1944) and Beck (1977), but these researchers were working in an upland hardwood stand which may not compare well to a river bottom stand.

The mean basal area marked in the low harvest level plots was 20.8 ft^2/ac, and the mean marked in the high harvest level plots was 39.2 ft^2/ac. Elm (*Ulmus* L. spp.), hackberry (*Celtis* L. spp.), red maple (*Acer rubrum* L.), and sweet gum (*Liquidambar styraciflua* L.) accounted for more than 56% of the basal area marked. A few trees which were marked were not cut; and in most plots, a few trees which were cut were not removed from the plot. Since most of these trees were in the 6 - 8 inch diameter range, they should not have had a great impact on the basal area actually removed from the plots. Plot three in stand one was excluded from the study because approximately half of the trees were felled with a chain saw due to a feller machine breakdown; and thus, it might have had less equipment traffic.

Since most of the plots did not contain all three of the species selected for sampling some substitutions were required. Twenty-nine swamp chestnut oaks, 22 willow oaks, 9 cherrybark oaks, 6 water oaks (*Q. nigra* L.), 5 laurel oaks (*Q. laurifolia* s. lat.), and 1 overcup oak (*Q. lyrata* Walt.) were sampled.

There were statistical differences ($P<0.05$) among the mean numbers of new oak seedlings in the three treatments (Table 3). All of the differences in new oak seedling numbers were due to differences in treatments; stand and the stand-treatment interaction were not statistically significant. The two positive treatments produced equal numbers of new oak seedlings and both produced at least 711 more new oak seedlings/ac than no treatment (the control).

Table 3. *Post-harvest new oak seedlings in three harvest level treatments in two bottomland hardwood stands in South Carolina.*

Treatment	Number/ac
Control	282
Low	1,321 a
High	993 a

Means followed by the same letter are not significantly different ($P<0.05$, N=289).

There were statistical differences ($P<0.05$) among the mean numbers of residual oak seedlings in the three treatments (Table 4). There were also statistically significant ($P<0.05$) stand and stand-treatment interaction effects. Harvesting did not appear to reduce the number of residual oak seedlings in stand one; however, results were inconsistent. The control plots from the two stands had similar numbers of residual oak seedlings; however, stand two had fewer residual oak seedlings in the positive treatments (Table 5). Incidental observations indicated that stand two was slightly wetter than stand one, and this may have allowed more damage to the residual oak seedlings during harvesting. These broken residual oak seedlings may have resprouted and been difficult to distinguish from new seedlings.

Table 4. *Post-harvest residual oak seedlings in three harvest level treatments in two bottomland hardwood stands in South Carolina.*

Treatment	Number/ac
Control	222
Low	25
High	139

($P<0.05$, N=289)

Table 5. *Post-harvest residual oak seedlings in three harvest level treatments per stand for two bottomland hardwood stands in South Carolina.*

Treatment	Stand 1	Stand 2
	----------Number/ac----------	
Control	286 ab	183 a
Low	40	14 c
High	475 b	5 c

Means within a row or column followed by the same letter are not significantly different. ($P<0.05$, N=289)

Since some of the new oak seedlings counted may have actually been seedling sprouts, the counts of new oak seedlings need to be corrected. This may be done by subtracting the number of missing residual oak seedlings from the number of new oak seedlings for each treatment. Even with this correction, the harvest treatments produced at least 628 new oak seedlings/ac more than no harvest activity.

Conclusions

The harvest treatments increased the number of new oak seedlings compared to no harvest activity. However, within the range of these treatments, greater

harvest activity did not result in more regeneration. Greater harvest activity also decreased the number of residual oak seedlings substantially in stand two; however, many of these stems may have been broken and reappeared in the counts as seedling sprouts. These results indicate that the lightest harvest treatment was at a level above which no further new oak seedling increase occurred with greater harvesting activity, or was above a threshold of disturbance for increased new oak seedling production. The study design did not allow isolation of the effects of soil disturbance from the effects of increased insolation resulting from canopy disturbance. Thus, the increased new oak seedling production may have been due to soil disturbance from equipment traffic and/or to increased insolation.

Since these harvest treatments were applied during a year when the acorn crop was above average, normal acorn crops may not produce the same results. These treatments need to be applied during normal seed years to determine whether they will work. These treatments might not be of much use if they work only with large acorn crops. Since the two harvest levels produced essentially the same results, lighter treatments, which may not be commercially viable, also need to be tested. The harvest treatment also needs to be tested under different site conditions. Since this experiment was conducted during a fairly dry fall, a wetter site or winter may yield different results.

These results indicate that intermediate harvest operations conducted shortly after acorn fall, especially in conjunction with a large acorn crop, can help produce an abundant crop of new oak seedlings. Since cherrybark oak in particular is capable of competing with sweet gum in bottomland forests (Clatterbuck and Hodges 1988), and since sweet gum is a major competitor in this study area, oak seedlings produced from intermediate harvest operations should become part of the dominant canopy of the next stand.

Seedling production does not guarantee successful oak reproduction; therefore, these plots need to be followed through the next ten years, particularly after the overstory is removed, to determine whether these seedlings can compete with the herbs and pioneer species on the site.

Acknowledgements

The authors would like to gratefully acknowledge the contributions of several people to this research. Frank Beidler, Jr. (land owner) generously allowed us to install these treatments on his property. Angus LaFaye (Milliken Forestry, Columbia, SC) served as a liaison with Mr. Beidler and located the logger. Mr. Chester Kearse of Kearse Manufacturing (Olar, SC) supplied the logging equipment and crew. The Millaree Hunt Club (Columbia, SC) donated many nights lodging in their clubhouse during this field work. Graduate students John F. Thompson and Dale Egbert (Clemson University) assisted in the field work.

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ESTABLISHMENT OF REGENERATION IN SMALL PATCH CLEARCUT OPENINGS IN AN ALABAMA RIVER FLOODPLAIN FOREST [1]

Michael S. Golden [2]

Abstract. Maintaining or increasing preferred tree species after harvesting is a major concern of managers of southern bottomland forests. This study focuses on reproduction processes in clearcut patches of sizes that may be applied in the group selection regeneration method. The study is located in a mixed hardwood forest in the floodplain of the Alabama River in central Alabama. A grid of plots was established in each of five clearcut patches ranging in size from 3/4 acre to 3 1/2 acres. These were inventoried by species and size classes for all trees, including seedlings, before harvest and again at the end of the second growing season. After two seasons, the potential was present for development of a well-stocked stand of commercially valuable species in each of the openings. As a group, the oaks increased their proportion of stems compared to both the preharvest overstory and advance reproduction. The water/willow oaks were very successful in increasing in numbers, proportions, and distribution. There was a large amount of post-harvest germination and seedling establishment for these species. Cherrybark oak was much less successful overall than water/willow oaks, but it had several hundred seedlings per acre present in the two openings where it had the highest preharvest overstory and advance reproduction stocking. It clearly had some post-harvest establishment in one of the openings.

Introduction

For natural regeneration of high-value southern bottomland tree species, there is a need for proven alternatives to the two approaches now most commonly used: diameter-limit (or "selective") cutting and complete clearcutting. The first tends to degrade the quality and composition of the resulting stand. The second, although usually successful, may be undesirable or unacceptable to many landowners for various reasons, and, in some cases, may result in undesirable elevation of the water table.

The group selection method involves harvesting trees in small openings scattered through the stand. In the classical application of the method, the entire stand is harvested through a series of these cuttings, spread over the rotation time period. The length of time between harvests in the stand is termed the cutting cycle, often 5-10 years. Harvesting this way maintains a "high" forest at all times, yet can provide adequate sunlight for satisfactory regeneration and growth of desirable timber and wildlife species, which mostly are not tolerant of heavy shade. Additionally, the method maintains a high diversity of species, age classes, and habitat conditions. Unfortunately, very little scientifically-based information is available on the application of the method to southern bottomland stands.

Where group selection has occasionally been applied to southern bottomlands, minimum opening sizes (left when the "groups" of trees are harvested) of 1 to 2 acres have generally been recommended. At these sizes, the method technically intergrades to "patch" clearcutting. In effect, the method entails the clearcutting of small "patches" (i.e., "groups"). This paper reports the early results of a study which has the objective of describing and quantifying regeneration development and dynamics of bottomland hardwood species in small clearcut openings that are of sizes that may be used in a group selection regeneration method.

Study Site

This study was established on the "King's Bend" tract owned by Buchanan Hardwoods, Inc., of Selma, AL. The small clearcut openings studied (which will hereafter be referred to as "groups") were

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[1] Paper presented at Seventh Southern Silvicultural Research Conference, Mobile AL, November 17-18, 1992.

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established in a stand on the alluvial floodplain of the Alabama River near Selma, in central Alabama. The Alabama River is formed by the confluence of the Tallapoosa and Coosa Rivers, about 80 miles upstream from the study site. These rivers are composed of flow originating primarily in the Piedmont and the Ridge and Valley Physiographic Provinces and carry alluvium from those areas. The river has dams both above and below the study site which affect flooding. During a normal year, floodwater covers the site for one or more short periods during December - May.

Two soil types are found within the group sites studied: Minter loam, a fine, mixed thermic Typic Ochraqualf, and Congaree loam, a fine-loamy, mixed, nonacid, thermic Typic Udifluvent. The Minter loam soils are poorly drained and typically have the water table at or near the surface during the winter and much of the spring, with floodwater disappearing slowly. This soil is found only in a small portion of the areas studied, primarily in low flats in part of Groups 1 and 3. The Congaree soils are slightly higher and are better drained, although the water table is near the surface (3-4 ft) during typical winters. Most of the area within the openings is on broad low ridges and well-drained flats having the Congaree soils.

Methods

Five groups of mature trees were marked for harvest by foresters employed by Buchanan Hardwoods. These were centered on groups of large high-quality oaks and sweetgums. The apparent edges of the openings to be created were marked and served as reference for the location of the network of survey plots. The resulting harvested openings were irregular in shape and varied in size from approximately 0.75 to 3.8 acres.

Prior to harvesting, a systematic grid of 1/200th acre circular plots (16.67 ft diameter) was established in each group at a spacing of 33 ft (between plots in a line) by 66 ft (between lines). The lines were oriented perpendicular to the long axis of each group opening and extended at least 1/2 chain beyond the marked edge of each group opening. For purposes of exact relocation, the plot centers were marked by steel stakes and identified with aluminum tags. All tree species within the plots were inventoried by species and size class. Four size classes were used: 1--small seedlings, less than 6 inches tall; 2--seedlings, 6 inches tall to 0.5 inch dbh; 3--saplings, 0.5 inch to 4.5 inches dbh; and 4--trees, 4.5 inches and larger dbh (with the dbh measured). This provided a 10% sample of the area for stems less than 4.5 inches dbh. A separate 50% inventory (in alternating strips) of the trees 4.5 inches dbh and larger was taken, by species and dbh. The preharvest inventory was taken in late May, 1990. The groups were commercially harvested in late May and June, 1990, with both sawtimber and pulpwood removed by chainsaw felling and skidding to loading areas outside of the groups. All remaining stems greater than 10 ft tall were chainsaw felled within several weeks.

A resurvey of the 1/200th acre plots was accomplished during fall, 1991. This provided results at the end of the second growing season following the harvest.

Results and Discussion

In aggregate (average of samples from all five groups), the preharvest group trees (stems >4.5 inches dbh) were dominated in basal area by sweetgum [*Liquidambar styraciflua*; except where the authority is given, the nomenclature follows Little (1979)], sugarberry (*Celtis laevigata*), and red oaks (cherrybark oak, *Quercus pagoda* Raf.; water oak, *Q. nigra*; willow oak, *Q. phellos*; laurel oak, *Q. laurifolia*) (Table 1). Green ash (*Fraxinus pennsylvanica*) and hickories (primarily *Carya cordiformis*) were other species present in modest amounts. In numbers of trees, sweetgum and sugarberry were again most important, but the oak numbers per acre were quite low, with cherrybark and water/willow oaks having only 4 and 6 trees per acre, respectively (Table 1). In all analyses, water and willow oaks were combined, since it was impossible to reliably separate seedlings of these two species. In this stand, most of the overstory trees were water oak, with 84% of their combined basal area. The low oak numbers and the relative high number of tree-size eastern hornbeam (*Carpinus caroliniana*) stems (20 per acre), a tolerant nonmerchantable species, reflects the cutting history of the stand. It was "selectively" harvested on more than one occasion in the past, with the largest and most valuable trees removed each time. This practice ("high-grading") has been common among southern bottomland stands, and it typically results in a reduction in numbers and proportions of

Table 1. *Preharvest trees and advance reproduction by species categories for all five groups combined. "Trees" include all stems 4.5 inches and larger dbh. "Small" reproduction is that less than 6 inches tall, while "established" is that at least 6 inches tall, but less than 4.5 inches dbh.*

Species	Trees			Advance Reproduction		
				Small	Established	
	ft^2/ac	no./ac	% stems	no./ac	no./ac	% stems
Sweetgum	45.0	28	25	2	4	<1
Sugarberry	20.2	29	26	150	218	25
Cherrybark Oak	12.3	4	3	184	4	<1
Water/willow Oak	12.2	6	6	160	76	9
Green Ash	3.4	4	3	8	172	19
Other Oaks[1]	2.9	1	1	8	19	2
Other Commercial[2]	6.4	13	12	55	222	25
Non-commercial[3]	4.8	26	24	56	171	19
Total	107.1	110		623	886	

[1] *Quercus michauxii*, *Q. lyrata*, and *Q. laurifolia.*
[2] *Carya ovata*, *C. cordiformis*, *Ulmus americana*, *Tilia sp.*, *Diospyros virginiana*, and *Acer negundo.*
[3] *Carpinus virginiana*, *Morus rubra*, *Halesia diptera*, *Ilex opaca*, and *Cercis canadensis.*

quality oaks and concomitant increases in poor quality stems and tolerant unmerchantable species. The stand was last selectively logged around 1970.

Individual groups varied somewhat in the proportions of the major species categories. Sweetgum's preharvest overstory presence was very low in group 2 (1.66 ft^2 and 3 stems per acre), sugarberry's contribution was low in group 3 (2.51 ft^2 and 4 stems per acre), and red oaks were low in group 5 (4.85 ft^2 and 5 stems per acre, all water oak). The red oak overstory numbers were low in all five groups, only 5 to 14 per acre. Total tree stems per acre in individual groups ranged from 90 to 135, with a weighted average of 110, while group total tree basal areas ranged from 98.3 to 119.4 ft^2 per acre, averaging 107.1

In the advance reproduction survey (all stems less than 4.5 inches dbh in the preharvest inventory were considered "advance reproduction"), a large number of small tree seedlings less than 6 inches tall were present, averaging 623 per acre (Table 1). In the analyses of these and the post-harvest data, plants taller than 6 inches were considered "established". These have a higher probability of persisting and becoming a part of the new stand after harvest than do the "small" seedlings. A composite average of 886 "established" seedlings/saplings were present as advance reproduction. Sugarberry and green ash were the two species with the highest numbers, with 218 and 172 per acre, respectively (Table 1). Species proportions among the advance reproduction were similar to that of the tree sizes for sugarberry and for the noncommercial species. Hickories (the majority of the "other commercial" category of Table 1) had substantially higher proportions among established reproduction than among the trees. Sweetgum had very few stems less than tree size. The water/willow oaks had a slightly higher proportion than in the tree size, 9% vs. 6%, but cherrybark oak averaged only 4 stems per acre, which was only 0.45% of the established reproduction. However, cherrybark and water/willow oaks had substantial numbers of small seedlings present, 184 and 160 per acre, respectively.

In fall, 1991, at the end of the second growing season, commercially valuable tree species on all five group openings combined averaged 3242 stems per acre, 2865 of which were taller than 6 inches (Table 2). For the reproduction size classes, a "stem" was determined at ground level. Thus it is equivalent to "rootstock", with multiple stems from a single stump being counted as one stem. Taken together, the species most abundant in the openings were water/willow oaks (1466 per acre) and sugarberry (800 per acre). Cherrybark oak averaged 160 stems per acre, while green ash and hickory each averaged more than 150 stems per acre. There were 154 small seedlings per acre, with most of these being water/willow oaks (110 per acre). After two growing

seasons, the overwhelming majority of seedlings were greater than 6 inches tall.

Perhaps the best comparison between the preharvest stand and that after two seasons is the proportions of species among the dominant stems. This is obtained by comparing the percent of stems values of preharvest stems greater than 4.5 inches dbh (Table 1) with those taller than 6 inches of the new stand (Table 2). Sugarberry's proportion remained virtually the same, but there was a striking increase in the proportion of water/willow oaks (6% to 45%), a substantial increase in cherrybark oaks (0.45% to 5%), and a substantial decrease in the proportion of sweetgum (25% to 2%).

Table 2. *Tree reproduction by species categories after the second growing season for all five groups combined. "Small" reproduction is that less than 6 inches tall, while "established" is that at least 6 inches tall, but less than 4.5 inches dbh.*

Species	Small	Established	
	no./ac	no./ac	% stems
Sweetgum	1	52	2
Sugarberry	16	800	25
Cherrybark Oak	20	160	5
Water/willow Oak	110	1466	45
Green Ash	1	163	5
Other Oaks[1]	0	15	<1
Other Commercial[2]	5	209	6
Non-commercial[3]	1	377	12
Total	154	3242	

[1] Primarily *Quercus michauxii*, but some *Q. lyrata*.
[2] *Carya ovata, C. cordiformis, Ulmus americana, Tilia* sp., *Diospyros virginiana*, and *Acer negundo*.
[3] *Carpinus virginiana, Morus rubra, Halesia diptera, Ilex opaca*, and *Cercis canadensis*.

As a group, the oaks are among our more important trees, due to their high value for both timber and wildlife food production. However, they are generally considered difficult to regenerate naturally. This is due to the shade intolerance of most oak species, combined with their apparent lack of post-harvest seedling establishment. A large number of well-established seedlings and/or saplings ("advance reproduction") is usually considered necessary for maintaining or increasing oak numbers after harvest (Sander and Clark 1971, Johnson 1975, Loftis 1983).

In this study however, since the pre- and post-harvest inventories of the seedlings are for the same plots, it is clear that a large number of water/willow oak seedlings originated from seed after the early summer harvest. Comparison of total number of water/willow oak advance reproduction for the preharvest inventory (236 per acre) to the total stems after two seasons (1576 per acre) indicates an average increase of more than 1300 stems (rootstocks) per acre in the aggregate openings. Substantial post-harvest establishment is also evident for sugarberry. This is not clearly demonstrated for cherrybark oak, since its overall numbers declined slightly.

There was substantial variation in regeneration establishment among the five groups. For stems greater than 6 inches tall, abundances of total commercial species were much higher in group 2 (6848 per acre) and much lower in group 5 (982 per acre) than the overall weighted average for all groups (2865 per acre). The water/willow oaks were the most abundant in four of the openings, ranging from 818 to 3869 per acre. Their lowest level was in group 5, with 229 per acre. Cherrybark oak established seedling/saplings were absent in the plots of group 1, and at very low levels in groups 4 (13 per acre) and 5 (10 per acre).

Thus the unexpected high level of post-harvest seedling germination and establishment of water/willow oaks quantified here was examined more closely. One important issue is their distribution. Were these new seedlings all located in just a few dense patches, perhaps only near the few preharvest tree locations or in just one or two of the openings? To address this issue, the stocking percentages for water/willow oaks were determined for both the pre-harvest and post-harvest inventories and are presented in Figure 1. These percentages are the proportion of 1/200th acre plots within each group that had at least one water/willow oak stem of any size. There was considerable variation among the individual group openings. However, two points stand out. There was fair to excellent water/willow oak stocking in all of the openings after two seasons, ranging from 48% to 100%, with an overall stocking of 62%. Secondly, the stocking levels in four of the five openings increased when compared to the preharvest inventory of the same plots, further confirming substantial post-harvest establishment.

On suitable sites cherrybark oak generally produces a higher proportion of top quality sawtimber volume per tree in a given time period than any other

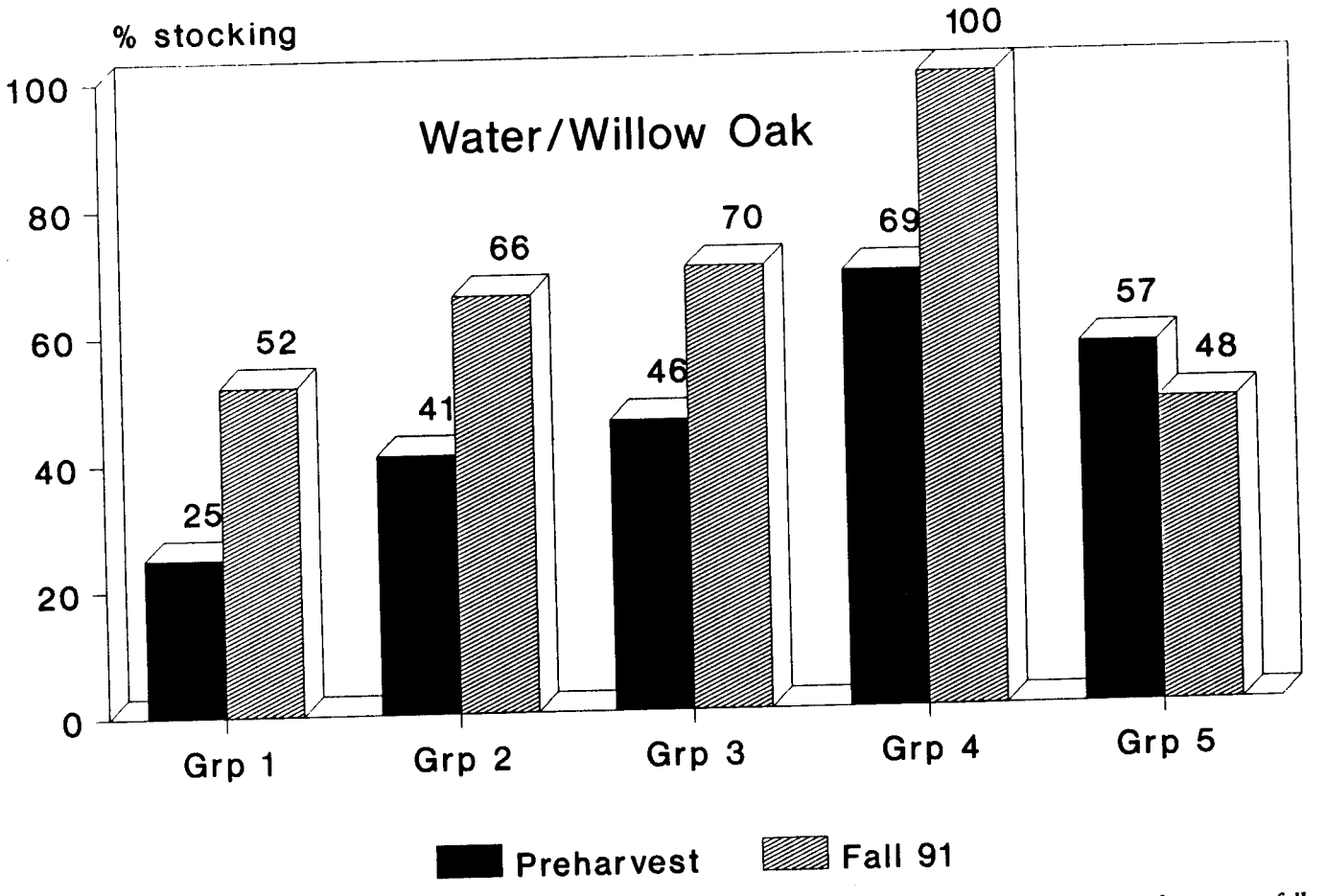

Figure 1. *Percent stocking of water/willow oaks within each group opening in the 1/200th acre circular plots: preharvest vs. fall, 1991 (two seasons after harvest). A plot was considered stocked if a stem of any size was present.*

southern bottomland species. It is fast growing, tends to be very straight, and naturally prunes very well. It also is a good wildlife habitat species, with frequent good mast crops. For these reasons, it is considered by many to be among the most desirable bottomland tree species.

Data for cherrybark oak present a somewhat different picture from that for water/willow oaks. When the numbers of stems in the pre- and post-harvest inventories of this species were compared (Figure 2), wide variation among the groups was evident. However, for four of the five openings, cherrybark oak numbers declined. In the two groups where a large number of advance reproduction was present (groups 2 and 3), a large number of post-harvest stems were present after two seasons (524 and 459 per acre, respectively). Moreover, in these groups, most of the cherrybark oak stems in the new stand were taller than 6 inches (441 and 432 per acre, respectively). Since the number increased, there was post-harvest establishment of cherrybark oak in group 2. The stocking percentage also increased in group 2, from 24% to 55 %, further verifying that post-harvest establishment occurred in this group. However stocking decreased in three of the groups and remained constant (at 43%) in group 3. Reasons for the differences among the openings were not clear, although differences in preharvest stocking may be important. Cherrybark oak preharvest basal areas were higher in groups 2 and 3 (17.4 and 31.4 ft^2 per acre), compared to those of groups 1, 4, and 5 (6.7, 4.2, and 0 ft^2 per acre, respectively). Cherrybark oak's overall early regeneration performance in these openings is somewhat better than was reported for a 7-year-old regenerating stand (Golden and Loewenstein 1991) in a nearby 40-acre clearcut area on the same floodplain, where cherrybark oak declined in proportion and numbers between the preharvest overstory and the dominant portion of the regenerated stand.

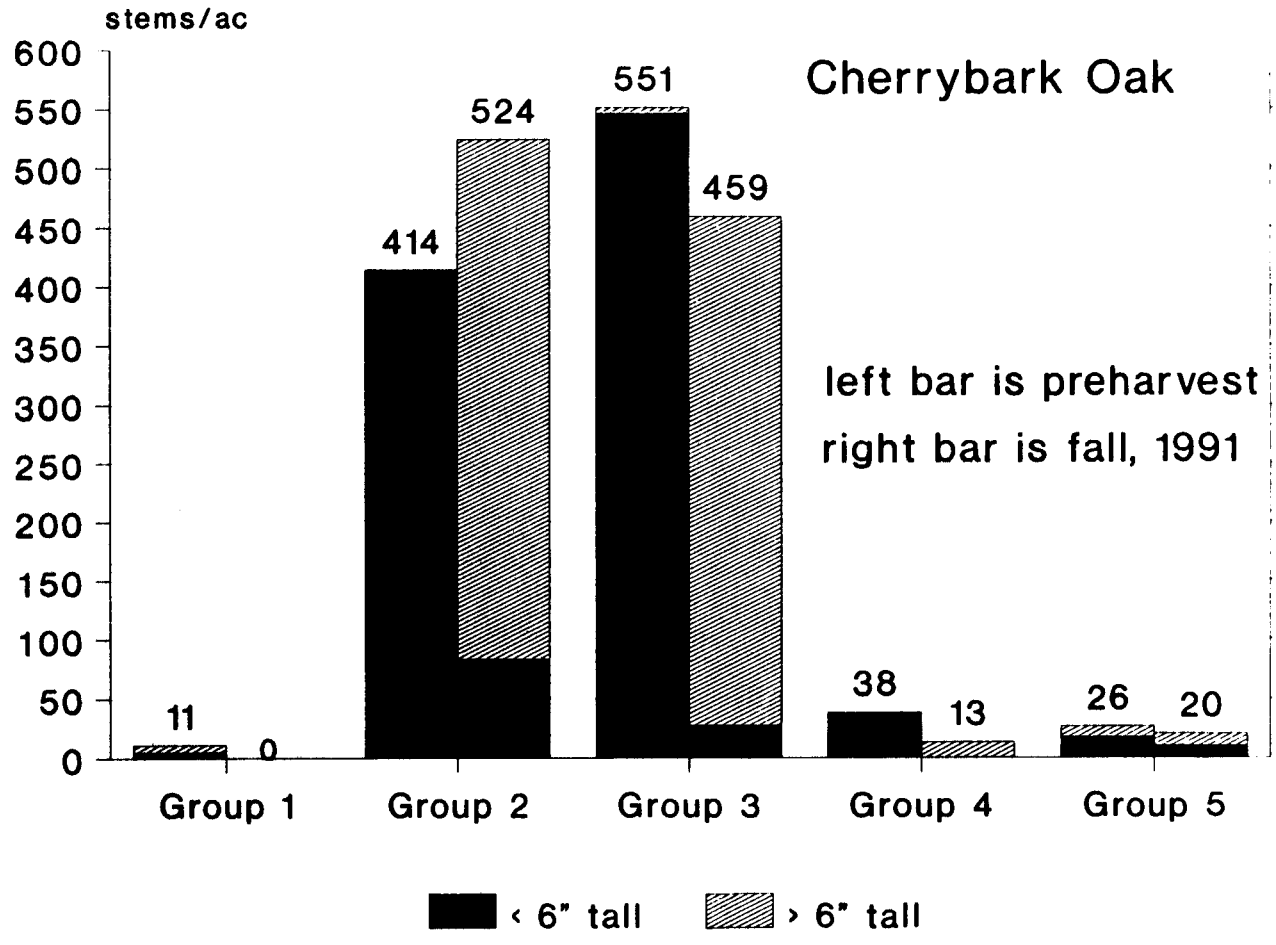

Figure 2. *Stems per acre of cherrybark oak in each group opening, preharvest vs. fall, 1991.*

The data after two seasons obviously indicate only the potential species composition of the future stand Effects of opening size may become evident later. Stand development will be followed through periodic remeasurement of the permanently monumented grid of 1/200th acre plots in each opening.

Conclusions

After two seasons, the potential was present for development of a well-stocked stand of commercially valuable species in each of the openings. As a group, the oaks increased their proportion of stems compared to both the preharvest overstory and advance reproduction. The water/willow oaks were very successful in increasing in numbers, proportions, and distribution. There was a large amount of post-harvest germination and seedling establishment for these species. Cherrybark oak was much less successful overall than water/willow oak, but it had several hundred seedlings per acre present in the two openings where it had the highest preharvest overstory and advance reproduction stocking. Cherrybark oak clearly had some post-harvest establishment in one of the openings.

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Impacts of Hurricane Hugo

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CHANGES IN BALDCYPRESS-SWAMP TUPELO WETLAND SOIL CHEMISTRY CAUSED BY HURRICANE HUGO INDUCED SALTWATER INUNDATION [1]

Charles A. Gresham [2]

Abstract. Several soil chemical characteristics were measured in three baldcypress (*Taxodium distichum* L. Rich. var *distichum*) - swamp tupelo (*Nyssa sylvatica* var *biflora* (Walt.)Sarg.) swamps that were either not inundated, or inundated to various depths by the storm surge associated with Hurricane Hugo. Soil chloride concentrations were high 2.5 years after the storm and were the only soil change directly attributable to saltwater inundation. Many other parameters including soil organic matter, nitrogen and phosphorus were indirectly associated with saltwater inundation via canopy tree mortality.

Introduction

Hurricanes frequently disturb coastal forests in the southeastern United States (Purvis 1973) with both short-term and long-term effects. Short-term damage is seen as saltburn (Gresham 1981) or wind damage (Gresham et al. 1991) and the degree of damage is a function of proximity to the hurricane's eye and species. Forest recovery from short-term damage is rapid because pre-existing regeneration will be released or residual stems will sprout. For example, heavily damaged stands on the Francis Marion National Forest were revegetated by loblolly pine (*Pinus taeda*) and sweetgum (*Liquidambar styraciflua*) by the second growing season after the hurricane.

Long-term hurricane damage to a forest results from saltwater inundation causing tree mortality and soil chemistry changes. This type of site alteration not only changes what is present in the short-term, but could also influence how fast an inundated area is revegetated and what species re-occupy the forest during recovery.

Along the Atlantic Coastal Plain, baldcypress (*Taxodium distichum* L. Rich. var *distichum*) - swamp tupelo (*Nyssa sylvatica* var *biflora* (Walt.)Sarg.) wetlands are the most vulnerable forest type to saltwater inundation because of their hydrologic connection to marshes and estuaries. Salinity tolerence of bald cypress has been investigated (Pezeshki et al. 1988) but little is known about the effects of saltwater inundation on wetland soil chemistry despite several hypothesized effects.

Overstory mortality resulting from saltwater inundation will allow more direct sunlight on the wetland floor, thus increasing soil temperatures and possibly nitrogen mineralization. This mortality will also add coarse woody debris to the wetland and will decrease annual leaffall. Chloride ions could extract ammonium and nitrate ions from the soil thus increasing the potential to lose nitrogen from the wetland. Soil microorganism metabolism could be reduced in the presence of saltwater, thus affecting the oxidation/reduction status of the soil. Saltwater inundation should not directly affect soil phosphorus concentrations.

Ammonium nitrogen mobilization by saltwater inundation has been reported in pine forest soil solutions (Blood et al. 1990, 1991) and freshwater and marine sediments (Gardner et al. 1991). Ion pairing of ammonium with saltwater anions and saltwater cations occupying soil cation exchange sites would increase ammonium loss.

Alterations of several soil chemical characteristics due to flooding are driven by microorganism oxygen consumption (Gambrell and Patrick 1978, Ponnamperuma 1984, Patrick et al. 1985). Since the activity of microorganisms is affected by soil salinity (McClung and Frankenberger 1985, Roseberg et al 1986), several wetland soil physical and chemical characteristics could be altered by saltwater inundation, as compared to freshwater inundation.

The intrusion of North Inlet estuarine saltwater into adjacent cypress wetlands associated with Hurricane Hugo on Hobcaw Barony (Hook et al. 1991) created an opportunity to monitor the effects of saltwater inundation on cypress-tupelo wetland soil

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992. Belle W. Baruch Forest Science Institute Technical Contribution: 93-2.

[2] Associate Professor, Baruch Forest Science Institute of Clemson University, Georgetown, SC.

chemistry. Similar wetlands that were not either inundated or less deeply inundated were also available for comparison. Specific objectives were to monitor (1) wetland hydrology, (2) selected soil chemical characteristics, and (3) canopy woody and foliage litterfall patterns.

Methods

Three baldcypress-swamp tupelo wetlands on Hobcaw Forest, 3mi east of Georgetown, South Carolina were chosen for study. The most severely impacted stand, referred to as Marsh Road, is a linear inter-dune swamp approximately 750ft from North Inlet estuary which was inundated to a depth of approximately 9ft during Hurricane Hugo's landfall on September 21, 1989. The soil is a Hobcaw soil (fine-loamy, siliceous, thermic, Typic, Umbraquult; Stuckey 1982). There was no evidence of saltwater intrusion since the hurricane. The least impacted stand was an isolated baldcypress-swamp tupelo-ash (*Fraxinus* (L.)) swamp approximately 1mi from North Inlet estuary. This stand, called Crabhaul suffered only light wind damage and is also on a Hobcaw soil. The third stand, referred to as Boardwalk, is a baldcypress-swamp tupelo headwater swamp that drains into a brackish marsh and was flushed with saltwater during the hurricane. Soil types are Rutledge sand (sandy siliceous thermic Typic Humaquept) on the brackish marsh side and Johnston loam (coarse loamy, siliceous, acid, thermic, Cumulic Humaquept) on the inland side.

Five 0.12ac plots were installed in each stand in the spring 1990, and two 10.7ft^2 wooden littertraps were placed in each plot in February, 1991. A soil sampling station and a shallow observation well was installed in each plot in May, 1991. At each sampling station, type K thermocouples and platinum redox probes (Letey and Stolzy 1964) were buried at approximately 3in, 7in, and 12in (Crabhaul and Boardwalk) or 12in and 16in (Marsh Road) below the top of the litter layer. A recording rain gauge was installed within a mile of each site and one observation well in each stand had a water level recorder installed.

Soil samples were taken twenty times from April 1991 to April 1992 by extracting two 3in by 18in soil cores with a sharpened pipe from each plot in each stand. The soil cores were divided into upper and lower 6in sections and samples taken by depth. Equal volumes of soil from both depths of the first core and DDW were mixed in the field and pH was measured with glass electrodes. Thermocouples were read with a hand-held meter and redox probes were read with a hand-held millivolt meter and a calomel reference electrode in a KCl-agar salt bridge. Littertraps were emptied monthly and the water table depth in non-recording observation wells was measured weekly.

Results and Discussion

Water table dynamics of the three study areas is presented in Figure 1. In the Crabhaul stand, the water table drops rapidly due to leaf emergence, rises with frequent rains and drops again when the rainfall decreases. This stand dries out the most because of the high basal area and floods the deepest because of its pond-like topography. Similar, though less pronounced patterns were noticed in the Marsh Road stand which had the most tree mortality. In contrast, the water table level in the Boardwalk stand rarely dropped below ground level nor flooded deeper than 4in. Since we noticed that part of the Boardwalk stand water table behaved differently from the other, two recording wells were installed and this difference is seen in Figure 1 as deeper flooding of the inland plots. The hydrologic connection between the Boardwalk stand and brackish marsh is probably responsible for both the lack of flooding (rainfall quickly flows from the swamp to the marsh) and the lack of drying (water flowing from the marsh to the swamp if the swamp water table level is low). This hydrologic connection is supported by the presence of short periods of high water levels not closely associated with rainfall. These "spikes" are explained by lunar tides pushing marsh water into the swamp.

The two saltwater impacted stands had similar soil and water temperatures, and both were warmer than the control Crabhaul stand. These temperature trends indicate that saltwater inundation indirectly affected soil temperature by reducing canopy shading of the swamp floor. The seasonal range of temperatures, within stand variation of temperatures, and yearly average temperature decreased along the progression of; air, water, upper soil, and deeper soil.

During most of the study period all soils were reduced (+100mv to -100mv) to highly reduced (-100 to -300mv) at both depths. However the upper layers were less reduced than the lower layers. Reduced conditions indicate that the microbial populations were active in the impacted stands. Crabhaul soils did not oxidize when the water table dropped below the soil surface, as would be expected in a drained soil.

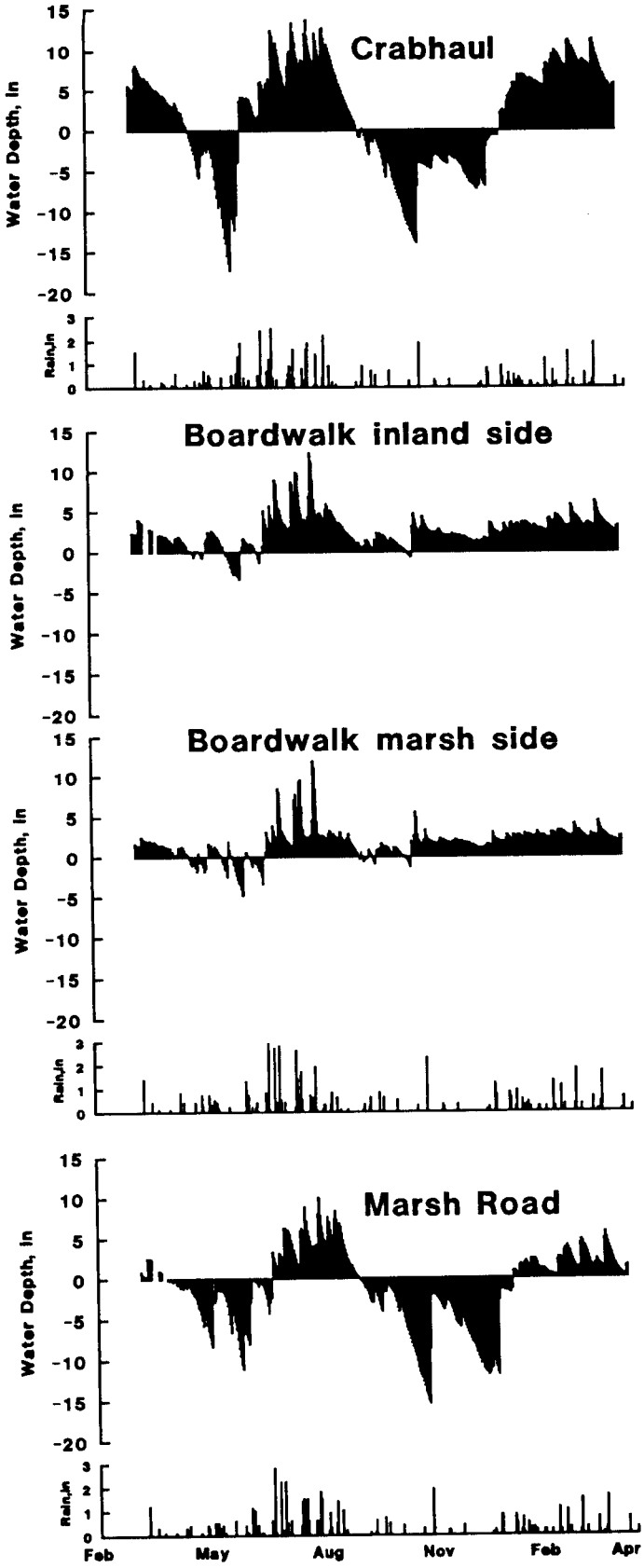

Figure 1. *Water level depths and rainfall for three baldcypress-swamp tupelo stands in coastal South Carolina that were severely impacted (Marsh Road), moderately impacted (Boardwalk), and not impacted (Crabhaul) by Hurricane Hugo's tidal surge.*

Soils of impacted stands were less acid than the control stand. Two factors probably contribute to this: more decomposing litterfall in the control stand contributing more organic acids and the displacement and loss of hydrogen ions by saltwater cations in the impacted stands (Blood et al. 1991).

Foliage and woody litterfall rates reflected saltwater induced tree mortality in opposite ways. The unaffected control stand had a foliage litterfall rate of 5900 kg ha-1yr-1 as opposed to 2800 kg ha-1yr-1 for Boardwalk and 1110 kg ha-1yr-1 for Marsh Road. Woody litterfall was highest for Boardwalk (10,900 kg ha-1yr-1) less for Marsh Road (2500 kg ha-1 yr-1) and far less (600 kg ha-1yr-1) for the Crabhaul, the control stand. Therefore saltwater inundation reduced foliage litterfall and increased woody litterfall.

Soil organic matter was highest in Crabhaul swamp, lowest in Marsh Road, with Boardwalk having slightly more than Marsh Road. Long term heavy litterfall and cooler temperatures of Crabhaul swamp probably contributed to soil organic matter buildup, while low litterfall rates and warmer soil temperatures probably reduced Marsh Road's soil organic matter. Boardwalk's intermediate soil organic matter may have resulted from different soil types and less tree mortality then Marsh Road. Upper soil layer organic matter content was higher than the lower layer in all three stands.

The stand with the highest saltwater mortality, Marsh Road had soil chloride concentrations of approximately 400 ppm and Crabhaul stand had far less. Boardwalk soil chloride levels were 5-10 times that of Marsh Road. This can be explained by repeated brackish water inundation from the marsh into Boardwalk over many years. Tidal "spikes" were noticed in water table level recordings indicating that marsh water entered Boardwalk during high lunar tides. Because this has probably been happening for decades the stand has apparently accumulated chloride.

Soil ammonium nitrogen levels were highest in Marsh Road, which may have resulted from mineralization of the high biomass input following tree mortality. Lower soil ammonium concentrations in Crabhaul may reflect tree uptake removing nitrogen about as fast as litterfall and mineralization replaces it. Similarly Boardwalk has less litterfall input and less basal area to remove ammonium from the soil. Also the high chloride levels may indicate that ion paring may be making ammonium more mobile.

Soil nitrate levels were low in all three stands which is expected in reduced soils where microorganisms reduce nitrate nitrogen to ammonium nitrogen. Among the low values, Crabhaul stand had the highest nitrate levels indicating that this stand had the least reduced soil. The water level in Crabhaul did drop below the soil twice during the study to deeper levels than in the other stands.

Soil phosphorus concentration patterns were similar to soil ammonium concentration patterns; highest in Marsh Road, lowest in Crabhaul. Like ammonium nitrogen, high phosphorus levels in Marsh Road are likely the result of mineralization of mortality related biomass input to the swamp floor. Lower phosphorus in Crabhaul may indicate a balance between litterfall mineralization and tree uptake.

Overall Saltwater Inundation Effects

Soil chloride was the only soil chemical parameter directly affected by saltwater inundation. Perhaps soil pH differences were influenced by hydrogen ion displacement due to saltwater anions, but the data could not verify this.

Most of the other soil chemical parameters measured were indirectly affected by saltwater inundation via tree mortality. Marsh Road, the stand with the highest tree mortality, had higher soil temperatures, less leaf litterfall, more woody litterfall, lower soil organic matter, and higher ammonium nitrogen and phosphorus. These same soil chemical changes would be expected if similar mortality were caused by another agent such as herbicide or insect infestation.

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SALT WATER MOVEMENT WITHIN THE WATER TABLE AQUIFER FOLLOWING HURRICANE HUGO [1]

Thomas M. Williams [2]

Abstract. Hurricane Hugo generated a tidal surge approximately twenty feet high which inundated a strip of coastal forest from Charleston to just south of Myrtle Beach. On the Hobcaw Forest, east of Georgetown, the surge was about 10 feet above sea level and inundated a strip about 3500 feet wide. Salt water infiltrated directly into the forest soil and water table aquifer during the surge and from ponded areas for a period after the storm. Early auger hole measures of water table aquifer salinity reflected the deposition of salt within the aquifer throughout the surge area. Later multi-level sampling indicated that salt concentrations have remained high (2000mg Cl/l) through 1992. Higher concentrations have persisted deep (12 ft) in the aquifer but groundwater flow has also carried high concentrations into hardwood drainages. Forest mortality was more closely related to salinity determinations in multi-level samplers than earlier auger hole data.

Introduction

Southern coastal forested wetlands are subject to hurricanes sometime during the lifetime of most of the tree vegetation (Conner In press). Tidal surges are associated with most hurricanes and affect coastal wetlands with the same frequency. The extent of flooding associated with a tidal surge depends on the tidal stage when the hurricane approaches the coast and the slope of the upland adjacent to the coast. Since much of the coastal landscape has very small relief a tidal surge occurring near high tide may cause flooding miles landward from the coast. Salt water carried into the forest will infiltrate into the soil and potentially move within the water table aquifer. Trees may be killed if water conductivity exceeds 5 millimhos/ cm (approximately 3000 mg Cl/l) around their roots (Franscois 1980). The fate of salt water within the water table aquifer will determine both mortality and the rate of forest recovery.

Hurricane Hugo struck the coast of south Carolina on September 21, 1989 approximately 2 hr before the astronomical high tide (Brennen 1991). The eye of the storm crossed the coast just north of Charleston, S.C. The tidal surge extended northeast of the storm center with a maximum height of twenty feet above sea level near McClellonville S.C., about thirty miles northeast of the center of the eye (Coch and Wolff 1991). Elevated tidal stages extended to Garden City about 75 miles northeast of the center of the eye.

The Hobcaw Forest is located approximately 50 miles northeast of the storm center. The forest is located directly behind a barrier beach and salt marsh. Tidal surge at this location was between 9.5 and 10.5 feet above sea level (7.5 feet above mean high tide) and extended into the forest up to 3500 feet landward of the salt marsh edge (Gardner et al 1991). Salinity measured in auger holes in this zone immediately after the storm ranged from > 100 to 4000 mg Na/l. The maximum was equivalent to 40% of the Na concentration in sea water.

Initial Damage

Wind damage from Hurricane Hugo was moderate on Hobcaw Forest. The most severely damaged tall oaks experienced less than 30% mortality while the more resistant trees had less than 10% mortality (Gresham et al. 1991). Initial damage due to salt stress was noted in November of 1989. By February 1990 many pines were showing severe stress with yellowing foliage and defoliation throughout the portion of the forest with elevations below 10 feet above sea level. Defoliation continued throughout the spring of 1990. By late spring pines with yellowing crowns were also heavily infested with southern pine beetle (*Dendroctonus frontalis* Zimmerman) and engraver beetles (Ips spp.) and the role of salt stress became ambiguous. Many deciduous trees within the same zone failed to produce foliage in the spring of 1990. Except for a few cypress (*Taxodium distichum*

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992. Belle W. Baruch Forest Science Institute Technical Contribution 93-5.

[2] Professor, Baruch Forest Science Institute of Clemson University, Georgetown, SC.

(L.) Rich.) that produced new sprouts in late 1990 and early 1991 these trees subsequently died. Aerial photographs taken in early February 1991 revealed the pattern of initial mortality within the zone of tidal surge flooding (Figure 1.).

Figure 1. *Distribution of living (gray) and dead timber (black) on Hobcaw Forest (February 1991) as a result of soil salinity.*

The pattern of survivors in 1990 was not predictable from the auger hole salinity measures taken by Gardener et al (1991). Salinity in auger holes was highest near the edge of the marsh and generally higher on pine ridges. Most surviving trees were on ridges and there was a fringe of living trees along the much of the marsh edge. The distribution of mortality suggested that salt had moved from the highest and best drained areas and accumulated in lower topographic positions. This suggested that a large portion of the tidal surge waters had moved within the water table aquifer.

Salt water within the water table aquifer poses a threat to the present survivors and to regeneration, either natural or planted. This study had the objective of determining three aspects of salt distribution in the aquifer: (1) What was the present distribution of salt in the aquifer? (2) What were the rates and direction of water movement and was salt moving with the groundwater flow? (3) What was the rate of salt removal from the system and when would salt no longer threaten forest health?

Methods

The premise of this research was that sea salt movement would be most easily characterized by piezometric potential and distribution of chloride ion. Piezometric potential measures allow determination of flow directions. Chloride is a major constituent of sea salt and most closely approximates a conservative tracer.

The study was conducted within a small watershed in conjunction with Gresham (this volume) and Conner (this volume). The watershed is located adjacent to the North Inlet salt marsh and is labeled marsh road in each paper. It is oriented from southwest to northeast with an outlet to the marsh northeast of the study site. A small stream draining the watershed to the northeast flows within a stand of cypress (*Taxodium distichum* (L.) Rich.) and swamp tupelo (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.). Elevations within the stream wetland vary from 4.5 to 6 feet above sea level. The bottom of the best defined channel slopes from 4.8 to 4.5 feet above sea level within the study area. The wetland is separated from the marsh by a ridge on the eastern side that ranges from 7 to 8 feet above sea level. A ridge along the western side separates the watershed from another stream to the west. The western ridge also ranges from 7 to 8 feet above sea level.

Groundwater was sampled from five transects along the stream section (Figure 2). A piezometer station was placed in the center of each vegetation plot established by Conner (this volume). Four more piezometer stations were established on a line perpendicular to the stream forming five transects from the top of the eastern ridge to the top of the western ridge each with five piezometer stations. Each piezometer station followed a design which had accurately measured water chemistry and piezometric potential in a layered sandy aquifer near the study area (Williams and McCarthy 1990). At each station, piezometric potential was measured at depth of 5, 7.5, 10, and 15 feet below the surface in capped 3/4" piezometers screened with #10 well screen for an interval of 4" at the appropriate depth. Water chemistry samples were collected from 1/2"x4" samplers screened with #10 well screen and connected to the surface by 1/4" polyethylene tubing. Water chemistry samplers were at 4', 6', 8', 10', and 12' below the soil surface.

Piezometric potential was measured weekly from April 1, 1991 through March 31, 1992. Piezometer top elevations were surveyed from a nearby benchmark. Water levels in each piezometer were measured with an electrical resistance probe.

Water chemistry samples were withdrawn from the soil on a monthly basis during the same time period. Samples were withdrawn from the samplers with a peristaltic pump. Water was pumped from each sampler and discarded until three to five sampler plus tubing volumes were removed. Then a 60 ml sample

was taken in a HCl washed polyethylene sample bottle which had been rinsed with distilled water to remove all traces of HCl. Samples were returned to the laboratory and refrigerated until analysis. Chloride analysis were performed on a Technicon II auto analyzer using the ferricyanide method (American Public Health Association).

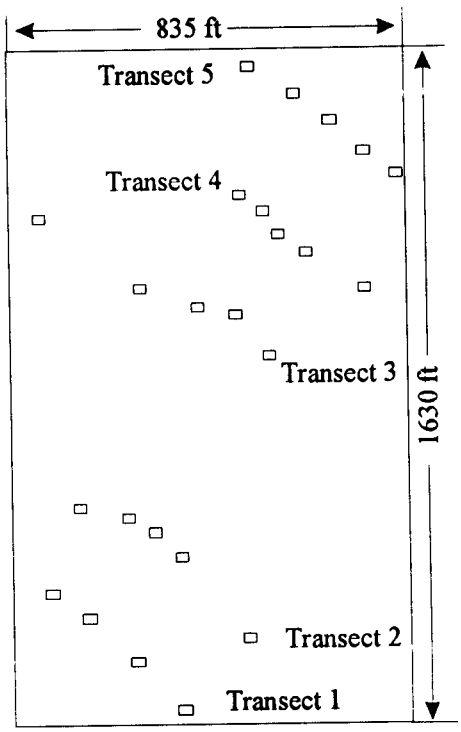


Figure 2. *Distribution of sampling piezometers.*

Results

Twenty four sampling stations were actually installed. The western ridge was indistinct on transect 1 and a station was not installed. Piezometric potentials were collected for 52 weeks from April 1, 1991 until March 31, 1992. Potentials varied with weekly changes in rainfall and potential evapotranspiration. Large weekly variability is normal for shallow water tables (Lipscomb and Williams 1989). During high rainfall periods piezometric potentials within the wetland were relatively uniform and equal to the height of water standing on the surface.

Groundwater chloride concentrations showed spatial as well as temporal variability. Individual measures varied from less than 50 mg/l to over 3000 mg/l during the year. Highest values were found during drier summer months while lowest values were found during high water in April 1991. However, any inverse relation of groundwater chloride concentration to antecedent rainfall was weak and obscured by spatial variability.

Chloride distribution and groundwater flow directions can be summarized as annual averages. The study site can be circumscribed by a 1630' by 835' by 20' thick block. Figure 2 shows the position and orientation of the five piezometer transects within this block. Figure 3a shows five cross sections of the block at each of the transects. Figure 3b represents horizontal maps of the block at each of the five sampling depths. Figures 3a and 3b each depict three aspects of the experiment. The maps represent an contouring of the mean chloride concentrations. At each actual sample point a small rectangle is shaded to indicate the 95% confidence interval of the mean value at that point. Arrows on each map are a two dimensional representation of groundwater flow direction determined from average piezometric potential gradients which were significantly (95%) different from zero. There were only four piezometers per station and they were at depths intermediate between chloride samplers. The arrows on figure 3b are representations of the flow at depths just below the samplers. The ten foot depth is the exception with flow directions of the 10 foot piezometers (same as the eight foot depth).

In figure 4 the mean concentration at the upper level (4') is compared to forest mortality determined from February 1991 color infrared aerial photography. Photography was digitized and rectified to the Hobcaw Forest GIS system base map (Lipscomb and Williams 1990). The base map in its present configuration has a error from true ground position of 7.5 to 10 feet. The digitized photography has a pixel size of 10 feet and an mean error of registration of 1.5 pixels or 15 feet. In the photography living vegetation has a bright red or pink appearance while dead material is dark blue or black. In the gray scale rendition the darker the gray the less living vegetation in the pixel.

Discussion

Spatial Distribution of Salt in the Aquifer

The contours in figure three clearly indicate heterogeneity in all three dimensions. High concentrations (> 1000 mg/l) are found near the surface in the centers of transects 2, 4, and 5. These high values show greater temporal variability resulting in 95% confidence intervals from 100 to 2000 mg Cl/l. Slightly lower concentrations were found at lower depths under both the east and west ridges.

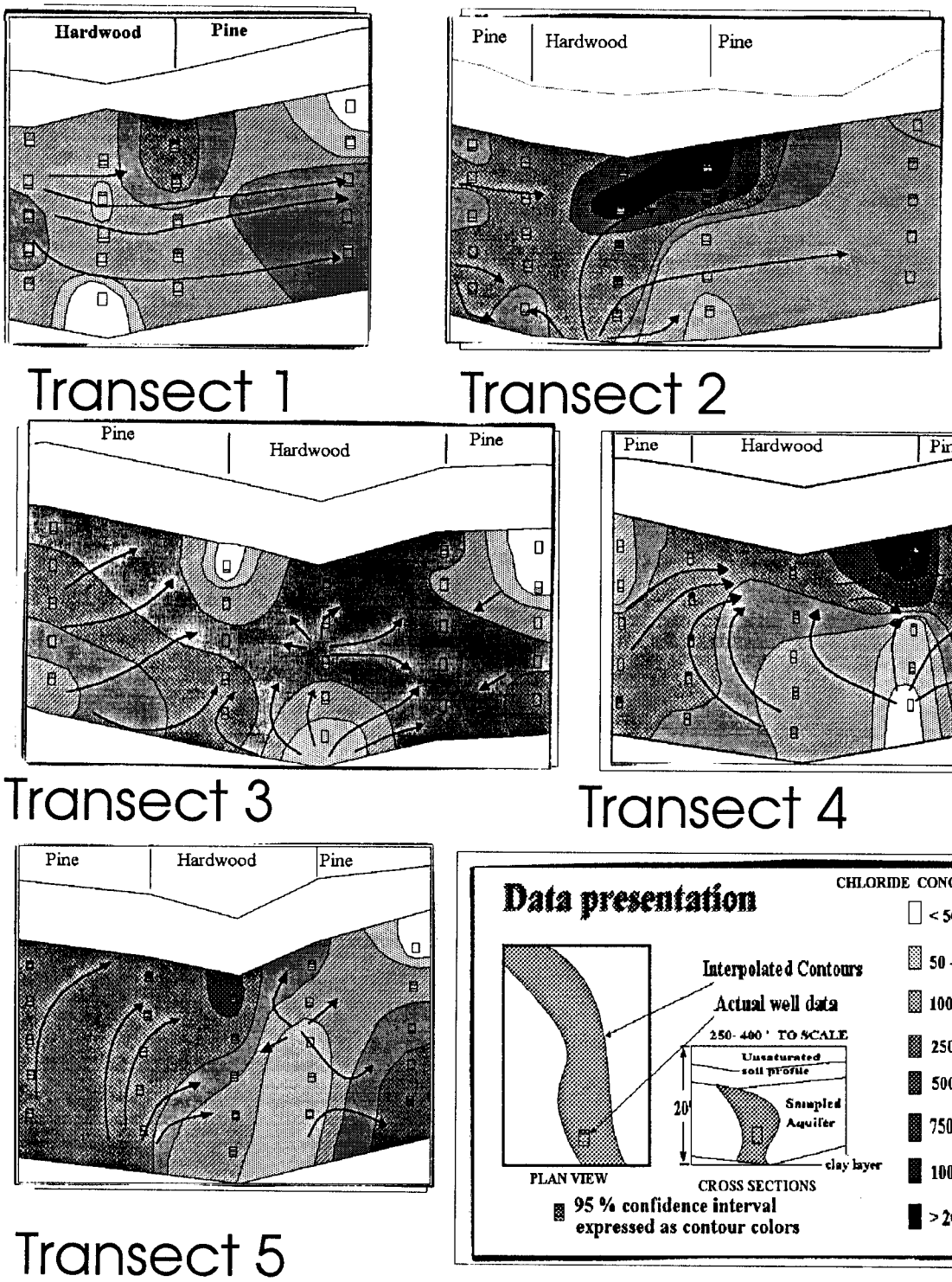
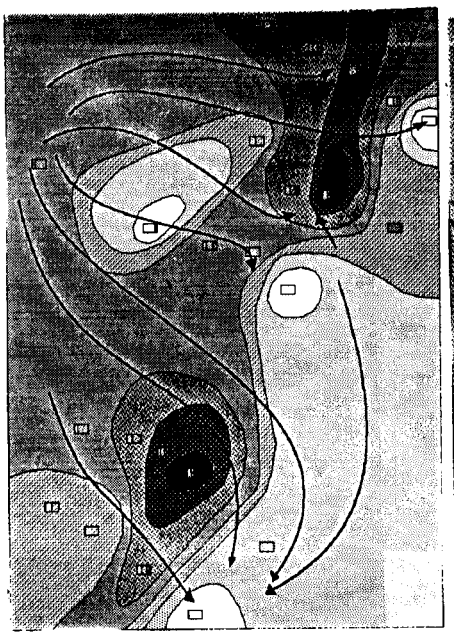
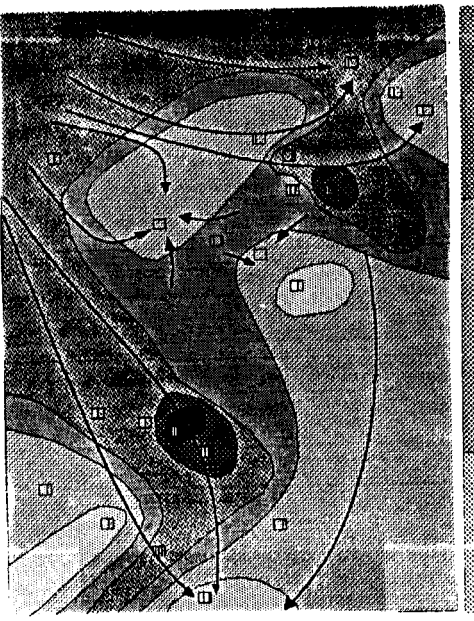


Figure 3a. *Cross sections of each transect showing mean chloride concentrations (contoured gray scales), 95% confidence limits on mean values for each sampling site (small rectangles with gray sales) and mean direction of groundwater flow (arrows).*

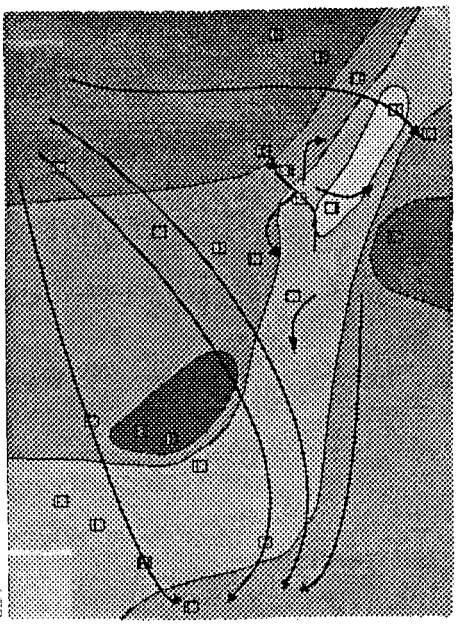
Values over 750 mg/l were found beneath the east ridge at transect 5. An extensive area with concentrations over 500 mg/l was present under the western ridge from transect 2 north all the way to transect 5. High concentrations in these locations were consistent throughout the study and 95% confidence limits were often less than 100 mg/l wide. Concentrations below 50 mg/l were found at the surface under the eastern ridge at transects 1, 3, and 5, and at the surface under the border of the western ridge at transect 4. Values below 100 mg/l were found at the aquifer bottom near the centers of all five transects.



4 ft. Depth



6 ft. Depth



8 ft depth

10 ft. Depth

12 ft. Depth

Figure 3b. *Horizontal cross sections of sampled area at each chloride sampling depth. Chloride concentration contours and 95% confidence rectangles use the same scale as figure 3a. Groundwater flow lines are for piezometer level just below sampling level.*

Figure 4. *Comparison of photographic mortality (right) estimates and 4 foot depth salinity estimates (left). Salinity map is the same as figure 3b and uses same gray scale. Mortality is gray scale of digitized February color infrared photograph. White box and markers are study area and well locations. Larger gray squares are 10 x10ft pixels with gray level indicating extent of live vegetation. Darker tones indicate greater mortality.*

Groundwater Flow Direction and Salinity

Groundwater flow direction combined with the chloride concentration distribution shows a relatively clear explanation of the data collected in this study. The bulk of the high salinity water is located under the west ridge, primarily beneath transects four and five. The bulk of the movement is to the southeast at most depths (Figure 3b). In addition at transects 2 - 5 there is a strong upward movement from beneath the western ridge. The eastern ridges do not show much movement and the fresh water beneath them is most likely an accumulation of rainfall since the surge. The low salinity areas at the bottom of the aquifer in transects 3, 4, and 5 are all consistent with artesian flow from an aquifer below the clay layer. At the eastern side of transect 4 a very strong gradient is moving fresh water in all directions and blocking the flow from the west. The saline water from the west is turned toward the south and the surface resulting in very high salinity at the surface in transects 4 and 5. Saline water also flows towards transect 2. In transect 2 the same upward movement of saline waters from the west and northwest seems to be caused by a very small upwelling. In this case relatively little water seems to be entering the aquifer but a high pressure area caused the waters from the west to rise.

In all cases high salinity occurred at the surface where upwelling of water from the lower aquifer forced the normal flow in the water table aquifer to the surface. At each of these points salinity rose rapidly during periods of little rainfall and high evaporation. In some cases the upwelling fresh water moved laterally and vertically. In transect 3 there is a small fresh area that may have resulted from upwelling water in transect 4 moving upward and outward at depths below 6 feet. Such a flow may have forced saline water to both the south and north at the edge of the lowland in transect 3.

Measured Salt Concentrations and Mortality

The similarity of spatial pattern of salt concentration in this study to that of tree mortality (figure 4)is quite apparent. Those portions of the site where mean chloride concentrations were found to average over 500 mg Cl/l also generally had dead trees. Likewise, the portions where concentrations were less than 100 mg Cl/l were mostly undamaged. Since the salt study was not begun until seven months after overstory death had occurred the measured salinity was not the cause of death. The measured salinity is more a record of groundwater flow patterns that may have also occurred during the period of overstory mortality. Also the mean chloride concentration of all samplers in March 1992 was only 5 mg/l less than that measured in April 1991

indicating relatively little change in overall salinity over the entire year.

Conclusions

High concentrations of salinity were found up to thirty months after a tidal surge covered a coastal pine and wetland area. Yearly averaged chloride concentrations at the top of the aquifer were found to be above 500 mg/l in most of the study area which experienced overstory mortality during 1990.

Chloride concentrations varied over two orders of magnitude in all three physical dimensions as well as through time. The spatial variability was consistent with measured flow paths and salinity patterns. With elaborate three dimensional sampling the pattern of overstory mortality was explained post priori.

A consistent finding in this study was that highest salinity and overstory death were found in areas where groundwater flow moved deeper groundwater toward the surface. One might expect that in coastal systems highest salt induced mortality would be along wetland borders where one would normally find perennial wet spots.

Acknowledgments

Funding was provided by the U.S. Forest Service and the State of South Carolina. Dedicated field sampling and preliminary data reduction on piezometric data were done by Steven Williams and laboratory analyses were conducted by Louwanda Jolley. Their efforts are greatly appreciated.

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ARTIFICIAL REGENERATION OF BALDCYPRESS IN THREE SOUTH CAROLINA FORESTED WETLAND AREAS AFTER HURRICANE HUGO [1]

William H. Conner [2]

Abstract. Permanent plots were established in three forested wetlands on Hobcaw Barony, South Carolina, during the spring of 1990 to monitor recovery of the wetlands following Hurricane Hugo. Plots were located in (1) an area that retained saltwater for several days following the hurricane storm surge, (2) an area flushed with saltwater, and (3) an area that received no saltwater. Because of the lack of natural regeneration occurring in the three areas, baldcypress seedlings were planted to help restock the stands. Tubex treeshelters were placed on one-half of the seedlings to determine if they improved survival and height growth. After two growing seasons, survival was greatest in the area that received no saltwater. The treeshelters seemed to increase survival of seedlings in the two storm surge areas. Height growth was greatest in the area that retained saltwater, and seedlings averaged over 10 inches taller than seedlings in the other two areas. Whereas the treeshelters seemed to have a beneficial effect on height growth during the first growing season, growth differences were not as pronounced during year two. Available light and salinity levels may be the two most important factors controlling survival and growth in the stands. More detailed research needs to be conducted to develop sound silvicultural plans.

Introduction

Hurricanes are an episodic, but normal, part of the climatic regime of the southeastern United States. Current evidence indicates that between 160,000 and 320,000 hurricanes have occurred in the Florida Keys during the past 2 million years (Ball et al. 1967). What coastal ecosystems would be like without hurricanes is unknown, but they would probably be different, both morphologically and ecologically (Conner et al. 1989). Hurricane disturbance can result from both wind and flooding effects. High winds can defoliate, break, or topple trees, with the severity of damage related to storm intensity, forest structure, species, and soil conditions (Weaver 1989, Gresham et al. 1991). Little attention has been given to storm surge effects since heavy rains accompanying the hurricane usually saturate soils to protect them from saltwater intrusion (Gardner et al. 1991, Hook et al. 1991).

Hurricane Hugo struck the South Carolina coast in September 1989 causing timber damage on nearly 4.5 million acres (Hook et al. 1991). Hobcaw Forest, 4 miles east of Georgetown and 56 miles northeast of where the eye of the hurricane came ashore, was hit with winds estimated to be 54 mi/hr gusting to 86 mi/hr (Purvis et al. 1990). Although heavy damage was sustained in pine forests and poorly drained bottomland forests, baldcypress (*Taxodium distichum* (L.) Rich.) forests suffered little wind damage (Gresham et al. 1991, Hook et al. 1991). The greatest damage to forested wetlands on Hobcaw was caused by saltwater flooding from the 10 ft storm surge.

Objectives

The objectives of this research were to initially document the effects of Hurricane Hugo on Hobcaw forested wetlands and natural recovery of the forest. However, the lack of natural regeneration during the first growing season after Hugo necessitated the establishment of long-term study plots to monitor regeneration patterns and to examine the feasibility of planting seedlings in the affected stands. This paper describes the damage done to three forested wetland stands, the lack of natural regeneration, and the initial success of underplanting baldcypress seedlings.

Methods

Study plots were established during March 1991, 18 months after Hurricane Hugo, in three forested wetland stands on Hobcaw Forest. The first stand (hereafter referred to as Marsh Road) was a

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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baldcypress/swamp blackgum (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.) forest that lies between two old beach ridges on the eastern edge of Hobcaw Forest. Saltwater from the storm surge was retained in the forest for several days. The second area (Boardwalk) was flushed by saltwater, and the third area (Crabhaul) received no saltwater but did receive minor wind damage.

Within each stand, five 0.12 acre plots were installed during the spring of 1990 to inventory trees larger than 4.0 inches diameter at breast height (dbh). Each tree was tagged, dbh measured, and condition or cause of death recorded. Natural regeneration was monitored in ten 3.3 ft X 3.3 ft subplots within each of the larger plots. Regeneration was inventoried in June and September 1990 and in January and May 1991. Seed banks were sampled by randomly collecting twenty 12 in X 12 in X 2 in sections of forest floor from each stand in July 1990. The soil samples were mixed, placed in trays, put in a greenhouse, kept moist, and inventoried weekly for three months. After three months, tree seeds were collected by sieving and tested for viability using Tetrazolium (Shuel 1948).

When it became evident that little natural regeneration was occurring in the stands, 80 one-year-old baldcypress seedlings (obtained from the South Carolina Forestry Commission) were planted adjacent to each tree measurement plot in March 1991. The planting design consisted of 20 equally spaced planting spokes radiating from a center point. Four seedlings were planted on each spoke at a 6.6 ft spacing. Two foot tall Tubex treeshelters were used on seedlings in every other row to determine if they increased survival and growth of newly planted seedlings in wetland conditions.

Results and Discussion

Tree Damage

Very few tops were broken out of trees in the wetland stands (Table 1), although 84% of baldcypress trees and 88% of swamp blackgum trees did suffer some limb breakage (Gresham et al. 1991). Major damage was caused by the 10 foot storm surge that struck the eastern edge of the forest. Runoff was impeded in the Marsh Road stand by old logging roads at each end of the low-lying area that the forest is in. Saltwater was retained for several days until water levels stabilized at prestorm heights. Salinity levels of 2 ppt were still being measured two years after the hurricane. Over one-half of the canopy trees were killed during the first few weeks following flooding. Saltwater also flooded the Boardwalk area, killing the mainly waxmyrtle (*Myrica cerifera* L.) understory. Only 28% of the canopy trees died immediately after the saltwater surge. Additional mortality occurred, however, during the summer following the storm surge. It is unknown why this delay in mortality occurred in the Boardwalk area. Canopy trees are still dying in the two saltwater areas, indicating that there are still residual effects of the salt.

Table 1. *Variation in Hurricane Hugo damage to three forested wetland stands in South Carolina. All values are given as percentages.*

Area	Top Breakage	Dead 1990	Dead 1991
Crabhaul	2.7	0	0
Boardwalk	3.8	28.0	40.8
Marsh Road	1.8	57.1	65.5

Natural Regeneration

There was very little natural regeneration of woody species during the two growing seasons following Hurricane Hugo. The greatest number of baldcypress and water tupelo seedlings came up in the Crabhaul stand, but they failed to grow tall enough to survive subsequent flooding. In the Marsh Road and Boardwalk stands, some redbay (*Persea borbonia* (l.) Spreng.), waxmyrtle, fetterbush (*Lyonia lucida* (Lam.) Koch), and red maple (*Acer rubrum* L.) became established on old stumps, cypress knees and buttresses, and other raised areas that kept them out of the water. Overall, only 3 water tupelo seedlings survived in the Crabhaul stand, along with 5 baldcypress in the Boardwalk stand and 2 baldcypress in the Marsh Road stand.

The soil seed banks were surprisingly devoid of seeds from the canopy species. A total of 7 baldcypress and 13 swamp blackgum seeds germinated from the soil sections taken from Crabhaul. This was much better than the Boardwalk stand (no germination) or the Marsh Road stand (3 baldcypress). Although a number of seeds were sieved from the soil samples at the end of three months, none tested viable with Tetrazolium. This pool of dead seeds is similar to that observed by Schneider and Sharitz (1986) for another forested wetland site in South

Carolina. They suggested that too much flooding may result in nonviable seeds. Saltwater may have also had an impact in this study. Additional work needs to be done examining the seed longevity and viability in relation to flooding and salinity.

Planted Seedlings

Survival of baldcypress seedlings during the first growing season was greatest in the Crabhaul stand and least in the Boardwalk stand (Table 2). Tubex treeshelters seemed to greatly increase survival in the Boardwalk area, while there were no differences in survival of Tubex and non-Tubex seedlings in the Crabhaul stand. Survival was greater with treeshelters in the Marsh Road stand, but not significantly. Survival percentages after two growing seasons were similar to first year survival in the Crabhaul and Marsh Road stands, but the Boardwalk stand continued to lose seedlings. Saltwater in the Marsh Road and Boardwalk areas may still be affecting survival. Examination of Cl^- levels in seedling leaves revealed 71 ppm in the Boardwalk area and 57 ppm in the Marsh Road area compared to 17 ppm in the Marsh Road area. Whereas chloride is an essential micronutrient, excess chloride can be detrimental (Ghosh and Drew 1991). Pezeshki et al. (1988) found that salinity causes accumulation of several ions in baldcypress leaf tissue significantly decreasing photosynthesis levels.

Table 2. *Survival of planted baldcypress seedlings in three South Carolina wetland stands.*

Area	First-year survival		Second-year survival	
	Tubex	non-Tubex	Tubex	non-Tubex
Crabhaul	100	100	100	99
Boardwalk	79	48	72	38
Marsh Road	94	82	92	80

Height growth was best in the Marsh Road area during both growing seasons (Table 3). Average height of seedlings in the Marsh Road stand were 3 inches greater than seedlings in the other two areas after one growing season and 10 inches greater after two growing seasons. The Tubex treeshelters seemed to have a beneficial effect on height growth during the first growing season but not as clear an effect during the second year. Non-Tubex seedlings grew slightly more than Tubex seedlings in Crabhaul during the second growing season and slightly less than Tubex seedlings in Marsh Road. The Boardwalk was the only area that exhibited significantly greater height growth of Tubex seedlings during the second growing season. Most of the seedlings grew out of the 2-foot treeshelters during the first year. Therefore, the treeshelters did not offer much of an advantage over non-Tubex seedlings during the second year. Taller treeshelters should be tested to see if they remain beneficial for longer than one growing season.

Table 3. *Average height growth (inches) of planted baldcypress seedlings in three South Carolina wetland stands.*

Area	First-year growth		Second-year growth	
	Tubex	non-Tubex	Tubex	non-Tubex
Crabhaul	3.5	3.0	4.6	5.0
Boardwalk	3.4	1.3	5.0	0.9
Marsh Road	7.0	4.2	11.6	10.7

One factor that probably influenced growth rates at the Crabhaul and Boardwalk stands was the amount of sunlight reaching the forest floor. Only 4% of available light reached the Crabhaul forest floor during the summer months. Even though 38% of available light reached the floor at Boardwalk, this may not have been sufficient for maximum growth. Baldcypress tends to be intermediately tolerant to shade and grows best in full sunlight conditions (Wenger 1984, Wilhite and Toliver 1990). The Marsh Road stand has the most open canopy and 58% of available light reached the forest floor. Conner and Flynn (1989) found similar results in a Louisiana wetland forest where baldcypress seedlings planted in more open areas grew better than those planted in shaded areas (9 inches versus 3 inches).

Conclusions

Natural regeneration in hurricane impacted forested wetland stands is very erratic. To ensure adequate stocking of the stand after disturbance, planting may be necessary. However, there is much to learn before we can recommend large-scale reforestation of baldcypress stands. More detailed, long-term studies need to be conducted to ensure that sound silvicultural practices be formulated.

Acknowledgments

Funding was provided by the U.S. Forest Service and by the McIntire-Stennis Cooperative Forestry Research Program. Comments by Chuck Gresham helped improve the manuscript. Belle W. Baruch Forest Science Institute Technical Contribution: 93-3.

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ESTIMATION OF ABOVE-GROUND BIOMASS IN A HURRICANE-IMPACTED COASTAL PLAIN FOREST [1]

Richard K. Myers, David H. Van Lear, and F. Thomas Lloyd [2]

Abstract. This paper describes one phase of a long-term study on the role of fire in post-hurricane forest plant community dynamics. Two years after Hugo but prior to initiation of fire regime treatments, the biomass complex within the 75-ac study area on the heavily damaged Santee Experimental Forest in South Carolina was assessed using a variety of techniques to establish pre-burn data baselines. Overall, downed woody debris comprised the largest biomass component at 57.8% of the total, followed by forest floor (16.3%), living residual trees (15.0%), dead residual trees (8.1%), and regeneration layer vegetation (2.8%). Detailed quantitative pre-treatment descriptions characterize biomass distribution and document variation in post-hurricane vegetative structure and fuel characteristics, and will permit assessments of nutrient pool variation among treatment plots. These baselines will allow for more sensitive testing and evaluation of fire effects on the development of plant communities following devastating hurricanes.

Introduction

Hurricane Hugo's profound impact on the Francis Marion National Forest in South Carolina has presented the rare opportunity to formally study plant communities as they develop following what is arguably the most severe of natural disturbance factors in the southeastern United States: the combination of strong winds from hurricanes and subsequent wildfires in heavy fuels. This combination has almost certainly been a highly influential force in the evolution of plant species and community successional patterns, and a driving factor in the development of coastal plain landscapes. However, little documentation of the ecological processes involved in this interaction have to date been reported in the literature.

One part of a current research effort (Van Lear 1990, Van Lear and Myers 1992) investigating the role of fire in hurricane-devastated coastal plain forest plant communities has involved the detailed description of the biomass complex of the study area. Measurement and description of post-hurricane/ pre-fire biomass components will allow for evaluation of such phenomena as nutrient redistribution and vegetation change following the implementation of burning treatments. One objective of this paper is to document post-Hugo stand conditions and to characterize biomass distribution of forest stands in which the fire-regime treatments are to be applied.

Characterizing post-hurricane forest structure and biomass becomes a difficult sampling problem. Forests severely damaged by windstorms and abetted by two growing seasons of early successional vegetative development are chaotic and highly variable assemblages of both living and dead plant material. Empirical description of the quantity of biomass and nutrients in various biomass components has required the use of both standard and improvised techniques. Thus, a second objective of this paper is to report on methods herein employed to describe the post-hurricane biomass complex.

Study Area

This research is being conducted at two sites on the Santee Experimental Forest (SEF) within the Witherbee Ranger District of the Francis Marion National Forest (FMNF). The FMNF is located in the Lower Terraces of the Coastal Flatwoods Region, a part of the Flatlands Coastal Plain Province in South Carolina (Myers et al. 1986). Soils are mostly moderately well drained to somewhat poorly drained, and include Craven, Duplin, Lenoir, and Wahee soil series. These are soils with slow to moderately slow permeability and seasonally high water tables (Long 1980).

Both of the two study sites on the SEF were natural, unevenage mature pine stands prior to Hurricane Hugo, with the oldest trees exceeding 150 yrs in age. Stand records indicate loblolly (*Pinus taeda* L.) and longleaf (*Pinus palustris* Mill.) pine were the predominant overstory species, comprising

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stands for decades, except for four small wildfires that burned in parts of both sites in the 1960's (USFS Witherbee R.D. Fire Atlas). Various species of hardwoods, notably the oaks (*Quercus* spp.), sweetgum (*Liquidambar styraciflua* L.), and blackgum (*Nyssa sylvatica* Marsh.), had become well-established in the under- and mid-stories, and were beginning to encroach into the overstory.

Fifteen, 5-ac burning plots, each surrounded by a wide (30 ft) firebreak, comprise the treatment areas in this study. A randomized complete block design was utilized with three blocked replicates of five treatment plots. Four burning regimes plus an unburned control constitute the five treatments, which were assigned at random for each block of five plots. Biomass and structure of vegetation, living and dead, was characterized prior to burning for each treatment plot. Biomass summaries will be presented here on an average per ac basis by treatment (3 reps combined) rather than on a plot by plot basis.

Biomass Categories and Estimates

Five distinct biomass categories were recognized which collectively comprised the vegetative complex of the hurricane-impacted forest two years following Hugo. These five biomass categories are: the regeneration layer (RL), forest floor (FF), downed woody debris (DWD), living residual trees (LRT), and dead residual trees (DRT). Empirical description of each of these components required specialized and, in some cases, improvised sampling methods.

Regeneration Layer

This biomass component consisted of living vegetation, both woody and herbaceous, much of which has developed in the two years following the hurricane-induced removal of the canopy. The regeneration layer (RL) was defined to include trees and shrubs less than 1-in dbh, woody vines, graminoids, forbs, and ferns. These six lifeform groups were arranged in a diverse assemblage of species associations and developing plant communities across the 75-ac study area.

It was subjectively observed prior to sampling that there was considerable variation in quantity and vegetative makeup of RL biomass within the study area. Nutrient content per unit weight of biomass can also vary greatly from one type of vegetation to another. Because of this perceived variation in amount and form of RL biomass, stratification was considered appropriate to decrease sample size, given the constraints of time, manpower, and funds available for this phase of the study.

A stratification procedure was developed that combined identification and estimation of unit area dry weight of Regeneration Layer Cover Types (RLCT) with measurement of area occupied by cover types within each plot. By combining RLCT weight per unit area with an estimate of cover type area, RL biomass and its composition in terms of lifeform plant assemblages for each pre-burn plot could be estimated. Weight per unit area was determined for each RLCT from destructive (ground) samples, and cover type area was measured on low-level helicopter-obtained aerial photography of each plot, a technique similar to that suggested by Helms and Shain (1981). This method increased sampling efficiency by reducing variability of stratified clip plots, resulting in a smaller sample size for obtaining acceptable weight estimates for each RLCT.

Eight rectangular (6.6 ft x 9.8 ft) quadrats were located in each of the five photo-identifiable RLCT's, and monumented with 5-ft conduit driven 1.5 ft into the ground. Four samples of each cover type (n=20) were placed in dormant season burn plots while the other 20 samples were located in growing season burn plots, allowing regeneration layer development comparisons between these two levels of the season-of-burn main effect. One half (3.3 ft x 9.8 ft) of each clip plot was sampled prior to initial fire treatments in late October-early November of 1991. The remaining unclipped plot-half was reserved for post-burn sampling in 1992 and 1993. Bormann (1953) described the advantages of using rectangular (long/narrow) plot shapes in uneven, discontinuous, and variable vegetation.

All herbaceous and woody plants less than 1-in dbh rooted in the plot were cut at or as near as possible to the groundline, and separated into the six previously-described lifeform groups. Vegetation was placed into separate paper bags by group, labeled, and returned to the lab for dry weight determination. Estimates for dry weight per unit area (T/ac) for each RLCT were obtained from the average of eight oven-dry sample weights, based on the composite weight of all plants clipped on each destructive sample plot. Thus, each RLCT pre-burn biomass estimate is based on 258.7 ft^2 of clipped plot area. Separation of RLCT destructive biomass samples into plant lifeform components allowed for determination and description of pre-burn plant community composition based on biomass proportions (Table 1).

Estimation of area covered by each RLCT for each plot was achieved by dot grid counts on aerial photographs. Photos were obtained on October 16, 1991 using hand-held 35-mm cameras and color slide films (400 ASA) during low-level (500 ft above land surface) helicopter flights over the study areas. Plots were framed within separate, nearly-vertical exposures using zoom lenses so that plot firebreaks were as close as possible to image borders. Accurate photo-interpretation of plots was possible with the high resolution slide images enlarged by projection. Corrections for photo scale distortion resulting from tilt were made by the use of rectified dot grid transparencies mounted in the same frames with color slide plot images. Rectified grids were constructed optically in the lab by photographing tilted dot grids drawn on white paper at a density of four dots per in^2.

For each plot, the total number of dots falling in each of the five RLCT's was counted. That proportion of dots per type to total dots per plot was calculated and used as an estimate for the proportion of area in each plot covered by each cover type. Table 2 presents area estimates for cover types in each of the five treatment areas.

As a check on this method of determining area in cover types from aerial photo interpretations and dot counts, an independent area estimate was made based on a set of 480 ground samples. Thirty-two cover type ground samples (3.3 ft x 9.8 ft) were systematically located in all 15 treatment plots. Each sample was given one of the five RLCT names based on its vegetative makeup. That proportion of ground samples (X/32) in each RLCT was taken as an estimate for the proportion of area in the treatment plot occupied by each RLCT, in the same manner as with the aerial photo procedure.

A simple correlation analysis was performed for the two methods of area estimation. While correlation was expectedly imperfect, the scatter diagram (Fig. 1) and high coeffecient of determination ($r^2 = 0.7598$) shows that there is a strong relationship between the estimates of the two methods. Since a statistically significant ($F = 230.95$; $df = 73$) relationship resulted from this analysis, it can be inferred that the two methods yield similar estimates of area in cover types. The aerial technique with its greater sampling intensity (n=2401) is less apt to exclude smaller areas of relatively rare cover types, while the ground method has obvious advantages for correctly identifying vegetative assemblages and assigning cover type names. Aerial photo area estimates were ultimately used to calculate both regeneration layer and forest floor biomass for this project. Overall, regeneration layer biomass averaged 2.3 T/ac across the 75-ac study area (Table 3).

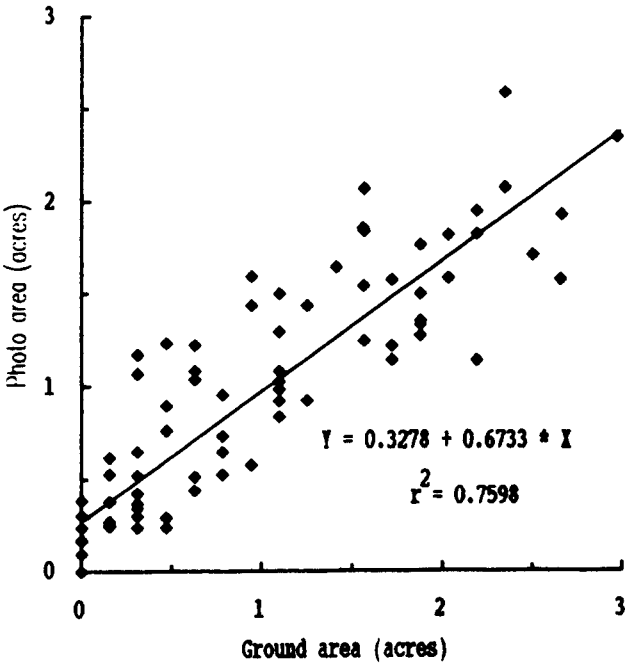

Figure 1. *Correlation of photo and ground RLCT area estimates.*

Forest Floor

Forest floor (FF) biomass was assessed by methods similar to those used in regeneration layer biomass description. High variation in characteristics of the forest floor across the study area were anticipated and assumed to be related in part to vegetation characteristics. To minimize sample sizes while still obtaining representative estimates for forest floor biomass and nutrient content, sampling was stratified by RLCT. One 0.672 ft^2 composite (litter + fermentation layer + humus) sample was collected from one of 48 possible random locations within each of the 40 clipped regeneration layer plots described above. All organic material excluding dead woody material visible on the litter surface was removed, placed in paper bags, labeled, and returned to the lab for drying, processing in a hammer mill, determination of mineral content, and storage for later nutrient content assays. Mineral fraction of samples was determined by the method of Hesse (1974).

Forest floor weight estimates were calculated for each RLCT based on the average of the eight samples per cover type. Area factors for RLCT's already established (Table 2) were used to determine

Table 1. *Dry weight of lifeform components comprising five regeneration layer cover types (RLCT), prior to burning and two growing seasons following Hurricane Hugo.*

Plant Lifeform	Regeneration Layer Cover Type				
	Pine	Herb.	Hwd.	Mixed	Shaded
	dry wt. - tons/acre				
Trees	1.97	0.25	1.38	0.72	0.25
Shrubs	0.49	0.07	1.53	0.47	0.39
Woody Vines	0.07	0.04	0.29	0.21	0.08
Graminoids	0.60	1.77	0.25	0.58	0.13
Forbs	0.40	0.13	0.03	0.24	0.04
Ferns/Moss	0.01	0.00	0.01	0.00	0.00
Total	3.54	2.26	3.49	2.22	0.89

Table 2. *Area in regeneration layer cover types (RLCT) estimated from aerial photos, summarized by treatment area.*

Treatment Area	Regeneration Layer Cover Type					Treatment Total
	Pine	Herb.	Hwd.	Mixed	Shaded	
	acres					
A	1.045	0.832	4.605	5.755	2.762	15
B	1.808	1.075	4.978	4.168	2.972	15
C	1.798	1.315	3.685	5.130	3.072	15
D	0.435	1.682	3.540	4.360	4.982	15
E	1.158	2.158	4.590	4.480	2.615	15
Total	6.242	7.062	21.398	23.892	16.405	75

Table 3. *Pre-burn regeneration layer (RL) biomass distribution, two growing seasons following Hurricane Hugo.*

Treatment Area	Regeneration Layer Cover Type					Total
	Pine	Herb.	Hwd.	Mixed	Shaded	
	dry wt. - tons/acre					
A	0.25	0.13	1.07	0.41	0.16	2.02
B	0.42	0.16	1.16	0.62	0.18	2.54
C	0.42	0.20	0.86	0.76	0.18	2.42
D	0.10	0.25	0.82	0.65	0.29	2.12
E	0.27	0.32	1.07	0.66	0.15	2.48
Mean	0.29	0.21	1.00	0.62	0.19	2.32

dry weight biomass estimates for the forest floor in each of the 15 treatment plots (Table 4). Overall, forest floor biomass averaged 13.7 T/ac across the 75-ac study area.

Downed Woody Debris

The planar intersect method described by Brown (1974) was employed to estimate pre-burn dry weight of wood and bark contained in down and dead trees and other downed woody material (DWD). Eight sampling planes were established on each 5-ac treatment plot using the permanent measurement points already in place as plane origins. A subset of the 16 points per plot was chosen by random selection of either the even- or odd-numbered stations. Compass bearings for sampling planes were also randomly selected from one of the three remaining cardinal or semi-cardinal directions not already used for plant cover measurement. Thus, eight samples per

Table 4. *Pre-burn forest floor (FF) biomass distribution, two growing seasons following Hugo.*

Treatment Area	Regeneration Layer Cover Type					Total Biomass
	Pine	Herb.	Hwd.	Mixed	Shaded	
	dry wt. - tons/acre					
A	0.93	0.31	5.55	4.48	2.70	13.98
B	1.62	0.40	6.00	3.24	2.91	14.17
C	1.61	0.49	4.42	3.99	3.00	13.52
D	0.39	0.63	4.27	3.39	4.87	13.56
E	1.04	0.81	5.53	3.49	2.56	13.42
Mean	1.12	0.53	5.15	3.72	3.21	13.73

plot (24/treatment area) were established for downed woody material biomass assessment.

Variable-length sampling planes were utilized to achieve high sampling efficiency. Long planes (50 ft) were used for the larger (3+ in), less-frequently-occurring pieces of DWD, while shorter transects were used for the numerous small pieces. Woody material 0-1 in diameter at the point of plane-intersection was measured on 6-ft planes, while 12-ft planes were used for material 1-3 in diameter. End-points of transects were marked with flagging and aluminum pins placed in the ground to facilitate reestablishment and remeasurement of sample planes after burning.

Table 5 summarizes quantities and variation in DWD distribution, by size class, for the five treatment areas. Given the severity of damage and the large size of trees in these stands prior to Hugo, it is not surprising that DWD represented the largest of the five components of aboveground biomass in the hurricane-impacted forest. Overall, DWD averaged 48.7 T/ac across the 75-ac study area. Variation was moderate, ranging from a low average of 41.8 T/ac for the three plots (15 ac) in treatment C to a high of 56.2 T/ac for treatment B.

Residual Living and Dead Trees

Biomass in living residual trees (LRT) and standing, dead residual trees (DRT) was quantified for each plot using tree measurements of dbh and total height obtained from fixed-radius plot samples. These tree data were used to estimate total aboveground biomass in living and dead residual trees in conjunction with published biomass equations for estimating wood and bark in the total tree (Clark and Taras 1976; Phillips 1981; Saucier and Clark 1985; Taras and Clark 1977). Each treatment plot was "cruised" using sixteen 1/20-ac circular plots with centers at the 240 monumented sampling points previously described. All trees 3.0-in dbh and larger, dead or alive, rooted within these plots were tallied for species, dbh, total height, and condition (vertical, leaning, downed, top-broken, etc.). In addition, 32, 1/200-ac samples per treatment plot (n=480) were established at monuments and at monument mid-points in which the above measurements were taken for trees and large shrubs 1.0 - 2.9-in dbh. Using information from these inventories, woody biomass descriptions were compiled in tabular form for each of the fifteen 5-ac plots.

The majority of trees in the hurricane area had abnormal form, with tops blown out or broken off, limbs removed from crowns to varying degrees, and (with hardwood species) two years of vigorous regrowth in the form of epicormic, limb, and basal sprouts. Equations generally used dbh and total height to predict whole-tree biomass. Trees with crowns completely removed (e.g. the numerous dead standing pine boles typical of the hurricane-impacted forest area) were measured for total height of that portion of stem remaining, and equations for dbh and merchantable height were used to estimate biomass of wood and bark, on a dry-weight basis.

The many published whole-tree equations are not designed to predict biomass in trees with wind-damaged crowns. Thus, the accuracy of the biomass predictions for the damaged residual forest stand may be in question. However, the alternative to the use of existing equations was to destructively sample many trees of many species, a prohibitively expensive and time-consuming task. Since the quantities of biomass estimated in this study are used primarily as a means for comparing effects of various burning treatments on the redistribution of nutrients, the method is defensible and valid. It is the repeatability of the measurements and estimates that is most important in this application, and not estimate accuracy. Tables 6 and 7, respectively, summarize distribution of LRT

Table 5. *Pre-burn downed woody material (DWM) biomass distribution, two growing seasons following Hugo.*

Treatment Area	0-3" size class			3"+ size class		Total Biomass
	0-.25"	.25-1"	1-3"	sound	rotten	
	dry wt. - tons/acre					
A	0.66	1.92	6.22	38.39	2.66	49.85
B	0.59	2.95	6.28	45.57	0.82	56.21
C	0.63	2.52	7.27	31.39	0.03	41.84
D	0.75	2.03	5.64	39.50	2.49	50.41
E	0.47	1.83	4.94	37.10	1.02	45.36
Mean	0.62	2.25	6.07	38.39	1.40	48.73

Table 6. *Pre-burn living residual tree (LRT) biomass distribution, two growing seasons following Hugo.*

Treatment Area	Species Group					Total Biomass
	Pine	Oaks	Sweetgum	H-Hwd	S-Hwd	
	dry wt. - tons/acre					
A	4.62	3.49	0.94	0.33	1.73	11.11
B	4.62	6.42	0.45	1.08	0.54	13.11
C	6.20	3.02	0.80	0.57	1.38	11.97
D	7.50	4.40	0.57	2.11	1.20	15.78
E	3.92	4.33	1.32	0.29	1.42	11.28
Mean	5.37	4.33	0.82	0.88	1.25	12.65

Table 7. *Pre-burn dead residual tree (DRT) biomass distribution, two growing seasons following Hugo.*

Treatment Area	Pine		Hardwood		Total Biomass
	Trees	Snags	Hard	Soft	
	dry wt. - tons/acre				
A	1.52	6.53	0.54	0.02	8.61
B	1.43	3.30	1.04	0.03	5.81
C	0.16	4.79	0.51	0.08	5.54
D	2.56	4.09	1.28	0.04	7.98
E	1.64	4.00	0.27	0.14	6.06
Mean	1.46	4.54	0.73	0.06	6.80

and DRT biomass. In Table 7, the term "snags" refers to dead pines whose crowns were completely broken out by strong wind, leaving only the standing boles.

Distribution of Biomass

Total aboveground dry biomass across the study area averaged 84.2 T/ac (Table 8). This quantity is similar to estimates from other studies for total forest biomass in natural, 60+-year-old southern pine and mixed pine-hardwood forests (Knight and McClure 1981). Downed woody debris comprised the largest (57.8%) component, by weight, of biomass in the hurricane-devastated forest. This finding was expected in view of the severity of Hugo's impact and the extensive windthrow and stem breakage of many large trees. The regeneration layer represented the smallest (2.8%) biomass component, but required the most effort for valid quantification because of its variability and the diversity of plant forms comprising it. This effort was considered worthwhile, since RL biomass is high in nutrient content relative to the other more woody biomass components (Van Lear et al. 1988), and because these plants represent the seed

Table 8. *Pre-burn aboveground biomass distribution for five treatment areas two growing seasons post-Hugo.*

Treatment Area	RL	DWM	FF	LRT	DRT	TOTAL
	dry wt. - tons/acre					
A	2.02	49.85	13.98	11.11	8.61	85.57
B	2.54	56.21	14.17	13.11	5.81	91.84
C	2.42	41.84	13.52	11.97	5.54	75.29
D	2.12	50.41	13.56	15.78	7.98	89.85
E	2.48	45.36	13.42	11.28	6.06	78.60
MEAN	2.32	48.73	13.73	12.65	6.80	84.23
PERCENT	2.8	57.8	16.3	15.0	8.1	100.0

sources and rootstocks that will play important roles in the colonization of the sites following burning treatments.

Conclusions

The biomass quantification phase of this study demonstrated that in the chaotic, complex structure of hurricane-devastated but rapidly regenerating forests, a combination of standard and improvised techniques is necessary for assessing forest attributes. On the Santee Experimental Forest after Hurricane Hugo, downed woody debris was the largest component of total biomass (57.8 %), followed by the forest floor, living residual trees, dead residual trees, and the regeneration layer. Baseline data have been collected and summarized which thoroughly describe pre-treatment conditions of stand structure and biomass distribution, allowing for subsequent assessment of nutrient pools. These baselines will enable burning treatment effects to be documented and analyzed in an on-going study of the interactive effects of hurricanes and fire on the development of forest plant communities.

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HURRICANE HUGO EFFECTS ON OLD-GROWTH FLOODPLAIN FOREST COMMUNITIES AT FOUR HOLES SWAMP, SOUTH CAROLINA [1]

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Abstract. We assessed hurricane damage and mortality of 1233 canopy trees (≥6 in dbh) in sixteen plots within the old growth floodplain forest in Four Hole Swamp. Sixty percent of the trees sustained major damage, and 22% had died within two growing seasons as a result of the hurricane. Higher elevation Ridge Bottom forest plots sustained the greatest damage (81%) and highest mortality (47%), while the lower Cypress/Tupelo forest plots had the least (43% and 4%, respectively), and mid-elevation Hardwood Bottomland forests were intermediate (64% and 24%, respectively). Among the more common species in our plots, water oak (*Quercus nigra* L.) and spruce pine (*Pinus glabra* Walt.) had the largest percentage of individuals damaged (≥93%), and baldcypress (*Taxodium distichum* (L.) Rich), blackgum (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.), water tupelo (*Nyssa aquatica* L.), and Carolina ash (*Fraxinus caroliniana* Mill.) had the smallest (≤47%). After two growing seasons, spruce pine had by far the greatest percent mortality (91%) of individuals alive at the time of the hurricane, and water tupelo and blackgum the lowest (1% and 3%, respectively). The dominant type of damage was main stem break (50% of affected trees). However, of the different types of damage, 70% of uprooted trees died and only 35% of the main stem broken trees died. Mortality among trees with major branch loss and bent stems has been less than 10%. Hurricane Hugo effects were not randomly distributed through the forest. While other factors may be involved, species present, and possibly community type, influence the kinds and degree of effects.

Introduction

In recent years there has been an increasing awareness of the role natural perturbations play in ecosystem dynamics. The concept that nature, undisturbed by man, is maintained in an equilibrium condition is being replaced with the concept that ecosystems are unstable, and different portions of them are changing at different rates under the influence of one or more types of disturbance (Runkle 1982, Pickett and White 1985). Major perturbations can in a matter of hours or weeks produce more change in an ecosystem than would occur during normal everyday processes over periods of decades or even centuries (Hook et al. 1991, Whigham et al. 1991). Documenting how these events interact with other natural processes to produce the earth's varied landscapes is critical to our understanding of how existing ecosystems have come into being and are likely to change in the future.

Hurricanes represent one type of severe perturbation that produces major changes in natural landscapes (Sheffield and Thompson 1992, McCollom and Duever 1992). They are regular visitors to the southeastern United States, although there may be many years between visits to any particular area (Neumann 1987, Duever et al. In Press).

On September 22, 1989, the eye of Hurricane Hugo, passed over National Audubon Society's Francis Beidler Forest in South Carolina, which contains the largest stand of old-growth baldcypress and water tupelo in the world (Brunswig & Winton 1978). An average of wind speeds estimated by Sparks of Clemson University for four cities (Camden, Sumter, Summerville, and Charleston) bracketing Beidler Forest along the hurricane's path place estimated mean hourly wind speed at 72 mph with gusts up to 115 mph (Purvis et al. 1990). Rainfall associated with the hurricane was 4-5 inches (Purvis et al. 1990).

The 6000 ac sanctuary contains approximately 1700 ac of old-growth forested wetlands which is one of the last remnants of the undisturbed floodplain forests that once laced the southeastern coastal plain. As one moves up the approximately 5 ft topographic and moisture gradient within the floodplain, the major swamp forest types include cypress-tupelo swamp on

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[1] Paper presented at the Seventh Biennial Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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the lowest sites, bottomland hardwood swamp at intermediate elevations, and a mixed hardwood-pine community on low ridges within the swamp (Porcher 1981).

Our initial Hurricane Hugo field studies in December 1989, included an overflight of Four Hole Swamp to assess damage to the forest. The strongest impression that resulted from this flight was of the patchiness of the storm's more severe effects. This led us to formulate a series of hypotheses as to the reasons for this patchiness. The first was that it resulted from random severe wind gusts. However, if the pattern of minor and major effects were not random, then they must be related to certain characteristics of these sites. In this paper, we will discuss hurricane damage to and mortality of canopy trees among the major community types and the more common canopy tree species present at Four Hole Swamp.

Methods

Sixteen 0.5 ac plots were established in old-growth stands of the three major forested wetland habitats listed above. All trees 6 in dbh or larger were identified to species where possible, tagged, and diameters recorded. It was not possible to determine species for elms (*Ulmus* sp.) and ashes (*Fraxinus*) except for Carolina ash. Ordination and clustering analyses of plot and species data matrices using Cornell Ecology Programs DECORANA, TWINSPAN, and COMPCLUS (Duever and McCollom, 1992) were used to determine which plots should be grouped into community types and which species were most closely associated with those communities.

Trees affected by the hurricane were classified into four damage types, listed here from most to least severe: main stem broken, uprooting, major branch loss (branches broken off at or near main stem), or bent trunk. Trees sustaining several types of damage were assigned to the most severe type of damage category.

Data on mortality were collected following the hurricane and at the end of the first and second growing seasons after the hurricane.

Results

Damage

Sixty percent of the 1233 trees over 6 in dbh in our plots were damaged by the hurricane (Table 1). Half of the damaged trees were in the break category. Uprooting and major branch loss each represented 22% of the damage, while bent trunks were uncommon.

The percent trees damaged at a site generally followed the topographic and moisture gradient, with more affected at drier sites. The highest elevation community, the Ridge Bottom, sustained damage to 81% of the trees (Table 1). Half of the tree damage was broken boles and one third of the trees were uprooted. This community had the smallest proportion of damaged trees with bent trunks or major branch loss.

Moving downslope, 64% of the Bottomland Hardwood community trees were damaged. Broken boles were less common in this community than in the other two communities, representing only 43% of damaged trees. Uprooting and major branch loss categories each claimed one quarter of the damaged trees. The Bottomland Hardwood community also had the highest proportion of bent trees, 9% compared to 3% in the other two communities.

At the bottom of the topographic gradient, the Cypress/Tupelo community had the lowest percent damaged trees, 44%. Two thirds of the damage to this community was due to broken boles, the highest proportion of any community. This community also had virtually no uprooting, with only 6% of the damaged trees falling into that category.

Species responded quite differently to the hurricane. Of the 14 most common species ($N \geq 15$), the two species which sustained the most damage were found mainly on the higher elevation sites. Over 90% of the water oak and spruce pine were damaged. The common species found mainly in the deeper parts of the swamp sustained the least damage. Carolina ash, blackgum, baldcypress, and water tupelo each had less than 50% damaged individuals (Table 2). The two most common species, water tupelo ($N=215$) and laurel oak (*Quercus laurifolia* Michx.) ($N=214$), sustained 47% and 66% damage, respectively.

Table 1. *Damage and Mortality in three old-growth floodplain communities from 16 plots at Beidler Forest Sanctuary, South Carolina.*

Community	No. Plots	No. Trees Before	No. Trees 2 Years After	Damage				
				Total	Break	Uprooted	Branches	Bent
Ridge Bottom	4	220	117	178	90	60	22	6
Bottomland Hardwood	8	612	467	393	166	95	98	34
Cypress/Tupelo	4	401	383	174	116	10	42	6
TOTAL	16	1,233	967	745	372	165	162	46
				Mortality				
				Total	Break	Uprooted	Branches	Bent
Ridge Bottom	4	220	117	103	55	43	4	1
Bottomland Hardwood	8	612	34	145[1]	63	66	10	3
Cypress/Tupelo	4	401	383	18	11	6	1	0
TOTAL	16	1,233	967	266	129	115	15	4

[1] Three trees died that did not fit in any damage category.

For most species, the most common type of damage was broken boles. Of the more common species, water oak, pignut hickory (*Carya glabra* (Mill.) Sweet), American hornbeam (*Carpinus caroliniana* Walt.), and red maple (*Acer rubrum* L.) had about equal numbers of uprooted trees and broken boles. Swamp chestnut oak (*Quercus michauxii* Nutt.) and the elms had similar numbers of individuals among the three most severe damage types: broken bole, uprooting, and major branch loss. Baldcypress had more trees with major branch damage than all other damage categories combined. However, it must be remembered that our sampling strategy only recorded the most severe damage for each individual. Thus, other species that had broken or uprooted stems could also have lost major branches, but this information would not have been included in our records.

Mortality

Two years after the hurricane, 78% of the 1233 trees sampled were still alive (Table 1). Deaths occurring immediately after the hurricane included 13% of all trees (N=160). Subsequent mortality through the end of the second post-hurricane growing season included an additional 8% (N=101).

Though broken boles were the most common type of damage and accounted for the most mortality in terms of numbers, uprooting was most likely to be fatal, with 70% of all uprooted trees dying by the end of the second growing season (Table 1). Mortality among trees with either broken branches or bent stems was less than 10%. Mortality patterns in the three forested community types followed a pattern similar to damage along the topographic gradient. Mortality for all trees was lowest in the deeper Cypress/Tupelo community sites, ranging from 1-10% in the four study plots at the end of two growing seasons after the hurricane (Table 1). Midway up the topographic gradient, the eight Bottomland Hardwood sites had mortality between 9% and 42%. The highest mortality was at the higher elevation Ridge Bottom sites, ranging from 38% to 52% in the four plots.

Mortality was highest for trees in the main stem broken damage category in both the Ridge Bottom and Cypress/Tupelo communities, while in the Bottomland Hardwood community mortality was more equally divided between broken boles and uprooted trees (Table 1).

Total Mortality for individual species ranged from only 1% for water tupelo (N=215) to 91% for spruce pine (N=43) (Table 2). For species with $\geq$15 individuals, percent Total Mortality was highest for species most commonly associated with the Ridge Bottom community, the first five species listed in Table 2, and lowest for species most commonly found in the Cypress/Tupelo community, the last four species listed in Table 2.

Table 2. *Damage and mortality for dominant species from 16 plots in the old-growth floodplain forest at Beidler Forest Sanctuary, South Carolina.*

Dominant Species (N > 15)[1]	No. Trees Before	No. Trees 2 Years After	Damage					Mortality				
			Total	Break	Uprooted	Branches	Bent	Total	Break	Uprooted	Branches	Bent
Water Oak, *Quercus nigra*	47	25	44	17	21	3	3	22	7	15	0	0
Spruce Pine, *Pinus glabra*	43	4	40	31	9	0	0	39	30	9	0	0
Pignut Hickory, *Carya glabra*	26	16	19	10	7	0	2	10	4	5	0	1
Swamp Chestnut Oak, *Quercus michauxii*	24	11	17	4	7	5	1	13	3	7	3	0
American hornbeam, *Carpinus caroliniana*	47	27	31	12	13	5	1	20	7	8	4	1
Elm (American or Winged), *Ulmus* sp.	62	50	41	15	12	11	3	12	5	4	2	1
Sweetgum, *Liquidambar styraciflua*	115	97	63	28	10	22	3	18[2]	7	9	1	0
Red Maple, *Acer rubrum*	65	60	50	18	18	11	3	5	1	4	0	0
Laurel Oak, *Quercus laurifolia*	214	141	141	51	39	30	21	73	35	36	1	1
Ash (all sp. but water ash), *Fraxinus* sp.	70	54	44	25	14	5	0	16[2]	4	11	0	0
Blackgum, *Nyssa sylvatica* var. *biflora*	94	91	43	29	0	11	3	3	3	0	0	0
Baldcypress, *Taxodium distichum*	136	122	63	29	2	32	0	14	12	1	1	0
Water Tupelo, *Nyssa aquatica*	215	212	100	78	1	17	4	3	2	1	0	0
Carolina Ash, *Fraxinus caroliniana*	15	14	5	5	0	0	0	1	1	0	0	0
TOTAL for Dominant Species Only	1,173	924	701	352	153	152	44	249	121	110	12	4

[1] Species not listed, in order of dominance: overcup oak (*Quercus lyrata* Walt.), common persimmon (*Diospyros virginiana* L.), redbay (*Persea borbonia* (L.) Spreng.), loblolly pine (*Pinus taeda* L.), water-elm (*Planera aquatica* J. F. Gmel.), American holly (*Ilex opaca* Ait. var. *opaca*), sugarberry (*Celtis laevigata* Willd.), water hickory (*Carya aquatica* (Michx. f.) Nutt.), cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.), red buckeye (*Aesculus pavia* L.), and waterlocust (*Gleditsia aquatica* Marsh.).

[2] One tree died that did not fit in any damage category.

The two most common conifers, baldcypress and spruce pine, died primarily of broken boles. Hardwood mortality was generally associated about equally with broken boles and uprooting. However, blackgum, water tupelo, and Carolina ash, which were common in the Cypress/Tupelo community, had so little mortality that it is difficult to ascribe it to any particular type of damage. Water oak, swamp chestnut oak, red maple, and ashes all died primarily as a result of uprooting. Swamp chestnut oak, American hornbeam, and elms had a relatively high percent mortality associated with major branch loss.

Two years after the hurricane, species composition of trees equal to or greater than 6 in dbh, viewed as the proportion of numbers of one species to another, was quite similar to pre-hurricane conditions. Exceptions were laurel oak whose numbers had decreased from 213 to 141, and particularly spruce pine, which had decreased from 43 to 4 live individuals.

Discussion

The results of our analyses of canopy tree damage and mortality among the various community types and species present in the old growth forest at Four Holes Swamp clearly indicated that the pattern of storm effects did not result solely from random wind gusts. There was a consistent pattern of more severe damage and mortality on the higher Ridge Bottom sites and much less effect on the lower Cypress/Tupelo sites. Also, the species exhibiting the most severe effects were most common on the higher Ridge Bottom sites, and those with the fewest impacts were the species that were dominant on the lower Cypress/Tupelo sites.

Putz and Sharitz (1991) reported that the more severe effects of Hurricane Hugo on trees in the Congaree Swamp were associated with certain species and community types. Their slough community would be comparable with our Cypress/Tupelo community, and, as at Four Hole Swamp, was much less impacted by the storm than was the bottomland hardwood community. They found that bottomland hardwood species were equally prone to being uprooted or to suffering stem breakage, whereas in the slough sites stem breakage was more common than uprooting. This was the same pattern of damage that we found in Four Hole Swamp.

Gresham et al. (1991) reported that Hurricane Hugo damage to the Hobcaw Forest along the South Carolina coast was largely a function of the species present. The species most and least effected were quite similar in our respective studies. They reported that baldcypress, water tupelo, and blackgum were the least effected species, and that pond pine (*Pinus serotina* Michx.), possibly comparable to spruce pine at Four Hole Swamp, and water and laurel oaks were by far the most effected species. They did note that several other upland species, including longleaf pine (*Pinus palustris* Mill.), loblolly pine (*Pinus taeda* L.), and live oak (*Quercus virginiana* Mill.), suffered relatively little damage. These genera at Four Holes Swamp tended to be among the more severely effected species, suggesting that vulnerability to hurricane impacts is related more to species than generic composition.

Whigham et al. (1991) also observed a differential mortality among dominant tree species during the two years after Hurricane Gilbert passed over their study sites in Quintana Roo, Mexico. Mortality associated with the storm varied from 1.4 - 31.3% among the different species. More individuals died from breaks in both Quintana Roo and Four Holes Swamp but branch damage caused the second most mortality in Quintana Roo, while at Four Holes death due to uprooting was the next most common. If we look at percent mortality among the damage classes by dividing the number that died within a damage class by the total number in that damage class, results for the two studies are quite similar. For Quintana Roo and Four Holes Swamp respectively, uprooting produced the highest mortality (43%, 70%), trunks snapped produced 28% and 35% mortality, and major branch loss resulted in only 6% and 9% mortality. These similarities are quite surprising given that the species present on their tropical sites were much different from the temperate species we studied.

A variety of factors undoubtedly play a significant role in determining damage to and mortality of canopy trees from hurricanes. Among these factors, species present on a site appears to have a major influence on the kinds and degree of effects. Community type also appears to be closely associated with hurricane impacts. However, it is difficult to decide whether these effects are intrinsically related to integrated community characteristics or are more a function of specific aspects of the community, such as species present or substrate or hydrologic characteristics.

Acknowledgements

Portions of this research were funded jointly by USDA Forest Service Cooperative Research Agreement No. 29-738 and National Audubon Society. We would like to thank Norm Brunswig and Mike Dawson from Beidler Forest for their generous help in many aspects of this effort.

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HURRICANE DAMAGE TO AN OLD-GROWTH FLOODPLAIN FOREST IN THE SOUTHEAST [1]

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Abstract. The old-growth forests of the Congaree Swamp National Monument, an 8988 ha floodplain tract in South Carolina, were damaged by Hurricane Hugo in 1989. The effects of the hurricane on forest structure and species composition were examined in ten 1.0 ha plots established in the winter months following the storm. Trees and large saplings (stems $\geq$ 2.5 cm in diameter) were tagged and measured, mapped, and the nature and extent of the damage was recorded. Effects of the hurricane were greater in bottomland hardwood forest communities (37 % of trees seriously damaged) than in adjacent forested sloughs (10 %). Among the hardwoods, highest damage was sustained by several oak species (61 %), especially laurel oak (*Quercus laurifolia* Michx.) and willow oak (*Q. phellos* L.). Broken boles and uprooted trees were common. Extensive branch loss occurred in sweetgum (*Liquidambar styraciflua* L., 24 %) and ash (*Fraxinus* spp., 26 %). In contrast, the dominant slough canopy trees, water tupelo (*Nyssa aquatica* L.) and baldcypress (*Taxodium distichum* (L.) Rich) sustained low damage (9 % and 3 % of the trees). Broken boles and severe branch loss occurred most frequently. Regeneration in the canopy gaps was dominated by early-successional species in the hardwood forests, but not in the sloughs. Thus, the structure of the bottomland hardwood forests was altered by the hurricane, but the slough communities were not greatly changed.

Introduction

Large-scale disturbances are important in shaping forest community structure, composition and successional processes. Early European travelers in the southeastern United States (such as Thomas Nairne in 1708) recorded the damaging effects of hurricanes to forests (Moore 1988), and recent studies of southeastern forests have examined the influence of hurricanes and tornadoes on stand composition and patch dynamics (e.g. Vogel 1980, Glitzenstein and Harcombe 1988, Platt and Schwartz 1990). Such storms are a normal, although episodic, part of the climatic regime of the South Atlantic Coastal Plain.

On September 21-22, 1989, Hurricane Hugo came ashore 20 km northeast of Charleston, SC. As the storm traveled inland, winds in excess of 155 km/hr struck the old-growth floodplain forests of the Congaree Swamp National Monument, causing significant damage (Putz and Sharitz 1991). Within the last 110 years, four other hurricanes as severe as Hugo were recorded in South Carolina (Purvis 1973) and many less severe storms have occurred. Several of these have tracked near the Congaree Swamp. Thus, it is likely that the structure of this forest, as well as other mature southeastern forests, may have been shaped by repeated wind-related disturbances.

We have initiated a study of long-term forest community dynamics in the old-growth forests of the Congaree Swamp National Monument. Included in this research is an examination of the effects of Hurricane Hugo. Our objectives were to evaluate the hurricane damage to these mature forests, and to establish a baseline for study of forest recovery processes.

Methods

The Congaree Swamp National Monument encompasses 8988 ha of swamps and bottomland forests on the floodplain of the Congaree River in central South Carolina. It lies within the Coastal Plain, just southeast of the fall line. For many years much of the property was privately owned and was protected from logging. In 1976, the tract was acquired by the National Park Service as a National Monument. Large areas of the floodplain support old-growth forests that show little or no signs of logging or other recent human disturbance.

The forests of the Congaree Swamp National Monument are relatively diverse. In a 1975 survey of the vegetation, Gaddy and Smathers (1980) reported

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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more than 45 tree species and distinguished 29 plant communities. The most extensive are a variety of mixed bottomland hardwood forests that are found on subhydric and mesic sites, and the baldcypress/tupelo forests that occur in hydric sites such as sloughs and large depressions. They described the forests as usually having 100 % canopy coverage of old and middle-aged trees. Because the forests were allowed to grow undisturbed on optimum soil conditions, they contain an unusual number of large trees with canopy heights of 30 - 50 m. A number of state and national record trees were reported (Gaddy 1977).

During the winter months following Hurricane Hugo, we established ten 10,000 m^2 (1 ha) plots (each divided into 25 400 m^2 subplots) in different forest communities within the Monument. Six plots were located in bottomland hardwood communities and four in slough communities. Within each plot, all trees ($\geq$ 10 cm diameter at breast height, dbh) were tagged, their diameters measured, and their locations mapped. Trees were measured at 140 cm above ground except for those species that develop a pronounced butt swell. These were measured 200 cm above the ground or, if necessary, 50 cm above the top of the swell. In the sloughs, all saplings (2.5 - 10 cm dbh) within each plot were also tagged and measured. Because of the high densities of saplings in the bottomland hardwood communities, only five subplots within each 1 ha plot were sampled.

Hurricane damage to trees and saplings was classified by type and severity. Moderate to severe damage included loss of major branches, bending of the stem or bole, breakage of the bole (snap-off, considered more severe if the break was nearer to the ground) and uprooting (tip-up, partial or total). Throughout the forest, the canopy was opened by wind-induced defoliation and loss of small branches. This type of mild damage was not quantified.

Percent damage by diameter size class was examined using ANOVA in a randomized complete block design. The subplots were used as blocks and the total number of trees of all species in each size class was used as a weighting factor. A least-squares means procedure, followed by a Bonferroni contrast of least-squares means, was used to assess significant differences between diameter size classes (Miller 1986). All statistical analyses were performed using the Statistical Analysis System (SAS Institute Inc. 1989).

Seedlings and small saplings (all individuals 0 - 140 cm high or >140 cm high - <2.5 cm dbh) were examined in two of the bottomland hardwood and two of the slough plots. In each of these, 30 circular subplots (radius 3.26 m) were established, giving a total area sampled of 0.1 ha per plot. Seedlings and small saplings were inventoried at the end of the second and third growing seasons following the hurricane; only third year data are reported here.

Results

Pre-hurricane Forest Structure

The pre-hurricane structure of the forests can be inferred since the survey included all trees judged to have been alive at the time of the storm. The six bottomland hardwood plots were dominated by sweetgum in the canopy, along with sugarberry (*Celtis laevigata* Willd.), American elm (*Ulmus americana* L.), ash (chiefly green ash, *Fraxinus pennsylvanica* Marsh.) and oaks (laurel oak, willow oak, *Q. phellos* L.; swamp chestnut oak, *Q. michauxii* Nutt.; cherrybark oak, *Q. falcata* var. *pagodifolia* Ell., Shumard oak, *Q. shumardii* Buckl. and water oak, *Q. nigra* L.) (Table 1). While never achieving high densities, the oaks were widely distributed throughout five of the six plots. Loblolly pine (*Pinus taeda* L.) was abundant in only one of the plots. The understory was characterized by holly (American holly, *Ilex opaca* Ait.), possumhaw (*I. decidua* Walt.), American hornbeam (*Carpinus caroliniana* Walt.), pawpaw (*Asimina triloba* (L.) Dunal.) and abundant red maple (*Acer rubrum* L.) and box elder (*A. negundo* L.).

Slough plots had a canopy of tupelo, either water or swamp tupelo (*N. sylvatica* var. *biflora* (Walt.) Sarg.), and baldcypress (Table 2). Scattered individuals of sweetgum were found, as well as laurel oak and overcup oak (*Quercus lyrata* L.). The understory was chiefly red maple and Carolina ash (*F. caroliniana* Mill.). Many of the maples, sweetgums and oaks grew on the slough edges or on elevated microsites that were less flooded.

Tree density was higher in the slough plots than in the bottomland hardwood plots, but the density of saplings was lower in the sloughs (Tables 1 and 2). The distribution of individuals of different sizes in the two forest communities also differed (Fig. 1). The bottomland hardwood plots were dominated by small diameter size class individuals; saplings comprised 59 % of the stems per hectare. There were also some trees in the very large size classes with diameters greater than 75 cm. In the sloughs, 37 % of the stems per hectare were saplings, and more than half (54 %) were in small to intermediate size classes (10

to 50 cm dbh). There were fewer very large trees in the slough plots than in the bottomland hardwood plots.

Table 1. *Dominant overstory and understory species in bottomland hardwood plots.*

	Trees[1] (≥10cm dbh)	Saplings[2] (≥2.5 - 10cm dbh)
	----- Density (stems/ha) -----	
Overstory		
Liquidambar styraciflua	99.3	5.0
Celtis laevigata	32.0	20.0
Ulmus americana	25.5	4.2
Fraxinus spp.	13.8	1.7
Quercus spp.	28.7	9.2
Pinus taeda	6.8	0
Understory		
Ilex opaca	111.8	130.8
Ilex decidua	7.3	207.5
Carpinus caroliniana	53.7	65.0
Asimina triloba	1.2	116.7
Acer rubrum	14.2	15.0
Acer negundo	14.5	10.8
Other species	23.4	36.6
Total density	432.2	622.5

[1] based on 6 - 10,000m² plots
[2] based on 30 - 400m² subplots

Within each forest type, size distributions of the dominant canopy species also differed. For example, in the bottomland hardwood plots there were many more sweetgum trees than saplings (Table 1). In contrast, sugarberry and the oaks had higher proportions of saplings. There were several very large oaks of diameters greater than 100 cm. Importantly, the loblolly pines were all large trees with no saplings occurring. In the slough plots, tupelo saplings were abundant (especially water tupelo) but there were fewer saplings of baldcypress (Table 2).

Hurricane Damage

Damage from the storm was more severe in the bottomland hardwood forest communities than in the sloughs. A total of 36.7 % of the individuals in the bottomland hardwood plots were moderately to severely damaged (Table 3), compared with only 10.0 % of those in the slough plots (Table 4). In both forest communities, damage increased with tree size (Fig. 2). For example, 17 % of the bottomland hardwood saplings (2.5 - 10 cm dbh) were damaged, compared with 60 % of the largest trees (> 100 cm dbh). In addition, the type of damage to the hardwood species tended to be more severe in larger individuals, many of which were broken off near the base or completely uprooted. In the sloughs, damage was relatively low (5 - 10 % of the individuals) in all but the largest size class (Fig. 2). Most of the heavily damaged large trees in the sloughs had severe branch loss or snapped off boles.

Table 2. *Dominant overstory and understory species in slough plots.*

	Trees[1] (≥10cm dbh)	Saplings[2] (≥2.5 - 10cm dbh)
	----- Density (stems/ha) -----	
Overstory		
Nyssa aquatica	286.0	61.5
Nyssa sylvatica biflora	139.3	18.5
Taxodium distichum	89.5	8.0
Liquidambar styraciflua	20.0	21.5
Quercus spp.	14.0	12.8
Ulmus americana	3.0	4.0
Understory		
Acer rubrum	26.8	32.3
Fraxinus caroliniana	21.3	113.3
Planera aquatica	9.3	20.0
Ilex opaca	9.0	21.5
Carpinus caroliniana	8.8	7.0
Ilex decidua	0.3	9.5
Other species	6.7	48.9
Total density	634.0	378.8

[1] based on 4 - 10,000m² plots
[2] based on 100 - 400m² subplots

In both forest communities, the type of damage differed by species. In the bottomland hardwood plots (Table 3), loss of branches was the most common form of damage to sweetgum in the canopy (23.6 % of all individuals). Ash and elm in the canopy also lost many branches, as did the oaks. Between 11 - 18 % of trees of all canopy species were snapped off. The oaks sustained the greatest total damage (61.2% of all individuals), chiefly due to uprooting (28.9%) and snapping (17.0%). Of the pines, 12.2 % were uprooted and 12.2 % snapped off. Many of the understory trees were broken beneath damaged overstory trees. Red maple and boxelder sustained the greatest damage (about 25 % of the stems snapped off).

In the slough plots, effects of the hurricane on canopy dominants was less severe (Table 4). In the two tupelo species, damage was 9.0 - 13.2 %, and only 3.1 % of the baldcypress were damaged. Most of the damage was in the form of branch loss or stem breakage. Sweetgums, oaks and elms tended to have higher percentages of tip-ups. The understory species, especially red maple, American hornbeam and

Table 3. *Percent damage to dominant overstory and understory species in bottomland hardwood plots.*

	Total damaged*	Branch loss	Bending	Snap off	Tip up	Projected mortal damage
	% Damage					
Overstory						
Liquidambar styraciflua	44.5	23.6	1.2	11.0	8.5	9.5
Celtis laevigata	31.0	9.3	3.2	11.6	5.5	4.2
Ulmus americana	39.9	12.6	0.6	18.3	7.0	7.6
Fraxinus spp.	51.8	25.6	4.7	16.3	3.5	3.5
Quercus spp.	61.2	11.0	3.3	17.0	28.9	33.4
Pinus taeda	31.7	7.3	0	12.2	12.2	12.2
Understory						
Ilex opaca	23.3	4.7	6.4	6.9	4.9	4.1
Ilex decidua	32.8	7.5	11.3	12.0	1.7	7.2
Carpinus caroliniana	39.0	6.0	7.8	13.8	11.2	11.2
Asimina triloba	25.2	3.4	7.5	10.9	4.1	7.5
Acer rubrum	49.6	4.9	6.8	25.3	12.6	17.5
Acer negundo	44.0	8.0	3.0	25.0	6.0	8.0
Average for all species	36.7	10.4	5.4	12.3	7.9	8.6

* May include additional damage not shown in other columns.

possumhaw lost branches or were bent or snapped, probably due to large debris falling from the canopy.

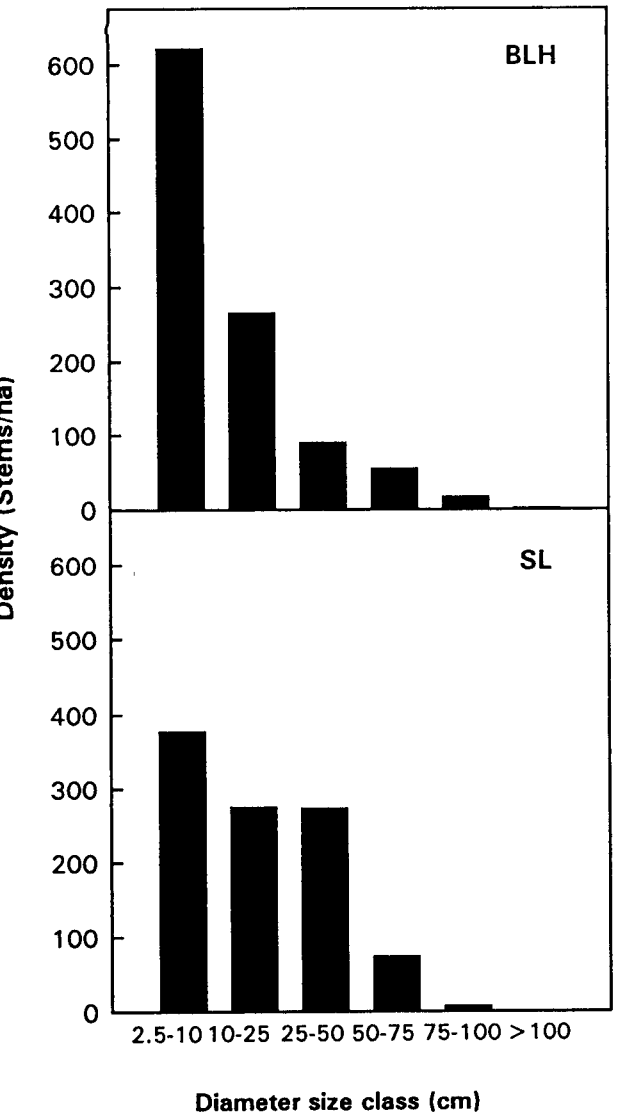
Projected mortality of injured trees was based on type and severity of damage. Trees broken off within 2 m of the ground and those completely uprooted were considered likely to die. In the bottomland hardwood plots (Table 3), the oaks had the highest level of projected mortality (33.4 %). Most of this mortality resulted from uprooting. Pines also showed relatively high projected mortality (12.2 %). This estimate is probably low, since many pines snapped off higher than 2 m will not survive. Other overstory dominants had much lower expected mortality (3.5 - 9.5 %). Although half of the ash trees in the plots were damaged, only 3.5 % are expected to die. In the understory, the most abundant species, American holly, sustained the least expected damage (4.1 % mortality). Red maple had the highest projected mortality (17.5 %), although this may be an overestimate as individuals completely tipped up have been observed to survive if a sufficient number of roots remain intact.

In the slough plots, estimated mortality of dominant canopy species was low (0.3 - 0.5 % for baldcypress and the tupelos). Almost all of the mortality resulted from snapped boles (Table 4). Possumhaw had the highest projected mortality (5.1 %) of the understory species. Only about 2.5 % of the understory dominants, red maple and Carolina ash, are expected to die.

Forest Regeneration

An examination of the densities of seedlings and small saplings (advance regeneration) of the major species gives an indication of the recovery potential of the forest. In the bottomland hardwood plots, regeneration was dominated by understory species such as pawpaw, although American hornbeam and red maple seedlings were also abundant. Seedlings and small saplings of the canopy dominant species were present but much less abundant. There were relatively few oak seedlings and none of pine. Likewise, there were few seedlings of the dominant understory species, American holly and possumhaw. In contrast, in the slough plots seedling densities were lower, but regeneration was characterized by the canopy and understory dominant species (Table 6).

It appears that in the highly disturbed bottomland hardwood forest communities, the canopy gaps are becoming dominated by rapidly growing successional species, especially pawpaw. The appropriate conditions for pine regeneration have not been met in this forest for some years, either before or following the hurricane. In the sloughs where damage was much less, seedling populations are similar to the overstory and understory composition.



gure 1. *Density (stems/ha) by diameter class of trees and saplings in bottomland (BLH) and slough (SL) plots.*

Discussion

The old-growth mixed bottomland hardwood rest communities of the Congaree Swamp National onument were much more severely damaged by urricane Hugo than were the slough communities. the time of the hurricane, leaf senescence prior to tumnal abscission was beginning for many of the ciduous species. It is possible that the defoliation of ldcypress and the defoliation and branch loss of the elo trees reduced their wind resistance. In dition, the buttressed boles of these species may ve decreased the likelihood of uprooting. Similarly, eetgum, elm and ash in the bottomland hardwood mmunities were defoliated and lost large branches t were less frequently uprooted than other canopy ecies that had not begun leaf senescence. The tardily deciduous oaks, such as laurel oak and water oak, and the pines were the most susceptible to windthrow. Differences in root architecture may also be important; although little is known about the rooting patterns of these floodplain species, the uprooted oaks were observed to have been very shallowly rooted.

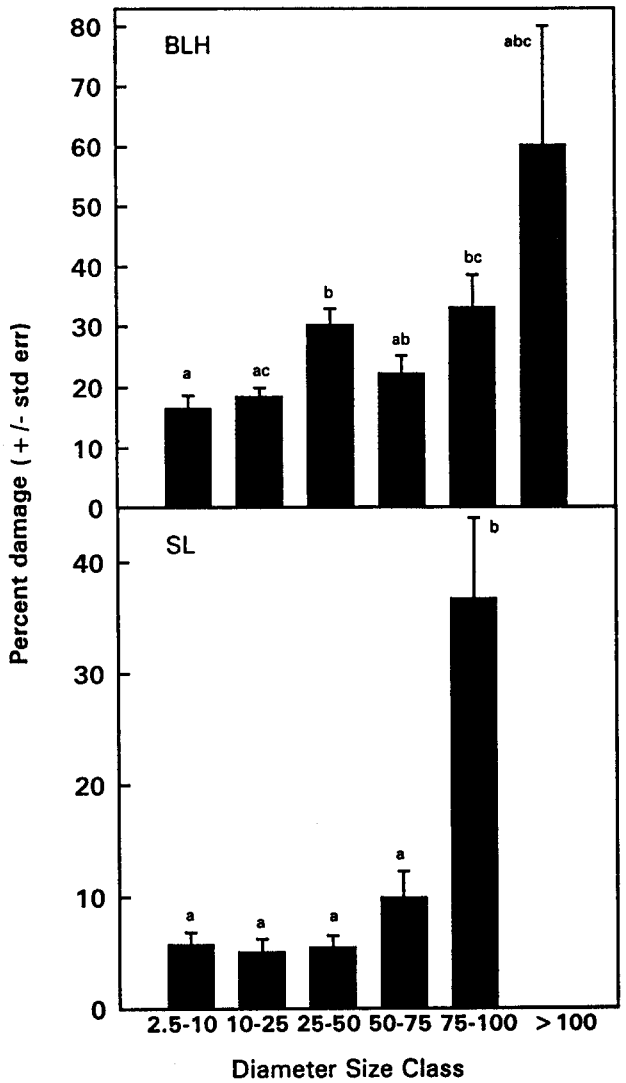


Figure 2. *Mean percent damage (± standard error) by diameter size class to trees and saplings in bottomland hardwood (BLH) and slough (SL) plots. Different lower case letters denote significant ($p<0.05$) classes within BLH and SL plots, based on pair-wise comparisons.*

Similar species responses were observed elsewhere in the southeastern U.S. in the path of Hurricane Hugo (Gresham et al. 1991, Hook et al. 1991, Duever and McCollom 1992, Sheffield and Thompson 1992). In the Hobcaw Forest of eastern South Carolina, baldcypress suffered light crown

Table 4. *Percent damage to dominant overstory and understory species in slough plots.*

	Total damaged*	Branch loss	Bending	Snap off	Tip up	Projected mortal damage
	% Damage					
Overstory						
Nyssa aquatica	9.0	3.9	0.8	4.2	0.1	0.4
Nyssa sylvatica biflora	13.2	4.7	1.9	6.2	0.2	0.5
Taxodium distichum	3.1	1.0	0	2.1	0	0.3
Liquidambar styraciflua	8.5	2.0	0.5	1.5	4.5	4.0
Quercus spp.	11.2	0	3.7	4.7	2.8	3.7
Ulmus americana	21.4	7.1	3.6	7.1	3.6	3.6
Understory						
Acer rubrum	19.1	7.6	4.2	4.7	2.5	2.5
Fraxinus caroliniana	10.3	3.2	2.2	4.3	0.6	2.4
Planera aquatica	8.6	2.6	4.3	1.7	0	0
Ilex opaca	2.5	0.8	0	1.6	0	0
Carpinus caroliniana	23.8	1.6	12.7	7.9	1.6	1.6
Ilex decidua	20.5	0	5.1	10.3	5.1	5.1
Average for all species	10.0	3.4	1.8	4.1	0.7	1.2

* May include additional damage not shown in other columns.

Table 5. *Dominant overstory and understory seedling and small sapling species in bottomland hardwood plots.*

	(0 - 140cm high, 140cm high - 2.5cm dbh)
	Density (stems/ha)*
Overstory	
Liquidambar styraciflua	1,020
Celtis laevigata	1,590
Ulmus spp.	1,625
Fraxinus spp.	280
Quercus spp.	170
Pinus taeda	0
Understory	
Ilex opaca	185
Ilex decidua	195
Carpinus caroliniana	3,120
Asimina triloba	10,720
Acer rubrum	2,540
Acer negundo	145
Lindera benzoin	325
Crataegus spp.	240
Ligustrum sinense	105
Other species	145
Total density	22,405

* based on 60 - 33.3m^2 plots

damage, whereas laurel and water oak were commonly uprooted or snapped off (Gresham et al. 1991). Duever and McCollom (1992) also reported greater damage to oaks and pines than to baldcypress in the Four Holes Swamp forest north of Charleston. Also, the greatest damage from high winds often occurs to the larger sized trees (Glitzenstein and Harcombe 1888, Gresham et al. 1991). In the old-growth bottomland hardwood forest communities of the Congaree Swamp, however, extensive secondary damage also occurred to small and medium-sized stems that were crushed beneath large overstory trees.

Mortality of the overstory trees is expected to be relatively low in the slough communities. Less than one percent of the baldcypress and tupelo trees were damaged so severely that they are likely to die. Mortality was higher for the sweetgum, oaks and elm that had become established in the sloughs. Many were growing on stumps, logs, or other elevated microsites that may not have served as stable rooting substrates. The hurricane actually reduced the diversity in the slough communities by having a disproportionally larger effect on invading bottomland or transitional species than on community dominants.

In the bottomland hardwood communities, projected mortality of canopy trees is much greater than in the sloughs. Half of the damaged oaks are expected to die (33.4 % of all stems). It is also likely that none of the loblolly pines that were snapped off or uprooted (24.4 %) will survive. The hurricane changed the stand composition in the bottomland hardwood communities by reducing the presence of oaks and pine in the overstory and also lowering the

undance of certain understory species, such as red aple and American hornbeam.

ble 6. *Dominant overstory and understory seedling species in slough plots.*

	(0 - 140cm high, 140cm high - 2.5cm dbh)
	Density (stems/ha)*
Overstory	
ssa spp.	770
xodium distichum	600
quidambar styraciflua	75
uercus spp.	270
lmus spp.	1,415
eltis spp.	225
Understory	
er rubrum	5,420
axinus spp.	1,380
anera aquatica	660
x opaca	5
rpinus caroliniana	80
x decidua	45
a virginica	820
her species	20
tal density	11,785

based on 60 - 33.3m^2 plots

It is expected that tree mortality from the rricane will continue as severely damaged dividuals gradually die. Repeated sampling in the our Holes Swamp forest has shown this to be the se (M. J. Duever, personal communication). amaged trees also may be more susceptible to insect fungal infestation or other disease. Furthermore, nce hurricanes are a normal part of the climatic gime of the southeastern U.S., trees weakened in e storm may be pre-disposed to future damage. In e Congaree forest, Putz and Sharitz (1991) noted at many of the trees damaged by Hurricane Hugo owed evidence of prior mechanical damage or sease.

Forest recovery from such disturbance is by growth and sprouting of damaged individuals, lease and rapid growth of established seedlings and plings (advance regeneration), and germination and tablishment of new seedlings. Following a rricane, light intensity at the forest floor should crease not only in canopy gaps, but also beneath rviving trees (Canham et al. 1989). Thus, both ght-demanding and shade-tolerant species can poten- lly regenerate. In the bottomland hardwood forests the Congaree Swamp, the regeneration is minated by rapidly growing successional species, especially pawpaw and red maple. Previously established saplings of several of the canopy dominants, especially sweetgum, sugarberry and elm, are also expected to grow rapidly in the increased light environment. Conversely, pine seedlings are not expected to become established. Although disturbances may increase the variety of microsites for seedling establishment (Schupp et al. 1989), the abundant coarse woody debris in many of the gaps may limit establishment of new seedlings by shading the forest floor and also providing structure for growth of light-demanding vines. Thus, in the bottomland hardwood communities, the removal of pines and large oaks and the invasion of canopy gaps by early-successional species have resulted in short-term changes in the forest composition. Recovery of the slough communities, where damage to the canopy trees was generally less severe, should be relatively rapid as a result of branch sprouting and canopy regrowth of damaged baldcypress and tupelo trees. Seedling populations were similar in composition to the canopy and subcanopy, and thus there is not expected to be a major change in forest structure in the sloughs.

Acknowledgments

This study was supported by contract DE-AC09-76SROO-819 between the U.S. Department of Energy and the University of Georgia's Savannah River Ecology Laboratory, and by contract agreement CA-5000-9-8020, #10 with the University of Georgia and the U. S. Department of Interior National Park Service. We thank the many individuals who worked with us on this study, especially R. H. Jones and N. Pedersen of Auburn University who collected the seedling data, F.E. Putz of the University of Florida who participated in the initial design, and R. A. Clark of the Congaree Swamp National Monument who assisted with local procedures. We appreciate the comments of K.W. McLeod and A.F. Schnabel on this manuscript.

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PRELIMINARY ECOLOGICAL CLASSIFICATION OF ARBORESCENT COMMUNITIES ON THE WINE SPRING CREEK WATERSHED, NANTAHALA NATIONAL FOREST [1]

W. Henry McNab and Sara A. Browning [2]

Abstract. Woody vegetation was studied on the Wine Spring Creek watershed in western North Carolina to determine community variation and environmental relationships. Sizes and numbers of trees and shrubs, and topographic and soil variables, were measured on 0.25 acre plots using techniques that minimized time and labor required for locating sample sites and obtaining field data. Sites were stratified on a detailed soil map and located by field reconnaissance. Multivariate classification of vegetative communities on 73 plots allowed identification of six communities with similar overstory composition. Community occurrence was highly correlated with elevation, landform, and soil thickness. Three hierarchical levels of vegetative communities were identified that are consistent with a proposed hierarchical framework of ecological units being developed by the Southern Region of the USDA Forest Service.

Introduction

Ecological classification of forest sites should predict potential species composition and productivity of land by integrating the environmental effects of climate, landform, soil, and vegetation (Barnes and others 1982). This technique is gaining favor in the United States over conventional methods based mainly on timber values because it provides information on interrelationships among many land resources. Another advantage of ecological classifications is that they can be applied over a range of map scales (Bailey 1988) and using geographic information systems (McNab 1990). The USDA Forest Service policy of using ecological principles for managing ecosystems requires development of an ecological classification system (USDA Forest Service 1992). Ecological classification systems have been developed for major geographic areas in the South, the Coastal Plains (Van Lear and Jones 1987), the Piedmont Plateau (Jones 1988), and the southern Blue Ridge Mountains (Gattis 1992, McNab and others, In prep).

Because ecological classification is relatively new, standardized field techniques are continuing to evolve. Ideally, plots should be located in old, relatively undisturbed stands because potential natural vegetation likely dominates those sites and results of analysis are easier to interpret. In the South Carolina Piedmont development of a classification system required undisturbed areas of old-growth vegetation (Jones 1988). The requirement was stringent because that region has been heavily disturbed by intensive agriculture since the 1800's, and many timber stands are undergoing changes in composition from conifer to hardwood domination.

Finding relatively undisturbed communities is easier in mountainous regions. There, most forested areas have probably been disturbed by logging, grazing, and burning, but not by cultivation (Ayres and Ashe 1905). Although the relative abundance may change, logged-over deciduous stands in the southern Appalachians regenerate largely to the preharvest species composition because seedlings and saplings are released and sprouts develop from stumps of harvested trees (Jemison 1946, Beck 1981, Leopold and others 1985). We hypothesized, therefore, that for development of ecological classifications in mountainous areas sample plots could be located in most hardwood stands where the overstory appears to be mature and there are relatively few yellow pines (*Pinus* spp).

We designed a study with two main objectives: (1) develop an ecological classification of vegetation in a typical, previously logged mountainous watershed of mature stands, and (2) evaluate a stratification and reconnaissance technique for quickly and efficiently locating plots to sample principal environmental gradients. Also, we wanted to

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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determine if the classification of ecological types[3] is consistent with a proposed national hierarchy of ecological units now being developed by the USDA Forest Service (Cleland and Avers, In prep.). The scope of this paper is limited to evaluation of ecological types associated mainly with arborescent vegetation. A future manuscript will present findings about understory shrub and herbaceous vegetation in the same study area.

Study Area and Methods

The study was conducted mostly in the Wine Spring Creek and partly in the adjacent White Oak Creek watersheds of the Nantahala National Forest, located in Macon County, NC, (35.2°N, 83.6°W). These watersheds cover about 9,800 acres of the southern Nantahala Range and include Wine Spring Bald, the highest peak (5430 feet) in the vicinity. Soil parent material consists mostly of metasedimentary and metamorphic rocks (North Carolina Geological Survey 1985). The Wehutty and Copperhill Formations, consisting of metagraywacke, mica schist, and metaconglomerate, form the lower third of the study area near Nantahala Lake, from 3013 feet to about 4000 feet in elevation. Geologic substrate of the upper part of the study area consists mainly of an unnamed metamorphic formation of biotite gneiss interlayered with biotite, garnet gneiss, and amphibolite. Soils on both geologic formations, and below about 4800 feet elevation, are mostly 20 to 60 inches in depth and are mapped as complexes that are classified as coarse-loamy, mixed, mesic Typic Dystrochrepts. Slope gradients over 50 percent are dominated by shallower soils of the complex. At elevations above about 4800 feet soils are mapped as Wayah, a series with solum 20 to 50 inches deep and classified as coarse-loamy, mixed, frigid Typic Haplumbrepts. Effects of geologic substrate on vegetation were not investigated, but will be determined in a future study.

Terrain, which is typical of other mountainous areas in the southern Appalachians, consists of broadly rounded ridges, narrow steeply sloping valleys and long connecting slopes. Climate is temperate humid with growing season length of about 180 days. Precipitation averages 60 inches annually and is uniformly distributed during the growing season with little occurring as snow. Mean monthly temperature ranges from 38°F in January to 72°F during July. Forest vegetation is mainly deciduous hardwoods dominated by oaks. Eastern hemlock (*Tsuga canadensis*) is the principal coniferous species; few naturally occurring pines are present. Ayres and Ashe (1905) visited Wine Spring Creek and reported little settlement, apparently because of infertile, sandy soils and steepness of terrain, and almost no disturbance from clearing, burning, or grazing. The Forest Service acquired most of the watershed in 1912, after it had been logged over (W. Culpepper, Per. Comm.). Human-caused disturbances to the timber stands from 1912 until the present time have resulted from salvage of blight-killed American chestnut (*Castane dentata*), diameter-limit cuts and thinnings. A mosaic of stand ages are present, ranging from young (10-50 years), to mature (75-125), and old-growth.

Field methods were simplified to collect only data relevant to development of an ecological classification of the study area. The area was stratified for sampling on a 1:12,000 soil map prepared by the junior author and the Soil Conservation Service in 1990. Each soil mapping unit listed in the map legend was sampled (Table 1), but not in proportion to its area. Because soil mapping units are associated with landform in the southern Appalachians, a range of geologic and topographic conditions was encountered. Results from similar studies in other areas of the southern Appalachians indicate that ecological types are associated with relatively few topographic and soil variables (Gattis 1992, McNab and others, In Prep). Environmental variables measured included elevation, aspect, gradient, landform index, terrain shape index and solum depth. Methods for measuring these variables are described by McNab (1990). Solum depth was measured with a 48-inch long auger; samples were not collected for laboratory analysis.

Plots were located along roads and trails for ease of access. Two criteria were used for plot selection: (1) homogeneity of vegetation and (2) lack of evidence of recent major disturbance (such as fire, harvesting, or windthrow) in the last 50 years. Woody vegetation was sampled on circular, nested plots. Trees 4 inches and larger in d.b.h. were recorded by

[3] Ecological type is defined as "a category of land having a unique combination of potential natural community, soil, landscape features, climate, and differing from other ecological types in its ability to product vegetation and respond to management." Ecological types may be mapped at a range of scales. (Forest Service Manual 2060.5).

classes on each 0.25 acre plot. Saplings 0.1 to 3.9 inches d.b.h. were recorded by species on a 0.025 acre sub-plot centered within the large plot. Tree seedlings and shrubs less than 4.5 feet in height were recorded by species as "present" or "absent" on ten, 0.0025-acre circular plots randomly distributed throughout the large plot. On plots where shrubs were not dominant, ground cover vegetation was recorded by major composition classes including ferns, herbs, and grasses.

Table 1. *Map units and characteristics of soils on the Wine Spring Creek watershed.*

Soil map unit	Geologic substrate	Elevation zone	Mean solum thickness
		feet	inches
Plott	Metamorphic	>4800	45
Wayah	Metamorphic	>4800	35
Burton-Craggy	Metamorphic	>4800	30
Cullasaja-Tuckasegee	Metamorphic	<4800	48
Edneyville-Stecoah	Metamorphic	<4800	30
Cleveland-Rock	Metamorphic	<4800	15
Spivey-Santeetlah	Sedimentary	<4800	45
Brasstown-Junaluska	Sedimentary	<4800	33
Soco-Stecoah	Sedimentary	<4800	25
Cataska-Rock	Sedimentary	<4800	16

Field data were summarized and ecological variables were calculated using ECOAID, a Forest Service computer program for summary and analysis of ecological data. Tree and sapling importance values (relative basal area + relative density/2) were calculated separately and used as variables for analysis. Constancy, the percent of plots within a classification group that contains a subject species, was calculated to examine relationships of composition among ecological types. Diversity of the overstory by classification group was quantified by species richness, the average number of species per plot.

Data were analyzed by a series of multivariate methods. Effects of unknown past disturbance on species dominance were partially overcome by using overstory, sapling, and seedling components as separate parts of the analysis data set (Peet and Loucks 1977). Plots were initially classified into groups of similar arborescent vegetation using TWINSPAN, a computer program that objectively forms clusters based on similar species composition and abundance (Hill 1979). We used the classification of natural communities[4] developed by Schafale and Weakley (1990) to test the hypothesis that ecological types could be identified in disturbed forest stands. Direct gradient analysis of tree communities was made with CANOCO, a computer program that determines correlation of environmental variables with major axes of the ordination (Ter Braak 1986). Major ecological types dominated by tree species were qualitatively subdivided into smaller, more homogeneous subgroups using shrub and ground cover vegetation. Species name and description of site moisture regimes[5] follows that used by Schafale and Weakley (1990).

A total of 73 plots were sampled during August and September 1992. All sample plots were dominated by vegetation consisting of tree species. The size class distribution of all sample trees over 0.5 inch d.b.h. is shown in Figure 1. Also shown is the mean diameter distribution of mixed-species, deciduous forests from a broad geographic area in eastern Tennessee (West and others 1981). The Wine Spring forest, in comparison, has more trees of smaller d.b.h. and fewer large trees over 18 inches d.b.h. Previous timber harvests in the study area apparently removed enough large trees to allow development of suppressed and intermediate trees as well as seedlings and saplings. The largest tree measured was a yellow birch (*Betula alleghaniensis*) with a d.b.h. of 35 inches. Many trees over 18 inches d.b.h. were poorly formed or defective northern red oaks (*Quercus rubra*) present at high elevation.

Results and Discussion

Classification of Plots

The TWINSPAN analysis indicated that the 73 plots could be combined into six groups based on composition of arborescent species (Table 2). Tree species were classed as ubiquitous (>45% species constancy in three or more groups) or restricted (>45% in fewer than three groups). As Whittaker (1956) also reported, red maple (*Acer rubrum*) was the most ubiquitous tree species encountered, occurring across the total gradients of elevation and moisture. Several trees, including American chestnut sprouts and pitch pine (*P. rigida*), were restricted to a single group.

[4] Communities are defined as a recurring group of species and their physical environment that occupies an area large enough to map.

[5] Classes of xeric, dry, mesic, wet, and hydric are used to describe a moisture gradient ranging from very dry to very wet.

Table 2. *Constancy percent and average percent basal area for ubiquitous and restricted tree species by community group on Wine Spring watershed.*

Principal Species	Community group (No. plots) I(8)	II(16)	III(14)	IV(8)	V(11)	VI(16)
	Ubiquitous species					
Red maple	88:14*	75: 7	28: 1	100:19	100:32	75: 6
Northern red oak	88:10	100:73	71:14	-	27: 2	50: 2
Chestnut oak	50:22	-	14: 1	100:35	91:17	31: 1
Eastern hemlock	-	31: 1	57: 4	-	45: 3	88:35
Mockernut hickory	75: 4	19: 2	-	62: 6	64: 5	-
Scarlet oak	50: 6	-	-	88:24	64: 3	-
	Restricted species					
White oak	100:22	25: 2	-	25: 3	45:14	31: 3
Black oak	100:15	12: 1	-	25: 1	64:12	-
Black locust	-	38: 1	28: 1	25: 1	54: 2	25: 1
Yellow-poplar	-	12: 1	7: 1	-	45: 2	81:30
Sourwood	38: 1	-	-	100: 7	82: 6	12: 1
Sugar maple	-	56: 1	100: 8	-	-	19: 1
Yellow birch	-	19: 1	100:42	-	-	6: 1
Sweet birch	-	-	14: 1	-	64: 2	88:11
Serviceberry	-	56: 3	28: 2	-	-	-
Black cherry	-	15: 1	57: 4	-	-	-
White ash	-	56: 2	43: 6	-	-	-
American basswood	-	-	43: 4	-	-	12: 1
Yellow buckeye	-	-	43: 2	-	-	-
American chestnut	62: 1	-	-	-	-	-
Pitch pine	-	-	-	62: 4	-	-

*Constancy:basal area percent by community group.

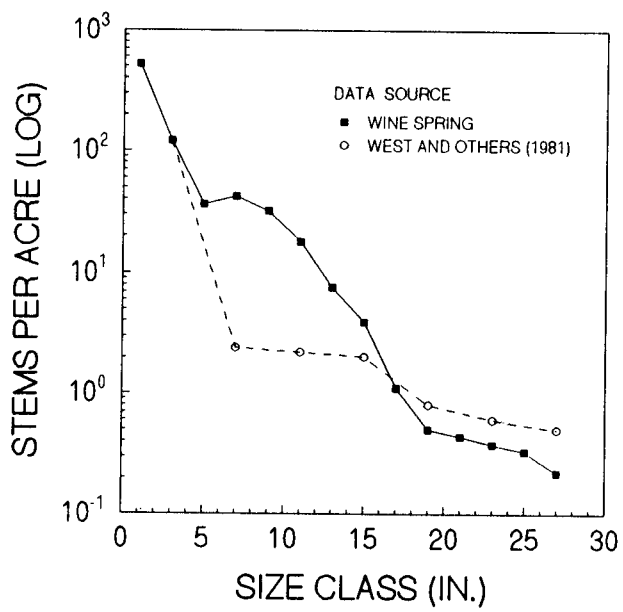

Figure 1. *Population structure of all tree species on the Wine Spring Creek watershed compared with that of mature stands in Tennessee.*

Average values of environmental variables for each group are shown in table 3. The canonical correlation analysis indicated that all environmental variables were significantly ($P < 0.01$) correlated with the species groups. Highest correlations were for elevation, landform index, and solum thickness; aspect and gradient were lowest. The analysis also indicated that canonical coefficients of the centroids representing the six species groups in multivariate space were significantly different at the 0.01 level of probability. When the centroid means are plotted on axes representing linear combinations of environmental variables, along with their 95 percent confidence ellipses (Figure 2), the ordinations represent unique combinations of environmental gradients and associated arborescent vegetation. Over 94 percent of the variation in location of centroids was explained by the first two axes. The first axis accounted for about 64 percent of the variation and was almost perfectly correlated with elevation ($r=0.99$) and closely correlated with landform index ($r=-0.65$). The second axis was highly correlated with solum thickness ($r=0.85$) and also with landform index ($r=0.56$). The landform index is represented by a diagonal axis that

Table 3. Mean values of environmental variables by community group in Wine Spring watershed.

Environmental variable	Community Group I	II	III	IV	V	VI
Elevation (ft)	4412	4828	4641	3621	3496	3447
Aspect (degrees)	235	188	157	243	200	216
Gradient (%)	45	24	33	55	52	35
Landform index	0.19	0.09	0.22	0.22	0.24	0.34
Terrain shape index	−0.01	−0.04	0.05	−0.04	−0.04	0.07
Solum thickness (in)	24	31	45	28	33	42

bisects the horizontal and vertical axes. A diagonal axis also represents the slope gradient, but its influence is in the opposite direction and it has a lower level of correlation with the first two canonical axes. Gradient was highly correlated (r=.65) with the third canonical axis, which is not shown in Figure 2.

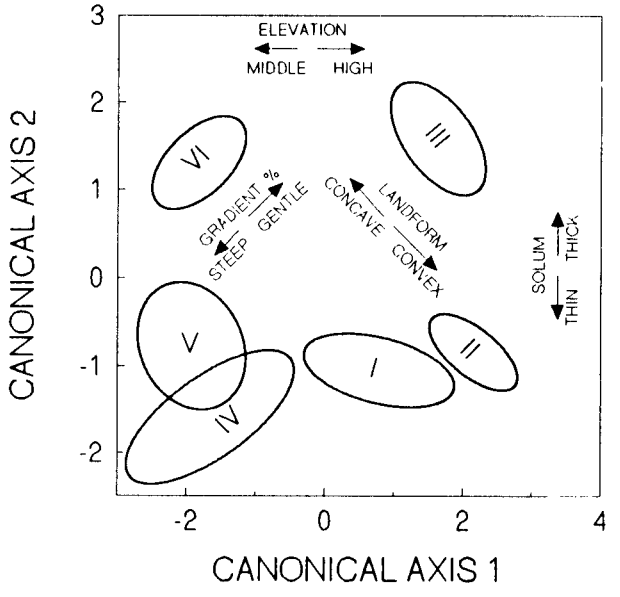

Figure 2. *Ninety-five percent confidence limits for centroids of six ecological types in relation to canonical axes 1 and 2.*

Examination of site variables correlated with the axes suggests that each ellipse represents a unique combination of environmental conditions and vegetative composition. Thus, the previously listed requirements of an ecological type are met. For example, vegetative communities dominated by northern red oak are associated with environments of higher elevation on sideslope or summit positions where soil is moderately deep. Other unique species:environment relationships are associated with the other five groups.

Understory vegetation was usually a homogeneous composition of shrubs or herbaceous plants. Examination of field data suggested that shrub and groundcover vegetation could be qualitatively classified into the following six groups:

1. Seedlings and herbs--Tree seedlings and herbaceous vegetation, including grasses and sedges. Shrubs were usually present, but were few in numbers.

2. Ferns and herbs--Ferns, including New York (*Thelypteris noveboracensis*), Broad Beech (*T. hexagonoptera*), and Southern Lady (*Athyrium asplenioides*), along with grasses and other herbaceous vegetation. Shrubs were usually absent but scattered tree seedlings were present, especially shade tolerant species.

3. Mountain laurel--Mostly mountain laurel (*Kalmia latifolia*).

4. Rhododendron--Mostly rosebay rhododendron (*Rhododendron maximum*).

5. Low deciduous heath--Consists of several ericaceous species of lowbush blueberry (*Vaccinium vacillans*), black huckleberry (*Gaylussacia baccata*), and maleberry (*Lyonia ligustrina*).

6. Tall deciduous heath--Consists mainly of ericaceous species, including flame azalea (*R. calendulaceum*) and highbush blueberry (*V. constablaei*).

The analytical correlation of shrub and herbaceous vegetation with environmental variables was beyond the scope of this paper and will be reported in a later manuscript. DeLapp (1978) studied understory vegetation beneath northern red oak stands throughout the Smoky Mountains, including the Wine Spring area, and found little correlation with the overstory. Understory shrub communities are likely shallow rooted and may indicate finer subdivisions of moisture gradients within ecological types segregated by overstory tree species.

Description of Ecological Types

The most important environmental variable correlated with vegetation was elevation, which

allowed the six tree groups to be combined into two associations of ecological types:

High Elevation Association--Three groups (I, II, III) of deciduous species occurred mainly at elevations of about 4400 feet. At this elevation average temperature is lower, growing season is shorter, and wind speeds are higher than at lower elevations. Although precipitation is also greater, factors related to temperature probably have a greater influence on overall species composition. Each group of species within this association, which is named following Schafale and Weakley (1990), appears to be distributed across the landscape in three perceived classes of soil moisture regimes.

I. Xeric (Montane White Oak)--Sites correlated with this group were located on narrow ridges or sideslopes with steep gradients, convex surfaces, and shallow soils. On sites of this type, evapotranspiration is assumed to be high and soil moisture storage capacity low. White oak (*Q. alba*) and black oak (*Q. velutina*) were typically found on these sites and American chestnut sprouts were prevalent. Three understory communities predominated: tree seedlings, mountain laurel, or tall deciduous heath.

II. Dry (High Elevation Red Oak)--These site were on broadly rounded summits or upper slopes with moderate gradients, moderate soil thickness, and little protection by higher landforms. Soil moisture regime of this ecological type was perceived as dry, or between xeric and mesic. Whittaker (1956) also considered landforms of this type as more mesic than those in Group 1. Northern red oak formed almost pure canopy cover, with lesser amounts of red maple. Two groups of heath species dominated the understory, along with tree seedlings.

III. Mesic (Northern Hardwood)--Many of these sites had northerly aspects, deep soils, and concave surface characteristics that tend to accumulate water and organic matter. These sites were dominated by a distinct group of species commonly described as "northern hardwoods" consisting of yellow birch, sugar maple (*A.* saccharum), American basswood (*Tilia americana*), and yellow buckeye (*Aesculus octandra*). Northern red oak was an important component of these stands, but red maple was uncommon. Understory vegetation was mainly ferns and herbs (Table 4).

Red spruce (*Picea rubens*) was not present in the study area, but it occurs at similar elevations in the nearby Great Smoky Mountains National Park. Its absence in Wine Spring watershed is consistent with observations of Whittaker (1956).

Middle Elevation Association--This association of ecological units was centered at elevations of about 3500 feet. Average slope gradients were slightly greater than at high elevation, but other site variables were about the same in magnitude. Communities are listed by three perceived soil moisture regimes:

IV. Xeric (Pine--Oak/Heath)--Most sites were on steep, narrow ridges, convex surfaces and thin solums with little protection by higher landforms. Species classified as xerophytic, scarlet oaks (*Q. coccinea*) and chestnut oak (*Q. prinus*), dominated these sites. Sourwood (*Oxydendrum arboreum*) was also common. Pitch pine occurred only on this type and was present in most plots. Understory vegetation was mainly mountain laurel. Low deciduous heath was found on north-facing sites judged to be slightly more mesic.

V. Dry (Chestnut Oak)--These sites were on sites with steep sideslopes with variable aspects and moderately deep soils. Soil moisture regimes were estimated as dry. The canopy was dominated by chestnut oak and red maple. Common understory vegetation consisted of tree seedlings or low deciduous heath.

VI. Mesic (Acidic Cove)--These sites occurred on lower slopes with variable aspect and were characterized by concave surfaces, high values of landform index, and deep soils. Many sites were situated along streams where rhododendron dominated the shrub layer and excluded herbaceous vegetation. Away from streams, ground cover typically consisted of ferns and herbs. Three trees species, eastern hemlock, sweet birch (*B. lenta*), and yellow-poplar (*Liriodendron tulipifera*), dominated the overstory of this community.

Three mesic sites in this association were almost completely dominated by eastern hemlock, but were not classified as a separate species group by TWINSPAN. Their composition and location on slightly less mesic areas of the landscape is consistent with the Canada Hemlock community described by Schafale and Weakley (1990).

Table 4. *Association of understory shrub communities with community group in Wine Spring watershed.*

Understory community	Community group I	II	III	IV	V	VI
	-Percent of plots-					
Tree seedlings	38	56	36	-	36	12
Herbs and ferns	-	-	57	-	-	38
Mountain laurel	24	19	-	62	9	-
Low deciduous heath	-	-	7	38	55	-
Rhododendron	-	-	-	-	-	50
Tall deciduous heath	38	25	-	-	-	-

Diversity of tree species was similar for communities of both high (7.6) and low (7.6) elevations, but the relationship differed by moisture class (Figure 3). On high elevation sites, average richness was lowest on ecological types judged to have a dry moisture regime, which were dominated by northern red oak and highest on mesic sites. At middle elevations, however, average richness was greatest on sites with dry moisture regimes. Many of the mid elevation, mesic sites were along streams where the overstory was dominated by relatively few tree species and the shrub layer consisted mainly of rhododendron. Site moisture relationships of ecological types within the two associations are not directly comparable because of the interactions with environmental effects associated with elevation. Whittaker (1956) describes this as a complex gradient.

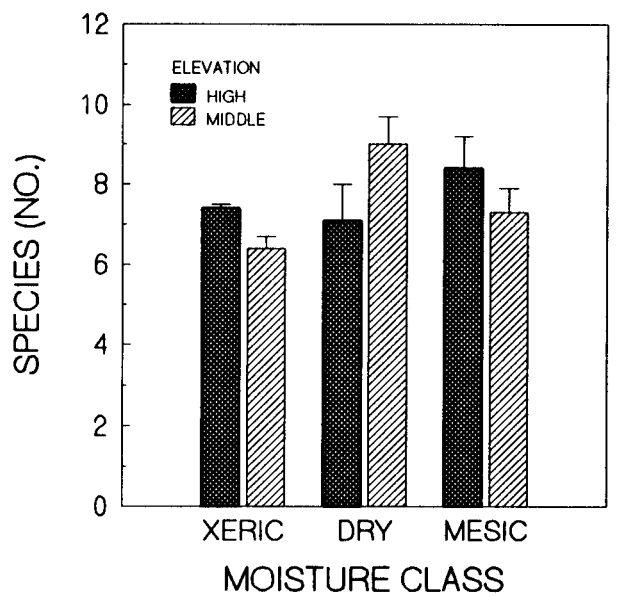

Figure 3. *Diversity of tree species in relation to landtype moisture regime in two elevation zones of Wine Spring study area. Vertical bars are 1 standard error of the mean.*

Classification Hierarchy

The proposed framework of ecological types consists of a hierarchy of nine levels, which can be delineated on maps ranging from broad to detailed in scale. At each level, ecological types are based on integrations of climate, landform, soil, and vegetation. A basic unit of the hierarchy at the lowest levels is landtype: a recurring, recognizable part of the landscape that formed from similar climatic and geologic processes. Landtypes can be aggregated into more generalized associations or subdivided into more specific phases. The lower four levels of the framework are applicable to the Wine Spring study area:

Level	Map Scale
Landtype Association	1: 126,720
Landtype	1: 24,000
Landtype Phase	1: 24,000
Site	1: 12,000 or larger

The lowest level, site, is the classification unit. Presented in table 5 are tentative ecological types for the three lower classification levels of the Wine Spring Creek watershed.

Following Whittaker's (1956) logic, vegetation in the study area can be viewed as a single continuum, not as discrete units, where relative dominance varies along a series of complex environmental gradients. The landtype association includes ecological types that occur within broad geographical areas of similar climatic conditions, which are segregated by elevation in the study area. Within each landtype association are three landtypes, each consisting of characteristic landforms, soils, and vegetation that define ecological types of broad moisture regimes. Each landtype is subdivided into a number of landtype phases that define ecological types consisting of smaller areas of uniform shrub and herbaceous vegetation, which might be correlated with soil texture, fertility, or past

land use. Other ecological types may be identified in the lower classification levels with more intensive field sampling. Although landtype associations were based on ecological differences correlated with elevation in the study area, other environmental variables such as geologic formation, soil fertility, and texture may be important factors in other areas.

Table 5. *Summary of ecological types present on landtype associations (two elevation zones), landtypes (three moisture regimes), and landtype phases (tree and shrub combinations) in the study area.*

Landtype	Landtype Association	
	High Elevation	Middle Elevation
Xeric	White Oak (tree seedlings) (mountain laurel) (tall deciduous heath)	Pine-Oak Heath (mountain laurel) (low deciduous heath) --
Dry	Northern red oak (tree seedlings) (mountain laurel) (tall deciduous heath)	Chestnut oak (tree seedlings) (mountain laurel) (low deciduous heath)
Mesic	Northern hardwoods (tree seedlings) (herbs and ferns) (low deciduous heath)	Eastern hemlock (tree seedlings) (herbs and ferns) (rhododendron)

Conclusions

Reconnaissance methods were successful for locating sample plots in a forested area of mature timber stands that had been initially stratified by soil mapping units. Standard ecological classification and ordination techniques were satisfactory for identifying vegetative communities using plot data for tree, sapling, and seedling components of the flora. In the Wine Spring watershed, which had not been farmed and disturbances resulted mainly from timber harvests, mature tree communities are strongly correlated with environmental factors of elevation, landform, and solum thickness. Composition of shrub and arborescent communities in the mature, but not old-growth stands, is similar to that reported for relatively undisturbed stands. Field data were analyzed and grouped into plant communities of varying complexity using a regional ecological classification system proposed for the Southern Region by the USDA Forest Service. The strong correlation of ecological types with topographic and soil variables will allow discriminant functions to be developed for applying the classification with a geographic information system (McNab 1990).

In summary, this classification can be used to delineate broad areas of the landscape in the study area that have similar environmental characteristics as indicated by tree and shrub vegetation. With additional field study, the classification can eventually be used to answer other questions concerning these communities, including response of vegetation to disturbance, productivity, and habitat suitability for other organisms.

Acknowledgements

We thank Bradley G. Smith, Ecologist, Okanogan National Forest, Okanogan, WA, for providing an early version of ECOAID, an integrated set of personal computer-based analysis programs for analyzing species-abundance data for community type definition and description.

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LANDSCAPE ECOSYSTEM CLASSIFICATION ON THE HIGHLANDS RANGER DISTRICT NANTAHALA NATIONAL FOREST, NORTH CAROLINA [1]

Jane T. Gattis, Steven M. Jones, and W. Henry McNab [2]

Abstract. Landscape Ecosystem Classification was attempted on the Highlands Ranger District in western North Carolina by using landform, soils, and late-successional vegetation to identify ecologically equivalent sites. Six distinct site units were identified using ordination, cluster analysis and discriminant analysis. A combination of four environmental features (elevation landform index, soil solum thickness, and epipedon thickness) identified site units with a success rate of 76 percent. Using these permanent landscape features, site units can be delineated without vegetation. If indicator plants are included, successful prediction of site units is increased to over 90 percent. This study provides the framework for future research including modeling seral stages of vegetation on the six site units and preliminary interpretation of ecosystem boundaries for management decisions.

Introduction

Due to increasing public involvement and concern, strategies for managing National Forests are changing rapidly. On the Highlands Ranger District of the Nantahala National Forest in western North Carolina, the local economy relies heavily on logging and on tourism associated with the scenic beauty of the Southern Appalachian Mountains. Environmental concerns and the need for quality timber have polarized the Highlands public, making agreement on land use decisions difficult. In light of these issues, the Highlands Ranger District adopted the New Perspectives management approach to strengthen the ecological basis of land management and to promote public acceptance and trust in land management decisions. To begin this new approach, the Ranger District designated a 6600-acre pilot study area where research on a wide variety of wildlife habitat and nontraditional forest management practices is being conducted.

A primary step in developing such a broad management plan is to gain an understanding of the vegetation mixtures that are possible for each portion of the landscape. A system for classifying units of land that are similar in type, species, size distribution, and productivity of vegetation would help identify the potential range of desired future conditions. In the Southern Appalachians, climate, topography, geology, and soils produce a complex range of possible site units, making such identification difficult. The traditional approach of using site index to quantify productivity often fails due to this area's history of disturbance from ice storms, harvesting and high-grading, the chestnut blight, and nonforest land uses (Van Lear 1991, Lloyd 1991, Monserud 1984). Land classification systems were developed by Smalley (1979) and McNab (1991) for neighboring regions. However, none combine landform, soils, and vegetation which are necessary to determine the range of desired future conditions.

The classification system used in this paper, Landscape Ecosystem Classification (LEC) was begun by Barnes and others (1982) and adopted by Jones and others (1984). LEC uses diagnostic vegetational species and their associated soils and landform to identify and classify ecological site units. Site units, which are defined based on vegetation, can be composed of many landform types and are discriminated from one another by major soil and landform features. One advantage of landscape ecosystem classification is that once a model for a particular physiographic region has been developed using late successional vegetation, landform, and soils, site unit prediction can be made from landform and soil characteristics without the vegetation component.

The objective of this study was to identify and describe the interrelationships among the varied landforms, soils, and vegetation in the Highlands Ranger District using the LEC approach. This study is the first step in developing and validating an LEC

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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model which can be used as the framework for determining desired condition of the National Forest in order to promote sound ecosystem management.

Methods

Study Area

The New Perspectives study area includes 6600 acres and lies in the southeast corner of Macon County, North Carolina, within the Highlands Ranger District on the Nantahala National Forest. Mean annual rainfall is 80 inches and mean annual temperature is 55°F (North Carolina Climatological Data Annual Summary 1990). The area lies in the eastern portion of the Blue Ridge Geologic Province and is composed primarily of high grade metamorphic rock (McKniff 1967). Soils may form entirely from residuum or colluvium, but, on most sloping landscapes they have developed in both materials (Graham and others 1990).

The New Perspectives area was relatively limited in size and did not have adequate distribution of late successional forest stands for the development of an LEC model. For this reason, the study area was expanded to other areas in the Highlands Ranger District which have similar climatic patterns and parent material, two factors thought to be important driving forces in species distribution (Hodgkins 1965). The larger study landscape lies entirely in the southern section of the Blue Ridge Province of the Southern Appalachians (Braun 1950), making the classification model applicable to the entire high rainfall belt on the Nantahala National Forest (Figure 1).

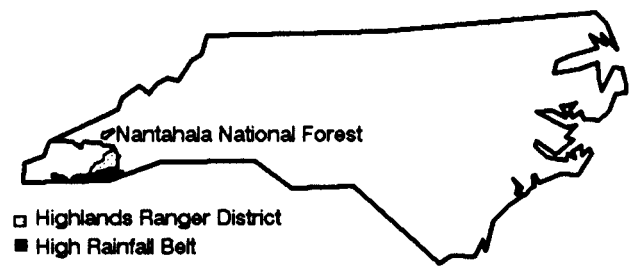

Figure 1. *High rainfall belt of the Southern Appalachians within the Nantahala National Forest.*

Sampling

Stands which demonstrated late successional, relatively undisturbed vegetation conditions were selected with the assistance of district office personnel and long-term local residents. Stands were required to have relatively uniform mixtures of overstory and understory species and to be homogenous with respect to ages of dominants and codominants (Jones and others 1988). Sites were chosen to represent the full range of environmental conditions found in the expanded study area in an effort to describe forest communities as they vary in relation to landform and soils.

One 10-by 40-m (0.04-ha) sample plot was located at the center of each stand with the long axis centered along the contour. On the plots, diameter of all trees larger than 4.5 inches in diameter at breast height (d.b.h.) was measured and recorded by species. Species and diameter class of saplings and tall shrubs less than 4.5 inches d.b.h. and greater than 4.5 feet tall were recorded. Five 1-by 20-m transects on each 0.04-ha sample plot were delineated. Seedlings and low shrubs less than 4.5 feet tall were recorded by species and number of stems within the second and fourth transects. Herbaceous species, vines, and rhizomatous low shrubs were recorded in each of ten square-meter plots (0.25-x 4-m) nested within the 1-by 20-m transects.

Soil samples were systematically collected by horizon from three locations in each 10-by 40-m plot. Like horizons were combined to form a composite sample and were described in the field by color, horizon depth, and depth to the C horizon (solum thickness). Each horizon was analyzed for texture and particle- size distribution (Day 1965), as well as nutrient content.

The landform variables of aspect, slope position, slope gradient, and elevation were recorded at each site. Aspect was measured as an azimuth and then transformed by the sine-wave method (Trimble and Weitzman 1956). Slope position was estimated as percent of distance from the ridgetop (100 percent) to the valley bottom (0 percent). Elevation was estimated from USGS topographic maps (1:24,000 scale). Other landform variables included Terrain Shape Index (TSI) and Landform Index (LI) as described by McNab (1989). TSI quantifies concave, convex, and flat land surface shape. LI is the mean inclination to the horizon from the plot center.

Data Analysis

Data on vegetation were summarized for each species for each plot. Species within canopy strata were considered distinct from that same species in other canopy strata. Therefore, each stratum class of a species was considered a "psuedospecies". Importance Value 200 (relative density + relative basal area/2 x 100) was calculated for trees, saplings,

and tall shrubs. Importance Values were based on relative density for seedling and low shrub species. Herb and rhizomatous shrub importance values were based on relative frequency.

Vegetational data were analyzed to determine vegetation types using detrended correspondence analysis (DECORANA) (Hill 1979). DECORANA is a method of ordination in which plots are sorted along one or more coordinate axes such that their relative positions provide maximum information about their ecological similarities (Ludwig and others 1988). The goal of ordination is to search for biological and environmental similarities that create patterns or groupings of plots which may be important in determining the structure of the ecological communities.

Vegetational data were also analyzed with TWINSPAN (Hill 1979), a cluster analysis program that uses information on all species present to arrange or cluster similar samples. TWINSPAN was used in conjunction with DECORANA to avoid subjectivity in the delineation of plot clusters. TWINSPAN also identifies one to several species which are diagnostic of each division in the classification.

Landform and soil variables were analyzed with stepwise discriminant analysis and discriminant analysis to determine their relationship to the vegetation groups identified by DECORANA and TWINSPAN. The goal was to develop a model that would be accurate, easy to use, and cost-effective. For that reason, two stepwise discriminant analyses were performed; one which used all landform and soil variables and a second which omitted soil chemical variables that are time-consuming and costly to obtain. Variables identified in the stepwise procedures were used in two discriminant analyses to develop models for predicting site unit membership. A third discriminant model was tested by adding diagnostic plant species identified through TWINSPAN to the better of the first two models.

Results

The primary data matrix consisted of 46 plots and 235 species and pseudospecies. After removing two outlying plots identified in the first ordination, six plot clusters were revealed by DECORANA (Figure 2). TWINSPAN results agreed with those of DECORANA, delineating the 44 plots into six clusters with no out-of-place plots.

Because one of the six plot clusters contained only two plots, it was removed from the data set. The two discriminant analyses using only soil and landform variables produced models highly correlated to the vegetation units defined by DECORANA and TWINSPAN. The use of soil chemical data in the first analysis improved model prediction success from 76 to 84 percent. However, indicator plants were added to the model without these data because of the high expense. In this third analysis, the predictive ability of the discriminant model increased to over 95 percent (Table 1). In all analyses, elevation was the primary discriminating variable accounting for over 70 percent of the prediction success between site units in the classification model. Other discriminating variables included landform index, soil solum thickness, epipedon thickness, 4 soil chemical variables of the A and B horizons, and 10 indicator species (Table 2).

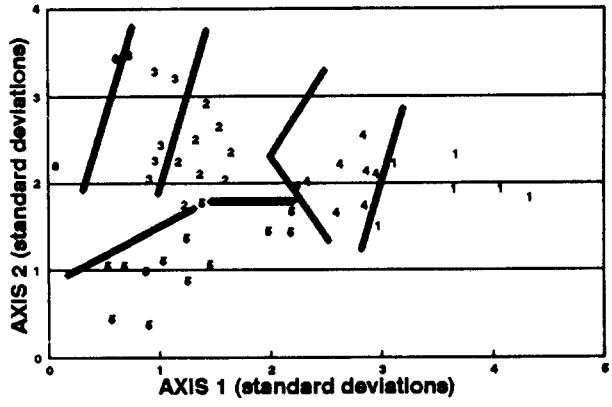

Figure 2. *Six site units identified by DECORANA and verified by TWINSPAN with 44 plots represented.*

Site Units

Using the results provided by the stepwise discriminant analysis, an environmental interpretation of Axis 1 for the second ordination was possible (Figure 2). Two gradients, one at high elevations, and one at mid elevations, produced two models. By combining elevation, landform index, and solum thickness, Axis 1 can be interpreted as a moisture gradient increasing from left to right. Low landform index values (convex shape) and shallow soils were associated with low Axis 1 scores, while high landform index values (concave shape) and deep soils were associated with high Axis 1 scores. These ranges combined with the identification of diagnostic species through TWINSPAN revealed two elevationalgradients (mid elevation and high elevation) with three site units each.

Table 1. *Classification success of discriminant analysis using 4 physical landform and soil variables and indicator species and 5 site units.*

Actual Site Unit	Predicted Site Unit Membership 1	2	3	4	5
1	100	*	*	*	*
2	*	100	*	*	*
3	*	*	83	17	*
4	*	*	*	100	*
5	*	*	*	*	100

Table 2. *Landform variables, soil variables, and indicator species identified by stepwise discriminant analyses at the .50 level.*

Physical Soil and Landform Variables

Elevation
Landform Index
Soil Solum Thickness
Epipedon Thickness

Soil Chemical Variables

CEC of the B Horizon (clay basis)
pH of the B Horizon
Extractable Aluminum of the A Horizon
Extractable Acidity of the A Horizon

Indicator Species

Sweet Birch (*Betula lenta*)
Pignut Hickory (*Carya glabra*)
White Oak (*Quercus alba*)
American Chestnut (*Castanea dentata*)
Witch Hazel (*Hamamelis virginiana*)
Blackgum (*Nyssa sylvatica*)
Rhododendron (*Rhododendron maximum*)
Eastern Hemlock (*Tsuga canadensis*)
White Catbriar (*Smilax glauca*)
Painted Trillium (*Trillium undulatum*)

1. Mid-elevation Mesic. The stands in site unit 1 were on protected lower slope positions with deep soils. The elevation ranged from 2800 to 3800 feet and landform index values were high (.23 to .42) corresponding to high Axis 1 scores (Figure 2). The vegetation was characterized by a northern red oak (*Quercus rubra*)- eastern hemlock (*Tsuga canadensis*) - birch (*Betula spp.*) vegetation type. Sweet birch was restricted to these sites sharing dominance with northern red oak, white pine (*Pinus strobus*), eastern hemlock, yellow birch (*Betula lutea*), and yellow-poplar (*Liriodendron tulipifera*). An open understory was characteristic of this site unit.

2. Mid-elevation Intermediate. A mixed oak - hickory (*Carya spp.*)- huckleberry (*Gaylussacia ursina*) vegetation type characterized the vegetation of site unit 2. Intermediate first axis scores corresponded to elevations ranging from 2600 to 3300 feet and intermediate landform index values and soil depths (Figure 2). Northern red oak, the dominant overstory species, was associated with chestnut oak (*Quercus prinus*), white oak, hickory, yellow-poplar, and white pine (Figure 2). The midstory contained abundant saplings of American chestnut and sourwood (*Oxydendron arboreum*). The herbaceous layer contained an average of 15 species per plot.

3. Mid-elevation Xeric. Associated with low first axis scores and shallow soils, site unit 3 was identified as a scarlet oak (*Quercus coccinea*) - chestnut oak - heath vegetation type (Figure 2). The dominant trees were scarlet oak, chestnut oak, sourwood, white pine, blackgum, and northern red oak. The midstory was almost fully dominated by mountain laurel (*Kalmia latifolia*) and saplings of blackgum and sourwood. Elevations in this site unit ranged from 2600 to 4000 feet. Indicative of highly exposed sites at mid-elevations, landform index values averaged 0.16.

4. High-elevation Mesic. Northern red oak, eastern hemlock, and witch hazel characterized the vegetation of site unit 4. High Axis 1 scores associated with deep soils and high landform index values were similar to those of site unit 1 (Figure 2). The two site units divided at 4000 feet, where there was an observable change in the vegetation composition. The dominant tree species included eastern hemlock, northern red oak, red maple, and chestnut oak. Unlike site unit 1, however, yellow-poplar and white pine, were no longer present. Elevations in site unit 4 ranged from 4000 to 4600 feet, whereas in site unit 1 all elevations were below 4000 feet.

5. High-elevation Intermediate. Indicative of the wide range of Axis 1 scores, site unit 5 was the most complex in terms of species composition (Figure 2). These stands were in elevations ranging from 3400 to 4800 feet and were characterized by a northern red oak-white oak-hickory vegetation type. Dominance was shared by many tree species including black oak (*Quercus velutina*), white oak, chestnut oak, scarlet oak, northern red oak, and pignut

hickory. The midstory was predominantly American chestnut and saplings of the overstory trees.

6. High-elevation Xeric. High elevation xeric sites corresponded to the lowest Axis 1 scores where landform index was lowest and soils were thinnest (Figure 2). Site unit 6 was a scarlet oak-white oak-heath vegetation type. Stands were almost completely dominated by scarlet oak and mountain laurel. Northern red oak, white oak, and chestnut oak trees showed evidence of wind and ice damage and were small in size. The understory was dominated by huckleberry and mountain laurel with few other species present. No distinct herbaceous species were found that characterized this site unit.

Summary and Conclusions

The landscape ecosystem classification approach was applied to the complex climate, topography, geology, and soils of the high rainfall belt of the Southern Appalachians on the Nantahala National Forest. By combining the three major ecosystem factors of soil, landform, and vegetation in ordination, cluster, and discriminant function analyses, six distinct site units were identified which recur across the landscape and represent an array of site types. Future research should identify the seral stages associated with each site unit and will aid in determining the range of possible desired future conditions on the Highlands Ranger District.

The LEC model now functions as a predictive model that provides the framework for broad, yet preliminary interpretations of ecosystem boundaries, but requires additional validation. Direct application of the predictive model beyond preliminary interpretations is limited without further research. Implicit in the LEC approach, however, is the assumption that a relationship exists between site productivity and site classification unit, where productivity is a function of a combination of soil moisture and elevation, increasing from xeric to mesic site units. Similar correlations have been found in the Coastal Plain and Piedmont classification models (Churchill and Jones 1987 and Lloyd and Waldrop 1992) and would be anticipated in the Highlands Ranger District model.

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DISTRIBUTION AND DEVELOPMENT OF ROOT MATS IN THE SOUTH CAROLINA PIEDMONT [1]

Rebecca E.B. Ball, Thomas A. Waldrop, and Steven M. Jones [2]

Abstract. Fire prescriptions developed for the fell-and-burn technique in the Southern Appalachian Mountains can result in excessive erosion when used in the Piedmont. The difference has been attributed to thin root mats (F and H forest floor layers) which are entirely consumed by high-intensity site preparation burns. This study examined litter layer (L layer) and root mat thickness across three successional stages and three types of sites to identify where root mats may be thick enough to allow burning. Preliminary indications are that root mat thickness is more closely related to site type than successional stage. A lack of information is indicated on the relationship of moisture to decomposition, root growth, root survival, and litter deposition.

Introduction

Establishment of pine-hardwood mixtures by the fell-and-burn technique (Abercrombie and Sims 1987) has proven successful in the Southern Appalachian Mountains. The procedure provides a low-cost alternative to expensive site preparation necessary to convert hardwoods to pine monoculture (Phillips and Abercrombie 1987). The technique involves spring felling of residual trees after a commercial clearcut, summer site preparation burning, and planting pine at wide spacings to allow hardwood regrowth. The burn reduces growth of the competitive hardwood sprouts allowing pine seedlings to become established (Waldrop and others 1989).

The high-intensity burning used in this technique has not been shown to cause significant erosion in the Southern Appalachians. Van Lear and Danielovich (1988) found that soil movement on a mountain site was not significantly increased because 22% of the root mat (F and H layers) remained intact and mineral soil was exposed on only 15% of the site. However, in a comparative study in the Piedmont, Van Lear and Kapeluck (1989) showed soil loss of 207 tons/acre/year when burning was conducted under a similar prescription and with similar aboveground fuels. The difference in erosion rates was attributed to differences in thickness of the forest floor. Mountain sites tended to have root mats that were from 3 to 5 inches thick before burning. Root mats of Piedmont sites were generally less than 1 inch thick and little was left after burning. McCracken and others (1989) reported a root mat that was 0.8 inch thick in a virgin Piedmont forest.

Successful application of the fell-and-burn technique in the Piedmont will likely be limited to only those sites where the root mat is thick enough that it is not entirely consumed by burning. Root mats protect the soil from erosion by absorbing kinetic energy of rainfall and by acting as a sponge to allow water to seep into the soil gradually (Wilde 1971). They also hold moisture on the site by acting as a mulch (Waldrop and others 1989).

Little is known about the factors that affect root mat development or how to identify sites in the Piedmont where it is likely thick enough to allow site preparation burning (Waldrop and others, 1989). Factors such as aspect, slope position, soil physical properties, time since disturbance, degree of disturbance, and vegetation cover may be important factors in the development of this necessary resource. This information would assist forest managers to identify sites that are likely to have root mats of sufficient depth to protect the soil from erosion and thin areas with high potential for erosion.

This study examines the variability of forest floor characteristics across the Midlands Plateau Region of the Piedmont Province in South Carolina. The specific objectives were to determine the relationship of root mat thickness to site types and to time since disturbance, or seral stage.

Methods

A model of ecosystem units for the Piedmont Province of South Carolina (Jones 1989) using the Landscape Ecosystem Classification (LEC) concept was used as a tool to define site types. This model

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describes site units across a moisture gradient by: 1) landscape position (slope position and aspect), 2) soil information (depth to clay and percent clay in the inhibiting layer), and 3) presence of indicator plant species. The model includes five site units that range from the xeric site unit found on upland slopes with shallow soils to the mesic site unit found on lower, protected slopes with deep soils.

For this study, a subset of stands was sampled from those of the original study (Jones 1988). Sampled stands included those of the xeric, sub-xeric, and intermediate site units (mesic and submesic were excluded) which were in one of three successional stages: early successional pine, mid-successional oaks, or old-growth mixed hardwoods. Three stands were sampled from each site unit-successional stage combination. All stands were in the Midlands Plateau Region of the Piedmont Province in South Carolina. The early and mid-successional stands were around 50 years old and the old-growth hardwoods were around 150 years old. Old-growth stands were chosen that were clearly within a specific landscape unit as interpreted by Jones (1988) from DECORANA ordination (Hill 1979). Early and mid-successional stands were chosen by comparing individual stand data to ensure the plot met the soil, landform, and vegetation requirements for a specific unit.

Sampling occurred within the same 33 x 131 ft (10 x 40 m) plot that was established for the LEC study. Starting at a random point within each plot, and using a 5-by-4 grid, twenty sub-plots were sampled at 13 ft (4 m) intervals. Each sub-plot was located at least 3.3 ft (1 m) from trees over 4.5 in (11.4 cm) dbh to eliminate large woody roots from the study. This factor occasionally resulted in a non-random starting point.

At each sub-plot, the thicknesses of the litter layer (L layer) and root mat (F and H layers) were measured at twenty systematic points using a 5 by 4 grid sampling frame (Ball 1992). Means of litter and root mat thickness for each stand were tested for significant differences across a spatial-temporal interaction gradient through General Linear Models Procedure (GLMP) and Duncan's Multiple Range test. The study used a 3 by 3 factorial arrangement (3 site units by 3 successional stages) of a completely random design. Differences were considered significant at the 0.05 level.

Results

There was little variation in litter layer thickness across site units and successional stages, ranging from 0.7 in. on sub-xeric site units to 1.1 in. in early-successional stands on xeric site units (Fig. 1). On xeric and intermediate site units, there was a general trend for the litter layer to become thinner in the later successional stages. However, there were no significant differences between successional stages for all site units combined or within the sub-xeric and intermediate site units. On xeric site units, the litter layer was significantly thicker in early successional stands (1.1 in.) than in mid-successional (0.9 in.) or old-growth stands (0.8 in.).

When successional stages were combined, litter thickness was significantly greater on xeric (0.9 in.) and intermediate (0.9 in.) site units than on sub-xeric units (0.7 in.). Even though this pattern was most pronounced in early-successional stands, it was significant only in mid-successional oak stands. There, litter thickness was 0.7 in. on sub-xeric site units and 0.9 in. on xeric and intermediate site units.

Root mats were much thinner in this study than previously measured on mountain sites. On these Piedmont sites, root mats ranged from 0.6 in. thick in mid-successional stands on intermediate site units to 1.2 in. thick in early successional stands on xeric site units (Fig. 2). There was no clear pattern of root mat development across the successional gradient. On xeric and intermediate site units, root mats tended to be thicker in early-successional pine stands than in either type of hardwood stand while the opposite pattern was observed on sub-xeric site units. However, none of these differences was significant.

With successional stages combined, there were no significant differences in root mat thickness between site units. However, there was a strong pattern within the two types of hardwood stands (mid-successional oaks and old-growth mixed hardwoods). In these stands, the root mat was significantly thinner on intermediate site units than on xeric and sub-xeric site units. The thickest root mat occurred on sub-xeric sites. This pattern agrees with McCollum (1992) who found above- and below-ground root development to be greater on sub-xeric than on xeric and intermediate site units.

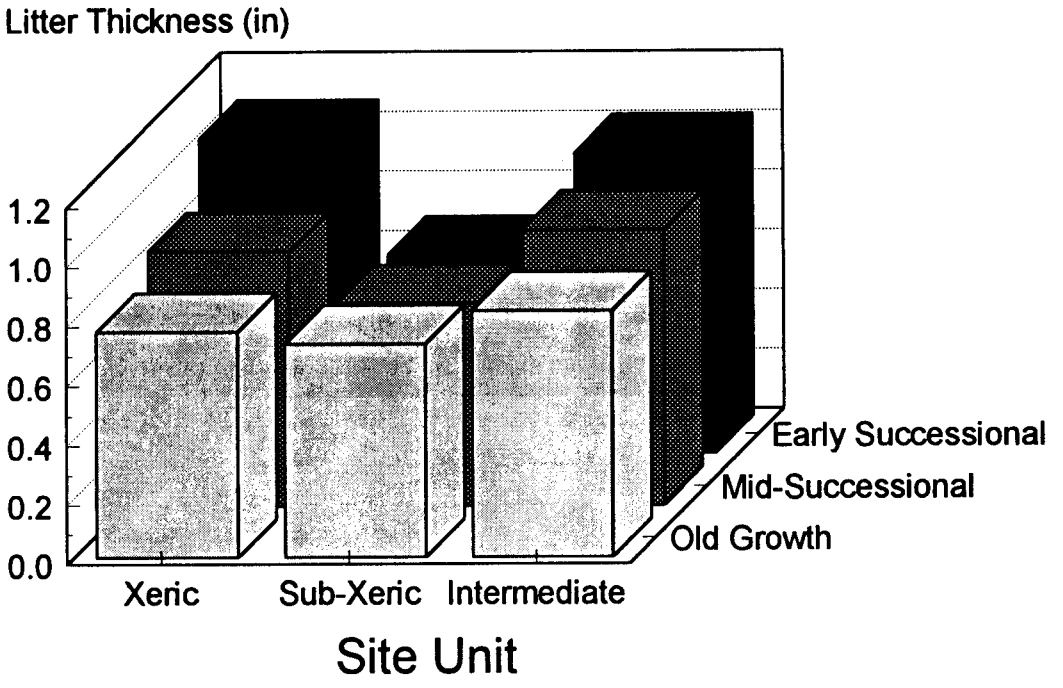

Figure 1. *Litter layer thickness by site units and successional stages across the South Carolina Piedmont.*

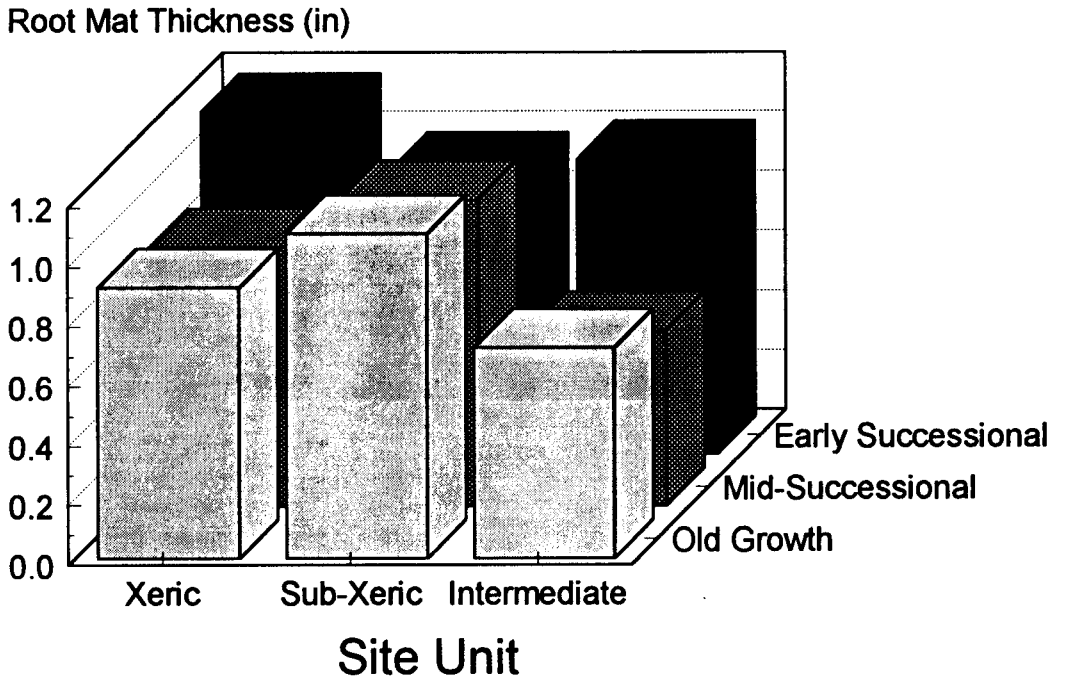

Figure 2. *Root mat thickness by site units and successional stages across the South Carolina Piedmont.*

Discussion

An early assumption in designing this study was that the amount of time since a major disturbance would have an impact on the development of the forest floor, particularly on the thickness of the root mat layer. However, the successional gradient chosen for this study failed to show a clear pattern. The litter layer tended to become thinner over time on two of three site units (Fig. 1), which may be due to the increased hardwood composition and the associated increase in decomposition rates. However, this pattern did not hold for root mats, which tended to be thicker in early-successional pine stands but showed no difference between the mid-successional oaks and the old-growth mixed hardwoods.

Arp and Krause (1984) found that forest floor characteristics such as oven-dried mass per unit area, depth, moisture content and several chemical attributes varied widely over a stand. They recommended that 10% of a site be sampled to obtain 95% confidence. This study covered only about 1% of each stand, which may have masked differences between successional stages.

A somewhat more meaningful pattern of forest floor development occurred across site units, particularly if the two hardwood successional stages are considered separately from the early-successional pine. The dry, xeric site units and the moist, intermediate site units typically had thick litter layers and thin root mat layers. Sub-xeric site units, which are more moist than xeric and drier than intermediate site units, were characterized by thin litter layers and thick root mat layers.

These patterns may be due to a combination of site quality and decomposition rates. Litter layers may be thicker on intermediate site units because more litter is produced on the higher-quality sites. Although xeric site units likely have less litter production, limited moisture would reduce the abundance of decomposing fungi and micro-arthropods. Sub-xeric site units likely have lower litter deposition than intermediate site units and greater decomposition than xeric site units.

McCollum (1992) suggested that root development, and thus root mat thickness, was related to the moisture gradient across site units. On xeric site units, root growth and survival is likely low due to limited moisture availability. Root growth is low on intermediate site units because of higher moisture availability. On sub-xeric site units, moisture availability may be low enough to demand increased root development but high enough to allow root survival.

Conclusions

Regardless of the time since disturbance, site unit, or species composition (pine vs. hardwood), the root mat of South Carolina Piedmont forests was much thinner than in the mountain areas where the fell-and-burn technique has been successful. This pattern suggests that the prescriptions used for site preparation burning used in the Southern Appalachians should be altered to adapt to the thin conditions of the Piedmont. Future studies should examine the root component of root mats to determine if they have sufficient soil holding capacities to prevent erosion after a fire. Also, research is needed to develop guidelines for fire prescriptions for each site unit.

Due to the inherent variability of soils, patterns of forest floor development observed in this study produced few differences that were statistically significant. Therefore, definitive guidelines for identifying stands with root mats thick enough to protect from burning cannot be stated. However, site units appeared to more important than successional stages. Stands on sub-xeric site units had thicker root mats than those on xeric and intermediate site units. Explanations for this pattern are mostly speculative but they indicate the need for a better understanding of forest floor development processes between site units. Future studies should focus on the relationship of moisture to the balance of root growth, root survival, decomposition, and litter production on each site unit.

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LONG-TERM EFFECTS OF FOREST COVER ON PROPERTIES OF ERODED SOILS IN THE GEORGIA PIEDMONT [1]

M.B. Edwards, B.G. Lockaby, D.T. Crawford, and R.H. Jones [2]

Abstract. Soil pits were used to compare the effects of long term forest cover on the properties of eroded Piedmont soils. The cover types were: 1) pasture; 2) second rotation, young loblolly pines, and 3) first rotation, mature loblolly pines. Properties compared were soil bulk density, soil carbon content, root density, root number, and root size distribution. Cover type significantly affected carbon content, bulk density, and root number and distribution. The pasture soils had a greater carbon content than the older pines in the A horizon with the younger pine soils being intermediate in carbon content. The soils under the mature pines had lower bulk densities in the B horizon and greater root numbers in both A and B horizons than those of the pasture. Root distributions also indicated that the mature pines had significantly more numerous roots in the 5 to 50 mm range compared to pasture or young pines. These results suggest that increased root activity in wooded areas could be the cause of the lower bulk densities in subsurface horizons. Reduced bulk densities in argillic horizons may lead to improved soil productivity across the Piedmont landscape.

Introduction

Although a variety of environmental benefits are thought to be derived from reforestation, knowledge of specific ecological benefits remains hazy. One such benefit that has received little attention is the utility of forest vegetation to ameliorate detrimental soil properties on low quality sites. This benefit may be particularly important on eroded clay soils such as those that dominate the Piedmont region of the southern US. Most Piedmont forest soils were substantially eroded during former agricultural usage. As a result, texture, structure, bulk density, and porosity are frequently not conducive to adequate aeration and infiltration of water. Consequently tree root extension is limited which, in turn, contributes to the reduced forest productivity of the Piedmont region when compared to that of the Coastal Plain. As an example, Van Lear and Kapeluch (1988) have found that the frequency of occurrence of pine roots is inversely related to bulk density and soil strength in the upper 1 m of Cecil soils in the Piedmont of South Carolina.

Reforestation is often assumed to improve degraded soils but few investigations have rigorously tested this potential (Fisher 1990). In terms of improved physical conditions, Fisher suggests that the most likely mechanism involved is accumulation of soil organic matter. Soil properties such as organic matter content, bulk density, porosity, cation exchange capacity, and soil aggregation have been shown to change in ways that could enhance site productivity as vegetation communities shift towards greater dominance by hardwoods during forest succession (Cromack 1981).

The influence of the hardwoods includes: 1) more rapid litter decomposition and therefore more rapid organic matter incorporation in the surface soils; and 2) more favorable subsoil structure due to the greater temporal and spatial development of living tree root systems. The latter stems from potentially greater longevity of the hardwood root systems as they survive harvests and expand to occupy an increasing soil volume over the course of successive rotations. The survival of hardwood tree roots immediately after harvest, and the rapid development of herbaceous root systems before new stands reach crown closure may provide additional benefits of nutrient recapture and erosion control (Bormann and Likens 1981).

The influence of rooting activity on soil physical conditions is variable but may result in increased macropore space, and decreased bulk density. In some cases the reverse of these trends has been reported, particularly in the proximity of actively growing roots (Glinka and Lipiec 1990). The latter

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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occurrences are apparently associated with pressure exerted by roots as they penetrate the soil as well as the presence of some root exudates. Consequently, it seems likely that the major longterm ameliorative influence of tree roots may be associated with root mortality and the presence of old root channels and organic debris.

Methods

A total of 26 soil pits were excavated on the Brender Demonstration Forest near Forsyth, GA during the summer of 1991. These were apportioned among areas that had been intensively farmed for cotton until the 1930s but diverged in land-use history thereafter. Pits were dug to a depth of approximately 2 m and were distributed as follows: 10 in portions of an 8-year-old loblolly pine plantation that had been intensively site prepared after harvest of a old-field pine stand (Edwards 1990), 13 in a 55-year-old stand that had been regenerated on abandoned cotton fields, and 3 in a field that had been planted in pasture following the discontinuation of cotton farming. Soils within the young plantation fell into the Cecil and Pacolet series, in the older pine, the Cecil, Pacolet, and Wilkes, and in the pasture, the Wilkes.

In each pit, three profile faces (0.30 m wide) were prepared at intervals on the pit wall of approximately 1 to 2 m. Each profile was described in terms of morphology and bulk density, soil carbon, and fine root biomass samples were collected by horizons, three samples of each being taken from each major horizon. The frequency of occurrence of roots was recorded by horizon on each profile.

Bulk densities were estimated using the clod method described by Blake and Hartge (1986). Bulk soil carbon (excluding that in roots) was obtained by determining mass loss-on-ignition at 500° C on the entire complement of samples. Following LOI determinations, a subset of 40 samples was selected from across the range of LOI values and subjected to total C analyses on a LECO C Analyzer. Total C was then regressed against LOI to develop an equation to predict C for the remaining samples.

Vegetation cover types were compared in terms of bulk density, fine root biomass, root frequency, and percent carbon using t-tests at the 5% level of probability.

Results

Due to limitations in the scope of the project and in the nature of the questions being addressed, the conclusions presented should be regarded as preliminary and correlative in nature only. Nevertheless, some interesting trends emerged.

There was a strong relationship among vegetation types and bulk density within the Bt horizons (Table 1). Densities were lower under forest cover types than under grass and may reflect a real effect associated with the activity of tree roots toward increasing the friability of subsurface soils. The differences are particularly noteworthy because the Bt horizons are very close to the surface on these highly eroded Piedmont soils (i.e. within 0.15 m usually). Consequently, these argillic horizons, which may naturally have very high bulk densities in the range of 1.5 to 1.7 Mg/m3, comprise the majority of the rooting zone for any type of vegetation. In addition, the downward shift in densities may be biologically significant because tree root growth may be limited as bulk densities climb above 1.55 (Pritchett and Fisher 1987).

Table 1. *Comparison of bulk densities (Mg/m^3) among vegetation types by major horizon.*

Vegetation	Horizon A	Horizon B
Pasture	1.56 a*	1.65 a
Mature Pine	1.51 a	1.49 c
Young Pine	1.47 a	1.57 b

*Column means followed by the same letter are not statistically different at the $\rho < 0.05$ level.

The conjecture that the previously described trends between bulk density and vegetation type are associated with root activity is supported by comparisons of root frequencies among vegetation types (Table 2). The number of roots in each of the three largest root diameter classes was highest in the older pine stands. This may reflect a capacity of the larger pine roots to penetrate the Bt horizons to a greater extent than fine roots of either trees or grasses. The vegetation types are statistically similar in terms of the smallest diameter class (0-5 mm). Also, no differences are apparent in terms of fine root biomass per cm3 (Table 4).

Concentrations of carbon in bulk soil did not differ among vegetation types in either major horizon (Table 3). This is somewhat surprising in the subsoil, given the tendency for root distributions to differ markedly between grass and forest cover. Given the higher bulk densities of subsoils under pasture, this implies that more C is stored within the bulk soil of the pasture vegetation type than under forest cover. However, this obviously does not include the substantial root pools of C that would occur in conjunction with the latter.

Table 2. *Comparison of root frequencies (# per 0.30 m wide profile) among vegetation types by root diameter class.*

Diameter Class	Pasture	Mature Pine	Young Pine
0-5 mm	10.0 a*	5.0 a	2.5 a
5-10 mm	3.5 a	241.0 b	112.0 c
10-25 mm	0.0 a	44.0 b	13.0 c
25-50 mm	0.0 a	23.5 b	3.0 c

*Row means followed by the same letter are not statistically different at the $\rho < 0.05$ level.

Table 3. *Comparison of carbon concentrations (%) among vegetation types by major horizon.*

Vegetation	Horizon A	Horizon B
Pasture	0.72 a*	0.70 a
Mature Pine	0.71 a	0.73 a
Young Pine	0.65 a	0.69 a

*Column means followed by the same letter are not statistically different at the $\rho < 0.05$ level.

Table 4. *Comparison of fine root dry weight (g/cm^3) among vegetation types by major horizon.*

Vegetation	Horizon A	Horizon B
Pasture	0.015 a *	0.003 a
Mature Pine	0.032 a	0.006 a
Young Pine	0.071 a	0.006 a

*Column means followed by the same letter are not statistically different at the $\rho < 0.05$ level.

Conclusions

While no definitive conclusions can be drawn from these data due to the small sample size, the preliminary data reveal some interesting correlations. On Piedmont sites that were degraded during and following cotton farming, the cover type that has existed for the last 50 - 60 years may have influenced soil physical properties that, in ways that affect forest productivity on a landscape basis.

Forest cover and associated below-ground components have the potential to substantially lower subsoil bulk densities. Several speculations come to mind if our data reflect actual relationships between soil and vegetation in the Piedmont. If a landscape mosaic has developed following Depression-era agriculture that reflects a strong interdependency between plant communities and soil properties, it is likely to have significant implications for future forest productivity in the Piedmont. Assuming that Piedmont subsoil properties, which often reflect a relatively harsh environment for plant roots, are slowly improving over time as a result of tree root activity, future site productivity in the Piedmont may, in the course of several rotations, increase as well. Also, it is obvious that such a relationship would have considerable variation associated with specific soil characteristics and plant community composition.

Many questions about specific effects remain and the few data presented here do not approach the basis for firm conclusions. However, they may serve to formulate testable hypotheses that can then be used to design studies of a more comprehensive nature.

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EFFECT OF SOIL CHARACTERISTICS AND PHOSPHORUS PLACEMENT ON THE GROWTH OF LOBLOLLY PINE AND ITS ROOT ORIENTATION [1]

Suresh C. Tiwari, Frank Chukwuma and Allan E. Tiarks [2]

Abstract. A Memphis silt loam soil (Typic, Hapludalf, silty, mixed, thermic) was mapped in its toposequence. Pine seedlings were established in a latin square design with five treatments. Phosphorus and nitrogen fertilizers were applied at various depths around the experimental plants at the rate of 75 kg/ha and 50 kg/ha respectively over the uniform basal dose of 50 kg/ha of N mixed on the surface soil of this experimental area. Six rows of pines were used as the experimental rows with buffer plants on both sides. Composite soil samples collected form the area were analyzed for organic matter, extractable P and Al, Ph, CEC, texture, bulk density, and the moisture content. The clay fractions were separated and analyzed for its mineralogy by X-ray diffraction technique revealing the dominance of kaolinite in its mixed mineralogy. Sixteen months after the phosphorus treatments, high levels of p absorption was found when P was applied at a depth of 11.5 to 19.5 cm. However, this effect of P gradually faded away with time. Root studies indicated non-significant differences of the root numbers due to the P treatments. However, the orientation of the roots showed significant differences due to their location on the slope. On the mid-slope position, 19% of the roots turned from a up slope to a down slope orientation. On the upper slope position, 14% of the roots changed orientation compared to only 6% in the lower slope. The change in orientation may effect the placement of fertilizer and herbicide applications required for successful seedling establishment on steep slopes.

Introduction

The immobility of phosphorus in soils is well documented so the placement of P has been very successful in agronomic crops (Robertson 1982). The application of P broadcast on top of soils has shown an increase in timber volume in the south, but the placement of the fertilizer has not been studied. Thus, it is not known how the placement of P at various depths in the soil on undulating topography affects root growth. Under the conditions described, it is also not known if the orientation of roots is affected by slope, soil moisture gradients, or soil bulk density.

Therefore, the objectives of this study were: (1) to determine the effectiveness of P placements at various depths on pine growth and its uptake on an undulating topography of a moderately well drained Memphis silt loam soil, as the time advances, (2) to determine the total number of roots, their turnings as affected by P placement, soil bulk density and soil moisture contents due to varying topography.

Methods

The topographical features of the location was prepared an a toposequence map was prepared (fig 1). Pine seedlings were planted in all the eleven rows 4.86 m apart in a latin square design, where the individual plants were at a distance of 2.43 m from one another. Rows II, IV, VI, VIII, and X were the experimental rows having all five treatments. The other rows I, III, V, VII, IX, and XI were buffer rows. Similar buffer plants also were planted across the rows. The treatments consisted of phosphorus fertilizer, at the rate of 75 kg/ha was placed at depths of 0-7, 10-19, 22-29, and 32-39 cm which represented T_1, T_2, T_3, and T_4 by boring holes around the seedlings. A control treatment T_o having no phosphorus application was also included at 0-7 cm depths. Nitrogen, at the rate of 50 kg/ha, was applied on the entire experimental area and mixed into the surface soil. The phosphorus was applied as triple super phosphate and the nitrogen as ammonium nitrate.

The treatments and measurements were taken as follows:

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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(A)	Seedlings planted	11-87
(B)	Composite soil samples collected	11-87
(C)	Fertilizer applied	3-88
(D)	Composite soil sampling of the area with no P added	7-91
(E)	Root excavation and count	4-91 to 8-91
(F)	Clay mineralogy	10-91
(G)	Pine needles collected for P analysis	3-88, 5-89, 6-91
(H)	Height and diameter measurements	3-88

Each treated unit consisted of three plants in a triangular fashion. One plant from each treatment in five replications were uprooted in 1991 to determine the total number of roots and the number of roots turned on each specific treated location. The roots turned from one quadrant to another were given one point and an additional point was added for additional crossing for the quadrants (Balneaves and LaMare 1988).

Soils, collected form the treated depths at the times noted above, were analyzed by standard procedure (Black 1982). Samples collected for determination of moisture content and bulk density were collected on 7-91, 24 hours after a rainfall. Pine needles were analyzed for P contents by the procedure outlined by Foggs and Wilkinson (1985) after dry ashing. Analysis of variance, as well as the paired comparison, were conducted at the 0.05 probability level by the procedure outlined by Dowdey and other (1982).

Results and Discussion

Memphis silt loam soil (Typic Hapludalf, silty, mixed, thermic) is a moderately well drained soil; where this pine experiment was initiated in year 1987 on its undulating toposequence (fig 1). The composite soil samples from various depths collected prior to this experiment had the Ph values ranging from 5.1 to 5.5 which had the decreasing trend with increasing depth. The range of extractable Al was from 1.25 to 2.4 ppm which was extracted by one normal KCl. These values appeared to be inversely affected by soil Ph but were below the toxic limits which persisted even with time for three years having no P treatments (table 3). Inspite of the minor increase in clay contents with depth which was 17% to 23%, the texture silt loam continued to be the same within the treated depth of this trial. These composite soil samples for various depths had the average available P of 38 ppm, which was extracted by Bray-2 method as outlined by Foggs and Wilkinson (table 3). This range is taken to be within the sufficiency level. The x-ray diffraction analysis of clay fractions showed the mixed mineralogy with the dominance of kaolinite ranging from 40 to 60% up to the placement depth of the representative soil profile. The technique used for x-ray diffraction is outlined in the Method of Soil Analysis, published by American Society of Agronomy (Black, 1982).

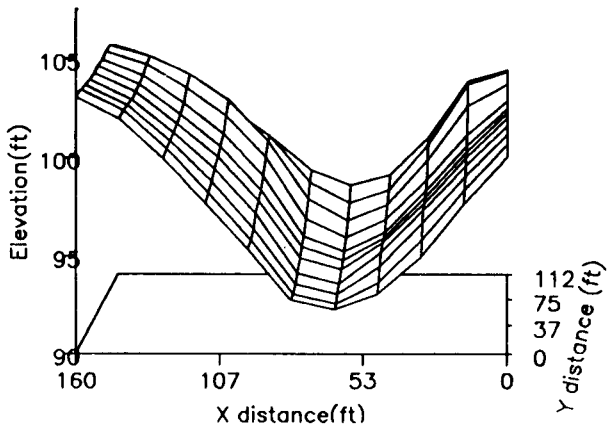

Figure 1. *Topographical features of the experimental area.*

The moisture contents in the experimental area after 24 hours of rainfall had certain fixed pattern of moisture distribution (fig 2). The row VI having located in the lower slope showed higher moisture contents in all the four depths as compared to other existing rows of upper slope (II and X), as well as of mid slope (Row IV and VIII) as depicted (fig 2). On statistical analysis, the percent soil moisture values from all the four depths of the upper and lower levels from rows II, IV, VIII and X when compared to the moisture % values of upper and lower levels of row VI respectively were found to be highly significant even at 0.01 probability level. This definitely confirms the lateral movement of soil moisture down the slope in this Memphis silt loam soil.

Three years after this trial, the chemical properties of soil from various locations and depths were analyzed for those areas which had not received any P (table 3). It was indicated that CEC, organic matter content, total P contents and soil Ph appeared to be somewhat higher in row VI as compared to row II and X which were at higher topographic locations. However, the pattern of extractable P didn't seem to behave accordingly. And after the three years of growth and for the area with no P application the higher topographic locations in rows II and X showed

lower extractable P values of 25.5 and 29.0 ppm as compared to P values of 44.5 ppm at 10 to 19 cm depth (table 3). This behavior may be due to soil moisture behavior as indicated by Fox and Lipps in 1960, as well as due to the dominance of kaolinite throughout in the clay fractions. As a result, P appears to be binded more in dry situation than in the moist situation at 10-19 cm depth, which shows clear difference in their moisture contents at that time (table 3).

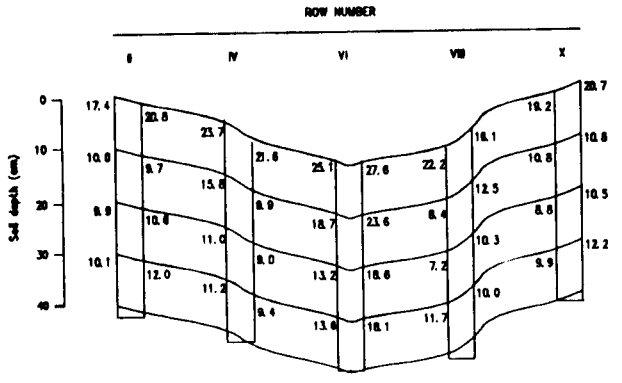

Figure 2. *Effect of topographical position and depth on moisture content of the soil 48 hours after a rainfall.*

When analyzing the pine for its growth and P contents collected for all the treated plots it is apparent that T_2 (10-19 cm depths of P placement) has a significantly higher content of P in the pine needles after 16 months of growth as compared to treatment T_4 (31.7 - 39.3 cm depth of P placement) as indicated in (table 1).

This significant uptake of P also significantly affected the diameter but not the weight of the pine trees. However, after 31 months and 54 months, these effects of P uptake became non-significant (table 1). This clearly depicts the declining concentration of P in pine with time. There was found no significant difference in the average number of roots due to treatments in 16 months (table 1). Hence neither the number of roots nor the turning were found to be affected by treatment. However, the topographical locations had significant effect on the root turning towards down slope. This clearly shows the direct significant effect of these turning of roots due to the translocation of moisture, which also flows laterally in this moderately well drained soil under undulating topography; but has no significant effect on the total number of roots as noticed in this trial (table 2).

Table 1. *Effect of P Placements on top Growth of Pine, and on the Concentration of P in Pine Needles, with time.*

Placement Depths	Treatments	Pine Growth in 16 months			P Concentration in Pine Needles after certain months		
		Height	Diameter	Roots/tree	16	31	54
--cm--		---m---	---cm---	---#---	---------- % ----------		
0-7	N	0.37 a*	1.33 a	28 a	0.61 a	0.14 a	0.08 a
0-7	N+P	0.28 a	1.25 ab	37 a	0.45 ab	0.13 a	0.11 a
10-19	N+P	0.39 a	1.50 a	32 a	0.61 a	0.14 a	0.09 a
22-29	N+P	0.34 a	1.32 ab	37 a	0.55 ab	0.15 a	0.11 a
32-39	N+P	0.34 a	1.05 a	44 a	0.40 b	0.15 a	0.10 a

* Means for each column differ ($P<0.05$) if not followed by a common letter.

Table 2. *Turning of roots as affected by slope positions.*

Slope Positions (Row #)	%Slope	Total Avg # of Roots	Avg % of Roots Turned
Upper Slope (II and X)	12.6	30.5 a	16.3 a *
Mid Slope (IV and VIII)	7.6	38.5 a	17.8 a
Lower Slope (VI)	4.6	39.4 a	6.1 b

* Values in rows followed by same letter are not significantly different at the 0.05 probability level.

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Table 3. Chemical Properties of soil from various locations and depth within the experimental site with no P added.

Location Row(#)	Depth (cm)	pH	CEC (meq/100g)	O.M. (%)	Total P (%)	Extractable P (ppm)	Extratable Al	Bulk Density g/cc
II	0-7	5.3	14.8	1.1	0.11	45.5	1.9	1.1
	10-19	5.2	12.0	1.0	0.10	25.5	1.8	1.5
	22-29	5.2	11.6	0.2	0.13	34.0	1.9	1.6
	32-39	5.2	12.4	0.2	0.11	44.5	2.2	1.6
VI	0-7	5.5	14.9	3.2	0.11	45.5	1.2	1.3
	10-19	5.2	13.1	1.7	0.14	44.5	1.6	1.8
	22-29	5.3	11.8	0.8	0.13	45.5	1.9	1.6
	32-39	5.4	12.5	0.2	0.11	42.0	2.0	1.6
X	0-7	5.3	12.5	1.1	0.10	44.5	1.6	1.2
	10-19	5.1	12.3	0.5	0.10	29.0	2.7	1.6
	22-27	5.2	11.0	0.2	0.10	35.5	2.6	1.5
	32-39	5.2	11.2	0.1	0.11	48.5	2.5	1.5

GROWTH RESPONSE OF SLASH PINE TO INTENSIVE DRAINAGE AND BEDDING [1]

R. Bruce Harding and Charles A. Hollis [2]

Abstract. This study reports on the impacts of intensive drainage and bedding on the productivity of slash pine (*Pinus elliottii* Engelm var. *elliottii*) in the Gulf Coast Flatwoods of Florida. The study was installed on two poorly drained soil types (Rutlege - Typic Humaquepts; Plummer - Grossarenic Paleaquults), with drainage intensity varying from no lateral drainage, to drainage at a maximum intensity of 1.5 chains between lateral ditches. Both study sites were bedded and fertilized, with the exception of the maximum intensity drainage treatment, which received bedding and non-bedding. At age fourteen, no statistical differences in mean height growth, volume or basal area were noted among the drainage treatments that were bedded. Significant height growth differences were noted between the intensively drained bedded treatment (34.5') and the intensively drained non-bedded treatment (30.5'), for the Plummer soil type. This data suggests that the influence of bedding on height growth involves more than micro-site drainage. The lack of a significant growth response to intensive drainage, combined with economic and regulatory limitations, implies that bedding is the best silvicultural option for micro-site water management on these soil types.

Introduction

Water management on poorly drained soils in the Lower Coastal Plain is a common silvicultural practice in establishing slash pine plantations. Intensive management of poorly drained soils usually involves access drainage associated with road construction and harvesting, followed by bedding and fertilization (Duncan and Terry 1983). On some sites, the removal of excess water is a prerequisite before successful logging and site preparation can occur (Terry and Hughes 1978). Many poorly drained sites have demonstrated large and sustainable pine growth responses to ditching (Miller and Maki 1957, Terry and Hughes 1975), with the actual growth responses varying by soil type and drainage intensity (Duncan and Terry 1983). Growth responses to drainage can be limited, however, on savanna soils where fertilization and bedding are needed for satisfactory pine growth (Pritchett and Smith 1974).

One question still unresolved for forest managers is whether intensive drainage can be substituted for bedding? The study described here addresses this question and involves the following objectives: 1) to evaluate pine growth responses to different drainage intensities on bedded and fertilized sites and 2) to identify if intensive drainage without bedding provides comparable growth to intensive drainage with bedding.

Methods

The study was installed during the summer of 1978 on two commonly occurring soils in the Gulf Coast Flatwoods of Franklin County, FL. Both soils (Rutlege - Typic Humaquepts; Plummer - Grossarenic Paleaquults) are located in the same 319 acre management block, being poorly drained and containing very low levels of extractable (double-acid) phosphorus (< 2.0 ppm). The major difference between the soils is that the Plummer has a sandy clay loam subsoil. Gallberry (*Ilex glabra* [L.] Gray) and titi (*Cyrilla* and *Cliftonia* spp. L.) are the predominant understory vegetation on both soil types, with lesser amounts of loblolly bay (*Gordonia lasianthus* [L.] Ellis) and St. Johnswort (*Hypericum petiolatum* [L.] Walt) being present.

The entire management block was chopped and burned prior to the drainage installation. Drainage for both soils included an intensive drainage treatment with lateral ditches 1.5 chains apart (Figure 1). Lateral ditches were 3' deep and 4' wide, with discontinuous spoil piles so surface water flow would not be impeded. Half of the intensively drained area received bedding parallel to the lateral ditches (TRT

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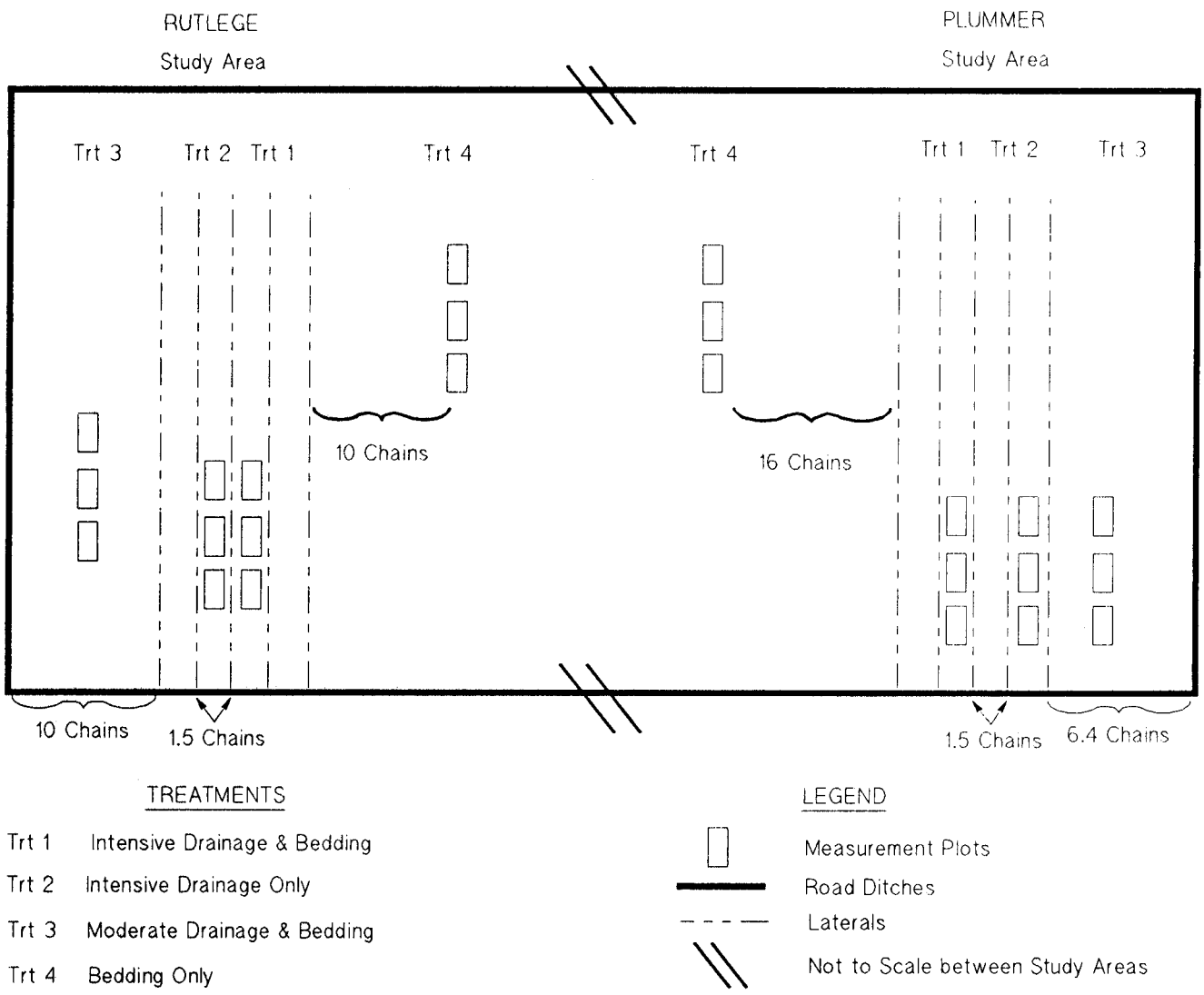

Figure 1. ***Location of lateral drainage by soil type.***

1), while the other half was not bedded (TRT 2). The remainder of the management block was bedded. Additional treatments were a moderate drainage treatment (TRT 3), which reflects the placement of lateral ditches every 6 to 10 chains apart (Figure 1), and a bedded only treatment (TRT 4). The management block was hand planted with slash pine during the winter of 78/79. The block was aerially fertilized in May of 1979 with 20 lbs. of elemental phosphorus (100 lbs. of TSP) per acre.

The original study design included the measurement of seedling survival and water table levels by treatment. Unfortunately, these data were lost in a laboratory fire at the University of Florida. For purposes of this report, three plots per treatment were installed following the ninth growing season. Stocking and height were measured on these plots at age nine and remeasured during the fourteenth growing season (7/92) for stocking, height and diameter. Five year incremental height growth, basal area per acre and outside-bark volume per acre (Bennett et al. 1959) were calculated for each plot at age 14. Treatment differences were determined by soil type using analysis of variance (ANOVA). Duncan's Multiple Range Test (P=0.10) was used to separate treatment means for the three drainage intensities (TRT's 1, 3 & 4), and bedded versus nonbedded treatments (TRT's 1 & 2). All analyses were conducted using the SAS general-linear-model (GLM) procedures (SAS Institute 1985).

Results

Increasing the intensity of drainage did not result in significant yield differences for the bedded treatments on either soil type, although large differences in growth occurred between some treatments (Table 1). For the Rutlege soil at age 14,

the intensive drainage plus bedding treatment (TRT 1) increased mean height by 4.2 ft., five year incremental height growth by 2.1 ft., basal area growth by 13 sq. ft. per acre and volume by 381 cu. ft. per acre, over the control (TRT 4). The Plummer soil had significantly lower stocking levels for the intensively drained treatment at age nine and age 14 (Table 1). However, due to the loss of the original stocking and survival data, interpretations for treatment effects are limited. The bedded portion of the Plummer soil had the same height growth response (4.2 ft.) to the intensive drainage treatment as the Rutlege soil, but increases in yield (volume and basal area) were limited by the lower stocking levels. The moderate intensity drainage treatment (TRT 3) provided no growth gains over the bedded only control (TRT 4) for either soil type (Table 1).

Comparisons of the cultivation response for the two intensive drainage treatments (TRT 1 & TRT 2) revealed a large growth response to bedding even in the presence of lateral drainage ditches every 1.5 chains (Table 1). For the Plummer soil the height growth difference was significant (P=0.10) at age nine (3.3 ft.) and age 14 (4.0 ft.). Height growth response to bedding on the Rutlege soil was of the same magnitude (age nine - 4.0 ft. & age 14 - 5.5 ft.) as on the Plummer, but these differences were not significant (P=0.10).

Table 1. *Growth response of slash pine to intensive drainage and bedding on the Rutlege and Plummer soil types.*

	RUTLEGE SOIL TYPE						
TREATMENT	GROWTH - AGE 9		GROWTH - AGE 14				
DRAINAGE EFFECT	STOCKING /ACRE	MEAN HT (FT)	STOCKING /ACRE	MEAN HT (FT)	5 YR HT GROWTH (FT)	VOL/AC (CU FT)	BASAL AREA (SQ FT)
TRT 4 - Bedding + No Drainage	705	20.5	687	30.3	9.8	922	75
TRT 3 - Bedding + 10 Chain Drainage	686	20.9	674	31.5	10.6	995	73
TRT 1 - Bedding + 1.5 Chain Drainage	781	22.6	757	34.5	11.9	1373	88
BEDDING EFFECT							
TRT 1 - Bedding + 1.5 Chain Drainage	781	22.6	757	34.5	11.9	1373	88
TRT 2 - No Bedding + 1.5 Chain Drainage	762	18.6	755	29.0	10.4	826	68
	PLUMMER SOIL TYPE						
DRAINAGE EFFECT							
TRT 4 - Bedding + No Drainage	611 A	20.1	611 A	30.3	10.2	876	67
TRT 3 - Bedding + 6.4 Chain Drainage	563 A	19.9	563 A	27.6	7.7	617	56
TRT 1 - Bedding + 1.5 Chain Drainage	404 B	22.9	404 B	34.5	11.6	827	55
BEDDING EFFECT							
TRT 1 - Bedding + 1.5 Chain Drainage	404 A	22.9 A	404 A	34.5 A	11.6	827	55
TRT 2 - No Bedding + 1.5 Chain Drainage	471 B	19.6 B	471 B	30.5 B	10.9	609	50

[1] Columns not having letters were not significantly different for the ANOVA (P=0.10). Means within a column followed by the same letter are not significantly different (Duncan's, P=0.10).

Discussion

The first objective of this study was to determine the optimum drainage intensity for the study soil types. Although a height growth response of 4.2 ft. was noted on both soils for the intensive drainage treatment, this growth response was not statistically significant (P=0.10). The moderate intensity drainage treatment did not increase height growth on either soil type. The ditch spacing of the moderate intensity treatment is similar to that of operational drainage projects, indicating that such efforts would not be economically feasible on these soil types.

The second study objective was to determine if intensive drainage could be substituted for bedding. At age 14 bedding resulted in an additional 4 to 5 ft. of height growth for the intensively drained soils. This result supports the observations of Haines and Haines (1978) that the benefits of bedding on pine seedling growth involves more than improved micro-site drainage. Such additional benefits include improvements in the soil environment for root

development, increased organic matter and increased competition control. Although the 14 year height growth of the intensively drained nonbedded treatment was equal to the bedded only treatment, the increased cost of lateral ditching every 1.5 chains would make this option less attractive to land managers. The lack of a significant growth response to intensive drainage, combined with economic and regulatory limitations, implies that bedding is the best silvicultural option on these soil types.

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ROTATION AGE EFFECTS OF DRAINAGE AND FERTILIZER TREATMENTS ON A WET PINE FLAT IN VIRGINIA [1]

John Torbert, Lisa Andrews, W. Michael Aust and James Burger [2]

Abstract. A drainage and fertilizer study was established on wet pine flats in Virginia in 1969. Two drainage treatments, ditching and bedding, increased average loblolly pine height after 23 years by about five feet. Site index (base age 25) increased from about 45 to 50 feet. Phosphorus, application (alone or with nitrogen) at age nine had no effect on tree size at age 23. A significant growth response did occur when phosphorus and nitrogen were applied with 1 ton of lime per acre.

Introduction

Drainage and phosphorus fertilization are important forest management activities on many poorly drained Coastal Plain sites. Two drainage practices commonly used in the southeast to increase rooting volume on wet sites are ditching and bedding. Several studies have shown that these treatments can improve growth during early years of a rotation (Gent at al., 1986; Allen and Campbell, 1988). Other studies, however, have shown less dramatic effects as stand age increases (Haines, 1975). The objective of this paper is to summarize the results of a drainage and fertilization study on a wet pine flat in Virginia after 23 years.

Specifically, the objectives were:

1) to evaluate the effect of bedding and ditching on water table levels at age 3 and 23.

2) to evaluate bedding and ditching treatments on loblolly pine growth at age 7 and 23.

3) to evaluate several mid-rotation fertilizer treatments on tree growth at age 23.

Methods

Three study sites (blocks) were selected in southeast Virginia, near Whaleyville, Holland, and Windsor. Each site was occupied by a natural loblolly pine stand, and growth was poor on all sites, presumably due to poor drainage. These sites appeared to be good candidates for response to drainage treatment.

In 1968, the stands were clearcut and the entire study area was chopped and burned. At each block, three 10-acre treatment areas were established. The **control** area received no additional treatment. The **bedded** treatment area was windrowed and bedded. The windrows contained a substantial amount of soil, such that 23 years later, distinct mounds (up to five feet tall) remained. The **ditched** treatment area was drained by a 5-ft deep ditch. The ditch entered the treatment area from a roadside ditch, and it was dug around the four sides of a 1-acre square subplot located in the center of the 10-acre treatment area. Loblolly pine was planted in 1969.

In 1978, prior to the tenth growing season, a fertilizer study was added. The 1-acre subplots at the center of each 10-acre treatment area were subdivided to create four 0.25-acre fertilizer plots. The four fertilizer treatments were: 1) control, 2) 75 lbs P/ac (as triple superphosphate), 3) 75 lbs P plus 100 lbs N/ac (as urea), and 4) 75 lbs P, 100 bs N, plus 1 ton dolomitic lime/acre.

Water table levels at age 3 (1970-71) were measured bi-weekly at six piezometers installed in the 1-acre subplot (at the center of each treatment area). Growth data for the first seven years were derived from 25 trees located in this 1-acre subplot.

After 23 years (1991), four transects were systematically established in the 10-acre treatment area for water table and tree measurements. The transects encompassed 12.5% of the area. Three piezometers were systematically installed in each transect (12/treatment plot), and water table heights were measured bi-weekly at these 12 piezometers as well as the original six piezometers installed in the central 1-acre subplot. Diameter (dbh) was measured for all trees and height was measured for every fifth tree. Heights for remaining trees were estimated from dbh

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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with a regression relationship developed on the measured trees.

To assess fertilizer treatment response at age 23, a 0.01-acre fertilizer subplot was located in the center of each 0.25-acre fertilizer plot. Diameter (dbh) was measured for all trees and heights were measured for every fifth tree. Heights of remaining trees were estimated from dbh with a regression relationship developed on the measured trees.

Results and Discussion

Drainage Effect on Water Table

Although these study areas were selected because productivity of the previous stands appeared to be limited by poor drainage, the water table was never at the soil surface for prolonged periods during the growing season. During the early years of the study, the water table was at the surface of the control and bedded plots only during the winter (Fig 1). The water table was about three feet deep in the ditched plots during the winter. During the growing season the water table level of the control and bedded plots varied from about one to four feet deep, and ditched plots were consistently about one half to one foot lower. After 23 years, the winter water table was about one to two feet deep in the control and bedded plots and about one foot deeper in the ditched plots (Fig 2). During the growing season, the ditching treatment lowered the water table by only about half a foot compared to the control and bedded treatments which fluctuated from four to five feet deep.

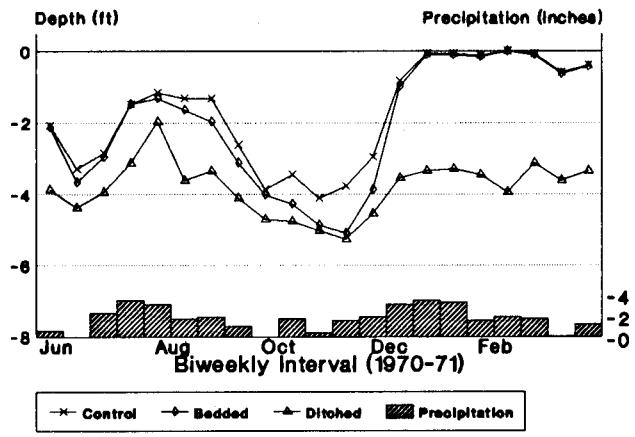

Figure 1. *Water table levels during the third growing season as affected by drainage treatment and precipitation.*

Drainage Effect on Tree Growth

Langdon (1976) reported on the effects of drainage treatments through age seven. At age 7, trees in the ditched treatment were significantly taller than trees in the bedded treatment, but neither treatment was significantly different than the control treatment (Table 1). The difference in height between ditched and bedded treatments was 7.5 ft (an 80% increase).

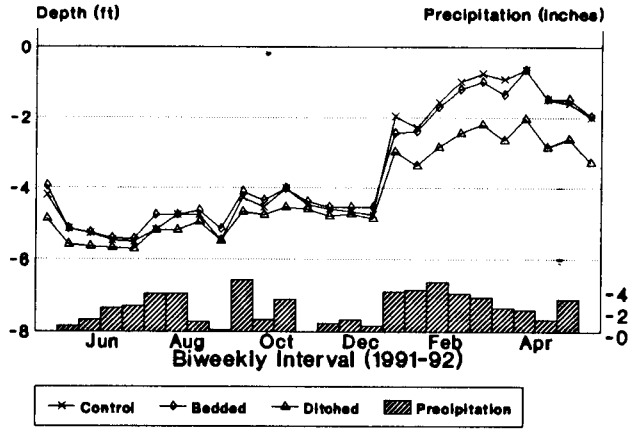

Figure 2. *Water table levels during the twenty-third growing season as affected by drainage treatment and precipitation.*

By age 23, tree heights of the ditched and bedded treatments were no longer significantly different from each other (46 vs 45 ft; Table 2), but both were significantly greater than the control. Average tree dbh was not significantly affected by treatment.

Table 1. *Age 7 average tree height and foliar P concentration as affected by drainage treatment (Langdon, 1976).*

Treatment	Ht(ft)	Foliar P (%)
Control	11.6	0.05
Bedded	9.7	0.05
Ditched	17.2	0.06

Values within a column followed by different letters are statistically different according to Fisher's Multiple Range Test (P=0.10)

On a volume-per-acre basis, the bedded treatment was the most productive; it had the highest pine and hardwood production. The bedded treatment had slightly more pine volume than the ditched treatment (23.6 vs 22.2 cds/ac) because it had more trees per acre. It is unknown whether higher stocking in the bedded treatment resulted from greater survival or more trees planted. Although there was not a significant effect of treatment on hardwood production, the average hardwood volume in bedded plots was twice as high as ditched plots. There was

Table 2. *Age 23 tree size and stand characteristics as affected by drainage treatment.*

Treatment	Average Ht	Average DBH	Stocking	Basal Area	Volume/Acre Pine	Volume/Acre Hdwd	Volume/Acre Total
	ft.	in.	#/ac	ft^2/ac	- - - - - - - - cds/ac - - - - - - - -		
Control	41 b	6.4	379	68	16.8 b	4.9	21.7
Bedded	45 a	6.4	464	86	23.6 a	7.5	31.1
Ditched	46 a	6.6	401	81	22.2 a	3.6	25.8

Values within a column followed by different letters are statistically different according to Fisher's Multiple Range Test (P=0.10)

an abundance of hardwoods in the windrows of bedded treatment areas. Total production (pine plus hardwood) was greater in the bedded treatment (31 cds/ac) than the ditched (26 cds/ac) or control treatment (22 cds/ac).

From a practical standpoint, neither of the drainage treatments had an enormous effect on tree growth. Although both treatments resulted in significantly increased tree height compared to the control, the difference was only about five feet. Furthermore the difference between the ditched and control treatments at age 23 was no greater than the difference that existed at age 7. It is worthy to note the low productivity of these study areas. The height of trees in the bedded and ditched treatments will only reach a height of about 49 ft at age 25. Furthermore, stocking will probably only be about 90 ft^2/acre. Water table level may not have been the primary growth limiting factor on these sites. The water table level of the control plots during the growing season of the third year and throughout the year during age 23 seems to have provided sufficient rooting volume such that a greater response to drainage did not result.

The relatively poor quality of the this site was observed at age 7 and Langdon (1976) speculated about a nutrient deficiency. Average foliar P levels at age 7 were only about 0.06% and there was a strong correlation between foliar P concentration and tree height (r^2=0.84). Consequently the fertilizer study was added and P was the nutrient of primary interest. However, despite the poor site quality and apparent P deficiency at age 7, no significant growth response was measured at age 23 as a result of P or NP treatments (Table 3). Furthermore, foliar P levels of unfertilized trees at age 23 averaged 0.12, which exceeds a critical level of 0.1% (Wells and Crutchfield, 1973), suggesting that a P deficiency was not the primary growth limiting nutrient.

The treatment which provided the most interesting result was the lime treatment. There was a statistically significant response to the fertilizer treatment that included lime. Even though the lime application rate was only 1 ton/acre and soil pH at age 23 was only 0.1 pH unit higher, the NPL trees averaged 3.1 feet taller (7% increase) than the other treatments and dbh was 0.4 inches greater (6% increase). The response to the lime treatment was not dramatic, but it was statistically significant and it corresponded with a significant increase in foliar Ca and Mg concentrations (Table 4).

Conclusion

Bedding and ditching treatments produced approximately 35% more loblolly pine volume (per acre) than the undrained chop and burn treatment. Most of this increase, however, resulted from a higher stocking level on the bedded and ditched treatment areas. Neither bedding or ditching converted this inherently low quality site into a productive loblolly pine stand. Drainage only increased site index from about 45 ft to 50 ft. Although the sites appeared to be P deficient at an early age, no growth response to P or N plus P was detected 14 years after fertilization. A minor growth response did occur with the addition of a slight amount of lime, which leads to speculation that perhaps the productivity of these wet pine flats in southeast Virginia are limited by Ca, Mg, or possibly some other unsuspected nutrient.

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Table 3. *Fertilizer effects on loblolly pine tree and stand data.*

Treatment	Stocking	Average Tree Height	Average Tree Dbh	Basal Area	Stand Volume
	#/ac	ft	in	ft^2/ac	cds/ac
Control	203	45.6 b	7.0	55	13.0 ab
P	205	45.3 b	6.8	52	11.8 b
NP	197	46.6 b	6.9	51	12.1 b
NPL	219	48.9 a	7.3	64	15.7 a

Values within a column followed by different letters are statistically different according to Fisher's Multiple Range Test (P=0.10).

Table 4. *Foliar nutrient concentration as affected by fertiizer treatment at age 23.*

Treatment	N	P	K	Ca	Mg
			%		
Control	1.23	0.12	0.61	0.08 b	0.08 ab
P	1.26	0.13	0.47	0.09 b	0.08 b
NP	1.22	0.13	0.57	0.08 b	0.08 ab
NPL	1.28	0.14	0.47	0.14 a	0.10 a

Values within a column followed by different letters are statistically different according to Fisher's Multiple Range Test (P=0.10).

THE EFFECTS OF A WET-WEATHER THINNING OPERATION IN A COASTAL PLAIN LOBLOLLY PINE STAND [1]

Thomas W. Reisinger, W. Michael Aust, and David B. Powell, Jr. [2]

Abstract. Mechanized thinning operations, consisting of a feller-buncher and a grapple skidder, involve machine traffic near the base of residual trees along access corridors. Heavy machine traffic, operating under wet soil conditions, has the potential to rut/damage forest soils. The effects of rutting caused by mechanized thinning operations (5 years earlier) were evaluated for a 31-year old natural loblolly pine stand in south central Arkansas. Data were collected on all trees within a 4.0-acre study area and soil physical properties were sampled uniformly over the study site and on skidding corridors. Data analysis compared the growth of trees located within 12 feet of a skidding corridor to the growth of trees located between the corridors (i.e. > 12 ft.). No significant differences were observed when bulk density, soil porosity, and saturated hydraulic conductivity of the surface of sandy loam soils on skidding corridors and untrafficked areas were compared. Diameter growth of trees within 6 feet of the corridors was significantly better than the growth of trees > 12 feet from corridors, but comparisons of other tree parameters were not significant. The only negative effects on growth observed were for trees growing near ruts deeper than 6 inches. In this case, shallow rutting in the corridors was not detrimental to overall residual stand growth in spite of the negative visual impressions at the time of thinning.

Introduction

Today's more mechanized harvesting systems are designed to operate year-round, regardless of weather. Machine traffic operating under wet soil conditions has the potential to damage forest soils. Typical mechanized thinning operations, consisting of a feller-buncher and rubber-tired skidder, involve machine traffic near the base of residual trees and on access corridors throughout the stand. Past research has documented that rutted and compacted soils can result in reduced growth of seedlings and young trees (Hatchell et al. 1970; Simmons and Ezell 1982; Lockaby and Vidrine 1984), but little research has evaluated the effects of mechanized systems on tree growth after thinning. Studies that have evaluated the changes in soil physical properties and the effects on tree growth after thinning report conflicting results (Moehring and Rawls 1970; Nickolich 1983).

Study objectives were to evaluate the soil condition and to determine whether or not soil rutting and/or compaction in the skidding corridors affected the growth of the residual trees 5 years after mechanized thinning during wet weather.

Study Area and Methods

The study area was a 4.0 acre portion of a natural loblolly pine *(Pinus taeda)* stand located on the coastal plain of Arkansas (Grant County). The rolling to flat site was thinned in 1987 by a contractor using a JD 70 tracked feller-buncher and JD 740A grapple skidder. The method of operation involved clearing access corridors every 40-50 feet, and then selectively thinning the trees between the corridors.

The residual stand was 31 years old and had 137 trees per acre with an estimated site index of 60 feet (base age 25). Detailed stand data prior to thinning were not available, but the stand was thinned during January-February when soils were wet. Because the soils were saturated, the operation was stopped because of concern for rutting. The study area attempted to include the area with the most severe rutting and corridor trafficking. The soil was a moderately drained, crumbly, sandy loam surface horizon (approximately 6 inches deep) over clay subsoil.

Soil core samples were taken along 4 transect lines uniformly spaced throughout the study area oriented east-west. Bulk density cores (103 cm^3) taken at one chain (66 feet) intervals were used to sample the surface 2 inches of soil in untrafficked (i.e.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Assistant Professors, Virginia Polytechnic Instit. and State Univ., Blacksburg; District Forester, Kilmarnock, VA.

undisturbed) areas. Three other bulk density cores were taken when the transect line intersected a skidding corridor (i.e. one in each tire track and one in the center of the tire tracks). The surface profile was also measured to determine the depth/severity of soil rutting in the corridors. The bulk density cores were also used to determine saturated hydraulic conductivity and soil porosity (i.e., total, macroporosity and microporosity).

Residual trees with a DBH (diameter at breast height) larger than 4.0 inches were measured and numbered (i.e. 100 % sample), but trees with mechanical damage were excluded from the analysis. Tree parameters such as DBH, total height, height to base of live crown, crown width, and age and annual growth were measured. Radial growth five years prior to thinning and annual growth for the five year period since thinning was determined from increment cores. The location of each residual tree was mapped and its distance from the skidding corridor was also measured. Simple t-tests were used for statistical comparisons of the data.

Results and Discussion

Soil Impacts

Roughly 25 % of the study site was trafficked during the mechanized thinning operation. Maximum rut depth was 18 inches, but 90 percent of the ruts were less than 6 inches deep. Surface soil characteristics in skidding corridors and untrafficked areas located between the corridors were not significantly different. As shown in Table 1, no significant differences were found when mean bulk density, microporosity, total porosity and saturated hydraulic conductivity were compared. No significant differences were found when bulk density in the rut/tire track were also compared to the in-between the rut position (i.e. 1.11 and 1.13 Mg/m^3 respectively).

Because soil data before and immediately after thinning was not available, it is impossible to determine whether or not machine traffic damaged the soil physical properties. However, bulk densities for corridor and undisturbed soils were below the bulk density values (i.e. 1.3 to 1.4 Mg/m^3) generally reported to restrict root growth in loblolly pine (Foil and Ralston 1967; Mitchell et al. 1982). Consequently, post-thinning evaluation of the surface soils suggests that either damage did not occur when the stand was rutted or that amelioration has taken place during the 5 years since thinning. Heavy grass cover and earthworm activity were observed in the skidding corridors; Hatchell and Ralston (1971) speculate that these may hasten soil recovery. Repeated wetting/drying cycles during the past 5 years may also have ameliorated any soil damage caused by the thinning operation.

Tree Growth Impacts

Tree growth (for the 549 residual trees) responded positively to the thinning during the past 5 growing seasons. Comparison of periodic annual increment (PAI) for the undamaged dominant and co-dominant trees 5 years before (2.89 mm/yr) and 5 years after thinning (3.52 mm/yr), indicated an overall positive 17.9 % increase in radial growth (Figure 1). The 18 % thinning response is reasonable given that the stand was thinned rather late (i.e. 26 years) and site index was not high (i.e. 60).

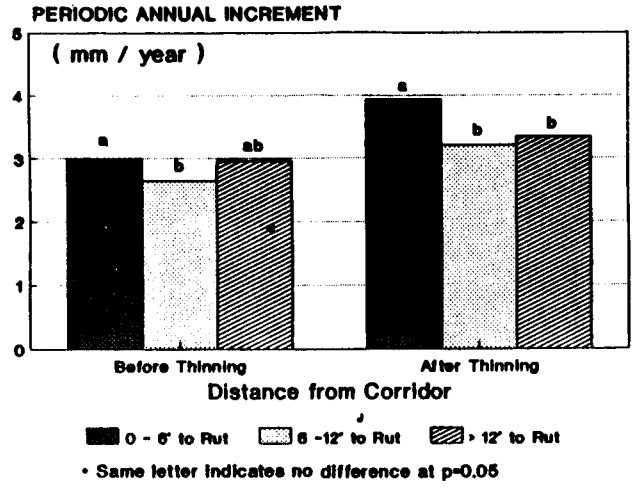

Figure 1. *Comparison of PAI before and after thinning by distance from the skidding corridor.*

The tree growth data were split into three zones based on how close the tree was to the skidding corridor in order to determine if machine traffic affected the growth of loblolly pine after thinning. The zones included all trees within 0-6 ft., 6-12 ft., and greater than 12 ft. from of the corridor (i.e. undisturbed). The parameters compared were DBH, total height, height to base of live crown, crown width, age, and 5-year PAI. Simple t-tests were used to compare the means as shown in Table 2. The differences in tree parameters were small, but tree growth in the 0-6 ft. zone was slightly better. However, this was confounded by the effects of thinning. DBH (10.2 in.) and radial growth (3.93 mm/yr.) in the 0-6 ft. zone, and crown width (18 ft.)

Table 1. *Sample Means for Soil Physical Properties.*

	Undisturbed			Corridor		
	N	Mean	Std.Dev.	N	Mean	Std.Dev.
Bulk Density (Mg/m^3)	19	1.17	0.21	106	1.12	0.24
Macroporosity (%)	19	9.3	3.41	106	11.0	5.11
Microporosity (%)	19	33.5	5.72	106	33.7	7.06
Total Porosity (%)	19	42.8	6.73	106	44.7	8.41
Sat Hydr Cond (cm/hr)	18	4.2	8.94	96	3.5	6.63

Table 2. *Tree Parameters by Distance Zone from Corridor.*

	Zone								
	0 - 6 Feet			6 - 12 Feet			> 12 Feet		
	N	Mean	Std.Dev.	N	Mean	Std.Dev.	N	Mean	Std.Dev.
DBH (in)*	94	10.2a	3.2	59	8.8b	3.3	92	9.1b	3.4
Total Height (ft)	82	70a	6.7	44	68b	7.8	68	69ab	8.3
Ht. to L. C. (ft)	82	40a	4.4	44	40a	4.9	68	39a	5.2
Crown Width (ft)	82	18a	19.0	59	15b	4.9	68	17a	6.4
Age (yrs)	80	31a	2.9	42	31a	3.2	65	31a	3.3

* Same letter indicates no significant difference at p = 0.05 level.

in the 6-12 ft. zone were significantly greater than in the > 12 ft. zone (9.1 in., 3.34 mm, and 17 ft.). Even though basal area point samples in each zone indicated no differences, the trees growing in the 0-6 ft. zone received more light (and moisture) from the corridor openings. When the mean 5-year PAI before and after thinning for trees growing in each of these zones were compared, radial growth in the > 12 ft. (2.96 mm/yr) and 0-6 ft. (2.99 mm/yr) zones were almost identical prior to thinning, but growth after thinning increased 15 % and 23 %, respectively.

Rutting Impacts

Tree growth data were also evaluated to determine if depth of rut influenced growth. Three depths of rutting were compared: 0-3 inch, 3-6 inch, and ruts greater than 6 inches deep. Diameter growth was again the parameter where significant differences were observed. Compared to trees in the > 12 ft. zone, mean radial growth increased 23 % and 29 % for trees growing next to ruts 0-3 and 3-6 inches deep, but decreased 5% on ruts greater than 6 inches deep (Figure 2). Again, these data were confounded by the effects of thinning. The rates of change in 5-year PAI before and after thinning for each rut depth class were 0.387 mm/yr for the > 12 ft. zone, 0.839 for 0-3 in., 1.052 for 3-6 in., and -0.169 for ruts greater than 6 inches deep. The 6-inch depth coincides with the depth of the A horizon for the sandy loam soils found in the study area. This horizon probably accounts for the majority of sub-surface drainage and aeration across the site. At the other rut depths, tree growth was not affected and the trees appeared to respond positively to the thinning treatment.

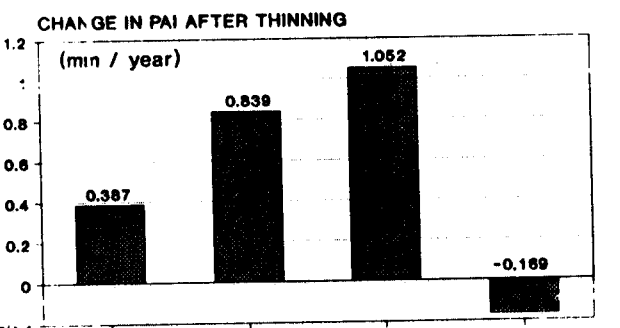

Figure 2. *Change in PAI after thinning by depth of rut.*

Conclusions

The objectives of this study were to evaluate the impact of soil rutting caused by mechanized thinning operations during wet conditions and to determine if residual tree growth was affected. In spite of heavy rutting during harvesting, evaluation of the condition of surface soils 5 years after thinning

indicated no permanent conditions that would affect tree growth. No significant differences were observed when bulk density, soil porosity, and hydraulic conductivity of the corridors and undisturbed areas were compared. Except for a few isolated areas where ruts were deeper than 6 inches, the residual trees responded positively to the thinning. This research can not definitely state that the soil was damaged immediately after thinning; but, if machine traffic did change the soil, those conditions have been ameliorated during the past 5 years.

Radial growth of trees in the 0-6 ft. zone adjacent to corridors was significantly better than the growth observed for trees in the > 12 ft. zone, but comparisons for other parameters were not significant. If increased diameter growth is the primary objective of a commercial thinning, the trees next to corridors were 1.1 inches larger than those growing in the untrafficked area. The increased growth rates for trees next to the corridors appears to be due to increased availability of light and moisture which confounded the results because the trees located between the corridors (> 12 ft.) did not received the same level of thinning intensity. Thus, the benefits of thinning overshadowed any negative effects that corridor rutting may have caused.

From a management standpoint, this study supports the literature regarding the negative effects on tree growth associated with excessively deep ruts. Rutting should be avoided whenever possible, but the study results indicate that shallow rutting of the skidding corridors when the soil is wet may not necessarily be detrimental to growth of the residual trees nearest to the corridors, as long as aeration and drainage are maintained.

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Forest Genetics

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BIOMASS PARTITIONING IN SEEDLINGS OF TEN *QUERCUS* SPECIES NATIVE TO THE SOUTHEASTERN UNITED STATES [1]

Terry J. Long, and Robert H. Jones [2]

Abstract. Seedlings of ten *Quercus* (oak) species from differing habitats were grown for one growing season in shade houses to study biomass distribution strategies. Acorns were planted in 15 gallon pots kept well watered and fertilized with a slow release 14-14-14 fertilizer shortly after seedling emergence. Compared to oaks with a large-leaf morphology, small-leaf oaks partitioned significantly more biomass to shoots (both leaves and stem) per unit of root mass. Also, oaks native to bottomland environments partitioned a significantly greater amount of biomass to shoots per unit of root mass than did oaks native to upland environments. All species of oak used an average of 70% (range 65-76) of initial acorn mass during the first growing season. The results suggest that biomass partitioning in oak seedlings is an evolutionary response allowing oaks to compete efficiently for the limiting resources on a site.

Introduction

To successfully compete and become established, plants must be able to obtain in sufficient quantities the limited resources present on a site. It has been suggested that plants have evolved biomass partitioning strategies that enable uptake of the most severely limiting resource on a site (Harper 1977, Harper and Ogden 1970, Abrahamson and Caswell 1982). Thus plants native to bottomland environments, that have plentiful water and nutrients, may be expected to partition a greater amount of biomass to shoots at the expense of root growth in order to obtain sufficient light resources. However, plants native to upland environments may partition greater biomass to roots for uptake of moisture at the expense of shoot growth.

An important assumption that must be made is that biomass partitioning represents discrete alternatives to the plant (Abrahamson and Caswell 1982, Gadgil and Solbrig 1972, Abrahamson and Gadgill 1973). Increased allocation to one plant part means decreased allocation to other parts. The optimum allocation pattern therefore, is one that balances the benefits of acquiring one resource against the costs of reduced acquisition of other resources (Miller et al. 1990).

Oaks in the southeastern United States inhabit a wide range of sites from swampy river bottoms to extremely dry sand hills. It is this large diversity that makes oaks the ideal plant species for studying the correlation between natural habitat and biomass partitioning. Oaks also demonstrate a high degree of variability in morphological traits. These include leaf size and shape, branch angle, bark thickness, and stomatal density among others. In addition to the potential influences of habitat preference, variability in morphology may affect biomass partitioning in oaks.

There have been many studies that have examined the correlation between seed size and seedling growth (McComb 1934, Larson 1963, Weis 1980, Dunlap and Barnett 1982, Singh and Rai 1988, Bonner 1987, St. Clair and Adams 1991). In general, the literature indicates that seed size at best is weakly correlated with seedling growth. McComb (1934) is the only author to report a strong correlation between first year biomass production and acorn size in Chestnut Oak (*Quercus prinus* L.). St. Clair and Adams (1991) in *Pseudotsuga menziesii* Mirb., Weis (1980) in *Mirabilis hirsuta* Macm., Singh and Rai (1988) in *Vigna unguiculata* L., and Dunlap and Barnett (1982) in *Pinus taeda* L. all found weak correlations between seed size and plant growth. Bonner (1987) using multiple species, and Larson (1963) in *Pinus ponderosa* L., found no significant relationship between seed size and seedling growth.

The objectives of this study were to determine: 1) if natural habitat is significantly correlated with biomass partitioning patterns during the first year of growth in oaks native to the southeast; 2) if morphological traits are correlated with biomass partitioning in oaks; and 3) if seed size

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Graduate Research Assistant and Assistant Professor, Auburn University, Auburn, AL.

is correlated with seedling growth both within and between species.

Methods

Acorns of ten *Quercus* species (Table 1) were collected in the fall of 1990, stored at 2°C over winter, and planted into 15 gallon pots in May, 1991. Pots contained a 4:1 mixture of washed medium grade mortar sand to vermiculite potting soil. Fifteen pots of each species were placed into each of two neutral density shade houses (30 pots per species) allowing 60% ambient light. Two acorns per pot were planted to insure that sufficient plant material was available for all species. In June, 1991 plants were thinned to reduce density to one healthy seedling per pot.

Drip irrigation was used to provide the same water regime to all pots. A consistent supply of nutrients was provided by a single 13.5 gram application of 14-14-14 controlled release fertilizer shortly after germination.

Twelve seedlings per species were harvested at the end of the growing season (October 22-28, 1991) to determine biomass partitioning patterns. Data collected included number of flushes, elongation of stem per flush, number of live and dead leaves, and general health of the plant. Seedlings were carefully lifted out of the pots with minimal loss of fine root material. At the end of the first growing season there appeared to be little root restriction caused by pot size. Seedlings were brought back to the lab and separated into component parts (roots, stems, foliage, and cotyledons). Roots were washed to remove soil particles and were then dried along with stems in ovens at 60°C. Total leaf area per seedling was measured using a LI-COR portable area meter (LI-3000). After measurement of leaf area leaves were dried and their weights were recorded.

It has been shown that the root/shoot ratio changes as a plant grows (Monk 1966, Ledig et al. 1970). This makes comparisons of root/shoot ratio between two individual plants problematic. With this in mind, data on dry-matter partitioning were analyzed using covariance analysis following the procedure of Ledig et al. (1970), and Monk (1966). This procedure constructs regression lines through the data of shoot mass versus root mass for all individuals of a species. Differences between two species in their root to shoot ratios can then be detected by testing for differences in the slope and intercepts of their regression lines. When using this procedure, $\log_{10}$ transformation of biomass is used to linearize the data. In this paper, $\log_{10}$ of root mass is used as the dependent variable when analyzing partitioning.

Results And Discussion

Bottomland-Upland Comparison

On average, bottomland oaks produced a greater number of flushes and had greater elongation per flush than did upland oaks during the first year of growth (Fig. 1). Black oak (*Quercus velutina* Lam.), however, grew quite well in this study and was comparable in size to the bottomland oaks.

Although biomass partitioning of the various upland and bottomland oak species overlapped, there was an apparent tendency for bottomland species to have more shoot mass per unit of root mass (Fig. 2). When all plants were classified as to their natural habitat (bottomland and upland), bottomland oaks partitioned significantly ($P < .05$) more biomass to shoots at the expense of roots than did upland oaks (Fig. 3). The difference between upland and bottomland oaks does however appear to be declining as the plants increase in size.

Leaf Size

Observations made during the study indicated that there may be a correlation between mean leaf size and shoot size. For this reason, analysis was run to test the correlation between leaf size and biomass partitioning. There appears to be a tendency for small-leaf oaks to have more shoot mass per unit root mass than large-leaf oaks (Fig.4); however, some overlap in biomass partitioning is evident. When all plants were classified as to their leaf size (small and large), small-leaf oaks partitioned significantly ($P < .02$) more biomass to shoots at the expense of roots than did large leaf-oaks (Fig. 5). The correlation is surprisingly strong and, to the knowledge of these researchers, has not been previously reported. This result may be due to the need for small leaf oaks to produce more stem tissue to support the same leaf area that large-leaf oaks of comparable total biomass would support.

Acorn Use Efficiency

During harvesting the cotyledon was recovered from the soil and dried. Dry mass of the cotyledon was compared to the original mass recorded before planting. All oak species lost approximately 70% (range of means = 65-76) of initial acorn mass during the first year (Fig. 6). Within species initial

Table 1. *Mean individual Leaf size, typical habitat, and leaf size class for one year old Quercus seedlings.*

Species	Leaf size (cm^2)	Std. dev.	Habitat	Leaf Class
Q. hemisphaerica	1.94	0.65	Upland	Small
Q. nigra	5.31	1.06	Bottomland	Small
Q. laurifolia	5.60	2.08	Bottomland	Small
Q. lyrata	9.76	3.99	Bottomland	Large
Q. marilandica	9.84	6.21	Upland	Large
Q. falcata	9.89	7.59	Upland	Large
Q. pagoda	10.12	3.55	Bottomland	Large
Q. velutina	10.26	3.59	Upland	Large
Q. shumardii	16.45	4.46	Bottomland	Large
Q. rubra	38.35	18.62	Upland	Large

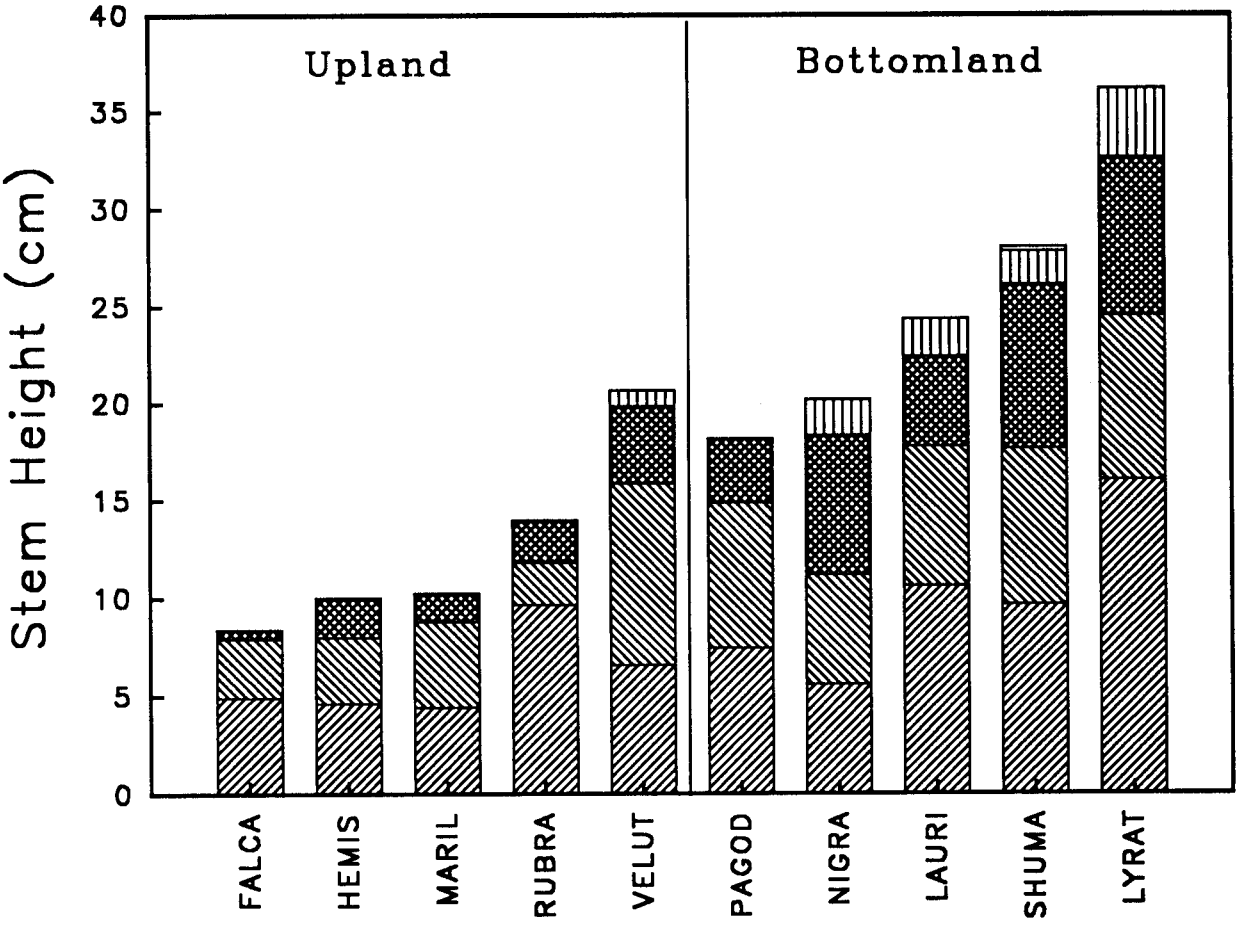

Figure 1. *Height growth of one year old seedlings. Each bar pattern within each bar equals one flush.*

acorn mass was not significantly correlated with final seedling size (regression analysis $P > .05$) except for *Quercus Marilandica* Muenchh. ($P = .04$). However, when species were grouped together initial acorn mass was significantly correlated with final seedling size (regression analysis $P < .0001$).

Conclusions

Based on this study it appears that biomass partitioning in oaks is an evolutionary response allowing oaks to successfully compete for the limited resources on a site. When grown in uniform environ-

ments bottomland oaks had greater shoot extension and maintained smaller root systems than did upland oaks. When examining correlation between morphological traits and biomass partitioning, it was found that mean individual leaf area was significantly correlated to partitioning patterns in oak.

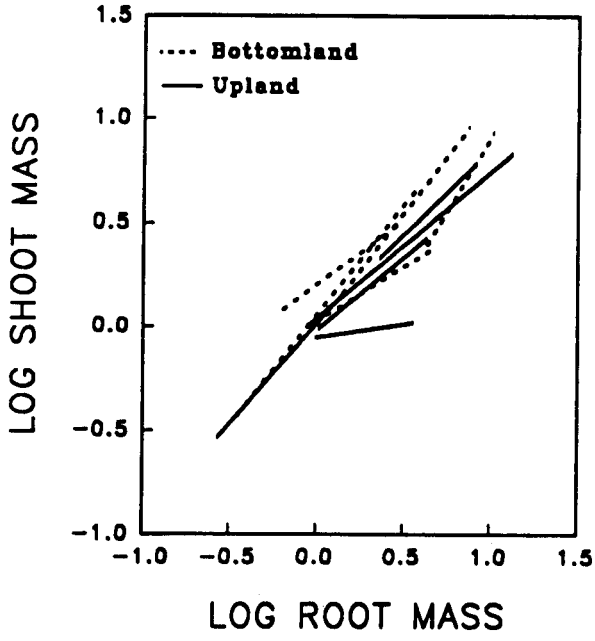

Figure 2. *Family of regression lines of upland and bottomland oak, showing biomass partitioning between the shoot and root. R^2 ranged from 0.21 to 0.87.*

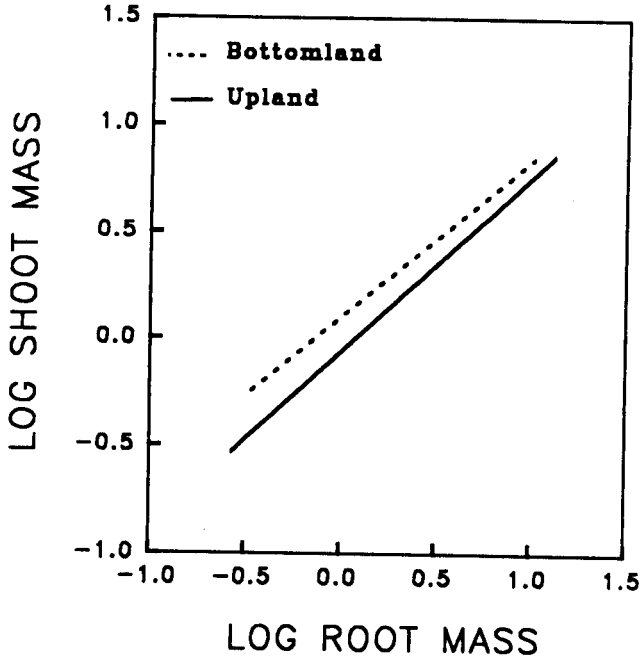

Figure 3. *Regression lines of shoot to root partitioning for bottomland and upland oak. R^2 0.65 for bottomland and 0.75 for upland.*

No attempt is made to place any adaptive significance to this result; it is possibly just a consequence of having small leaves. During the first year, all oak species used approximately 70% of the initial food reserves stored in the acorn and larger seeded oaks produced larger seedlings. This would seem to confer an advantage to large-seeded oaks over small-seeded oaks in that they obtain a greater total amount of energy from the acorn during the first year of growth.

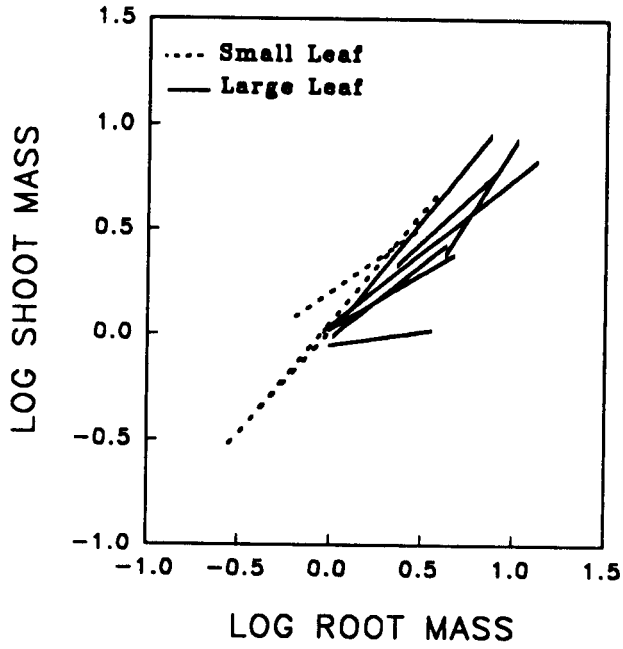

Figure 4. *Family of regression lines of small-leaf and large-leaf oak, showing biomass partitioning between the shoot and root. R^2 ranged from 0.21 to 0.87.*

Acknowledgements

We thank Lee Reynaud and Russell Parrish for valuable technical assistance. Art Chappelka and Bob Mitchell provided helpful comments on earlier drafts of the manuscript. This project was funded by the McIntire-Stennis Cooperative Forestry Research program. The paper represents contribution no. 9-923394 of the Alabama Agricultural Experiment Station.

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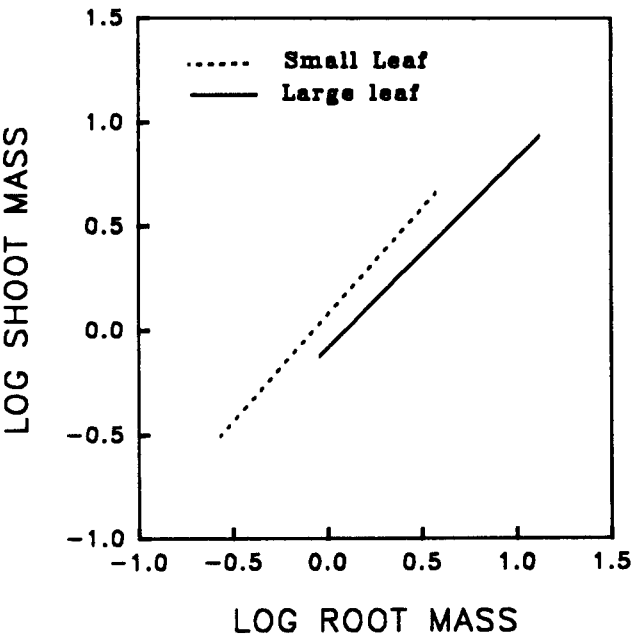

Figure 5. *Regression lines of shoot to root partitioning for small-leaf and large-leaf oak. R^2 0.86 for small-leaf and 0.70 for large-leaf.*

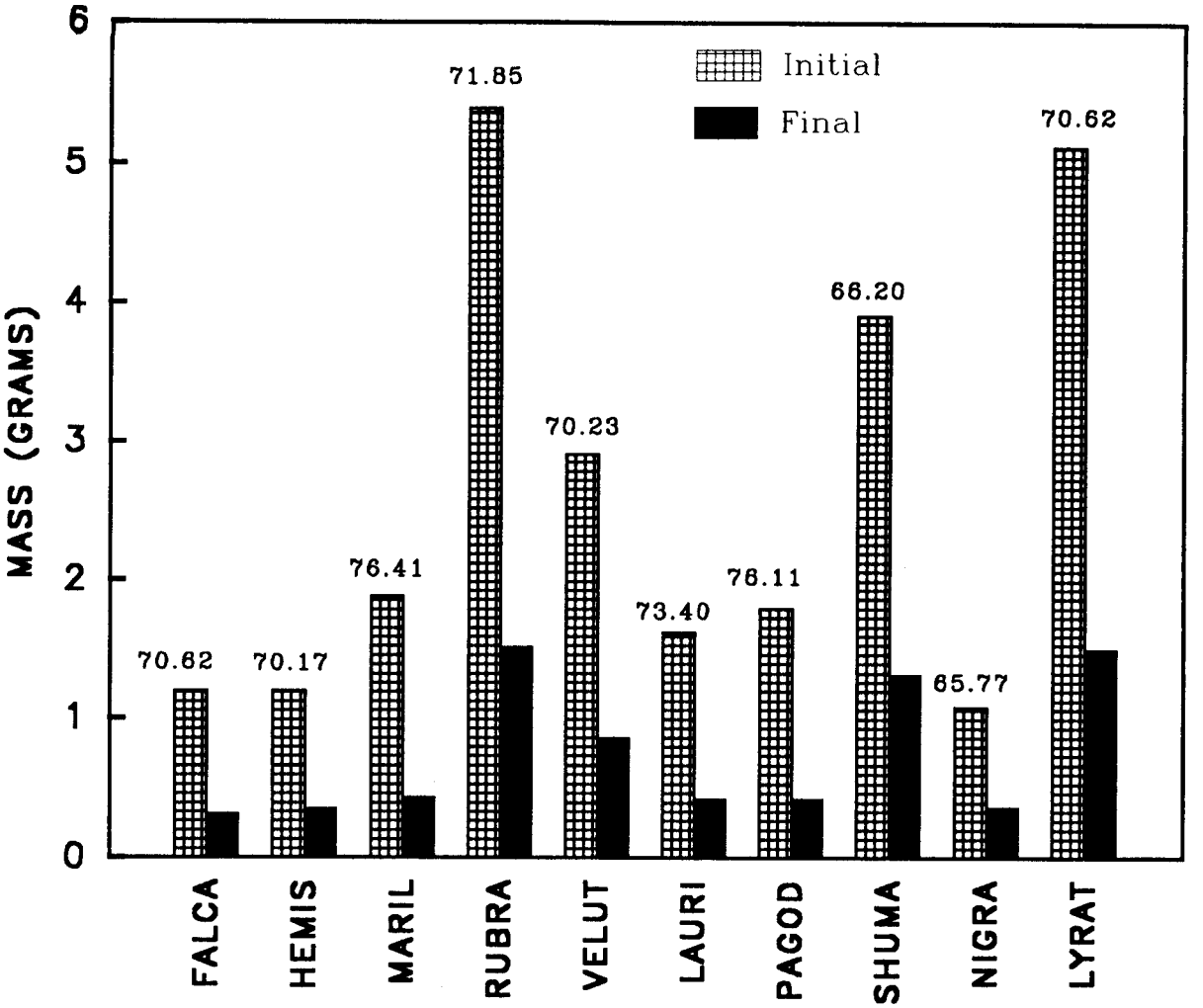

Figure 6. *Mean acorn mass before and after the first growing season. Number above bars is percent mass reduction.*

LIFTING DATE AND STORAGE DURATION AFFECT ROOT GROWTH POTENTIAL AND FIELD SURVIVAL OF SHORTLEAF PINE SEEDLINGS [1]

John C. Brissette and James P. Barnett [2]

Abstract. Seeds from bulked seed orchard lots of Kentucky, Ouachita and Ozark Mountains, and east Texas shortleaf pine (*Pinus echinata* Mill.) were sown at both Weyerhaeuser Company's Magnolia Forest Regeneration Center in southwest Arkansas and the USDA Forest Service W. W. Ashe Nursery in south Mississippi. Seedlings were lifted in December, January, and February and cold stored for ≤3, 21, or 38 days. Seedlings were used in root growth potential (RGP) tests and outplanted in central Louisiana. The pattern of RGP response was similar at both nurseries, except that the effect of lift date was more pronounced for seedlings from the Magnolia Nursery than from the Ashe Nursery. From both nurseries, RGP was least affected by cold storage following the December lift, but was highest among seedlings lifted in January. Mean RGP followed the geographic transect--it was greatest for seedlings from Kentucky and least for seedlings from Texas. Overall, field survival exceeded 95 percent for both nurseries. There were no significant treatment effects on survival for Magnolia Nursery seedlings. Among Ashe Nursery seedlings, there was an interaction between lift date and seed source. Among the sources, Kentucky seedlings had the poorest survival from the first two lifts, but were best from the February lift.

Introduction

Most bare-root southern pine seedlings are stored for a period of weeks between lifting at the nursery and outplanting. Storability depends on several factors, including seed source and level of seedling dormancy (Garber and Mexal 1980). During midwinter, when seedlings are most dormant, cold storage of loblolly pine (*Pinus taeda* L.) seedlings for up to 12 weeks has been reported without markedly decreasing survival (Williston 1974). However, Venator (1985) reported that shortleaf pine (*P. echinata* Mill.) seedlings may not have the storage potential of loblolly pine seedlings and recommended planting as soon as possible after lifting. In other studies with shortleaf pine (Hallgren 1992, Hallgren and Tauer 1989), seedlings from the Ouachita Mountains of Arkansas and Oklahoma lifted in December and January had higher root growth potential (RGP), survival, and growth than seedlings lifted later. Furthermore, storage for 28 days always reduced survival and growth of early- or late-lifted seedlings, but improved RGP on some lift dates (Hallgren 1992, Hallgren and Tauer 1989). Root growth potential is a good, general indication of the physiological quality of reforestation planting stock (Ritchie 1985). The objective of this study was to determine the effects of lifting date and storage duration on RGP and field survival of three geographic seed sources of shortleaf pine seedlings grown at two nurseries.

Materials and Methods

Seedling Material

Seeds from bulked seed orchard lots of three geographic sources of shortleaf pine were sown at both Weyerhaeuser Company's Magnolia Forest Regeneration Center (the Magnolia Nursery) in southwest Arkansas and the USDA Forest Service W. W. Ashe Nursery in south Mississippi. The sources were from Kentucky, the Ouachita and Ozark Mountains, and east Texas and represented a northeast-southwest transect across the western half of the range of the species. There was no attempt to apply a common growing regime at both nurseries. At each nursery, cultural treatments were applied based on the best judgment of the respective manager. Seedlings in this study were not top pruned at either nursery.

Seedlings were lifted during the same weeks from both nurseries. Lifting occurred during the weeks of December 16, 1985; January 20, 1986; and February 24, 1986. From each lifting date, seedlings

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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were planted the same week as lifting and after 21 and 38 days of cold storage (at approximately 2 °C).

From the January lift, a random sample of 50 seedlings from each source at each nursery was recorded for several morphological attributes: stem diameter was measured to the nearest 0.1 mm at as near the root collar as was discernable; height was measured to the nearest 1 mm, from the point diameter was measured to the top of the terminal bud if present; root volume was measured to the nearest 0.1 cm^3 by displacement in water; and a terminal overwintering bud was present if brown, woody bud scales were visible.

Field Planting

The seedlings were machine planted at the J.K. Johnson Tract of the USDA Forest Service Palustris Experimental Forest in central Louisiana. Four blocks with 25-tree row plots of each treatment combination were planted. Due to insufficient seedlings, one block of the Kentucky seed source lifted from the Ashe Nursery in February and stored for 38 days was not planted. Survival was measured at the end of the first growing season.

Root Growth Potential

On the same schedule as planting, seedlings were measured for RGP. Ten seedlings were potted into an 8-liter pot with coarse sand as the medium. Two such pots were used for each treatment combination. The seedlings were put into a growth chamber with a constant air temperature of 20 °C and a 16-hour photoperiod. The RGP of each seedling was determined after 28 days by counting the number of new, white roots greater than 10 mm long.

Experimental Design and Analyses

The experimental design for both RGP and survival was a split-split plot. For survival, there were 4 blocks, but for RGP, there were just 2 blocks (the pots). However, for RGP testing, there were 10 samples (the seedlings) per block. Lifting date was in the whole plots, storage duration represented the sub-plots, and seed source was the sub-subplots. Plot survival was transformed for analysis using the arcsin transformation, i.e. arcsin of the square root of the proportion surviving (Freese 1974). The RGP counts were transformed to their square root for analysis (Neter and others 1985). Although the same seedlots were grown at both nurseries, climatic, edaphic, and cultural differences between the nurseries could not be controlled. Therefore, data for each nursery were analyzed separately using analysis of variance (ANOVA).

Based on the work by Garber and Mexal (1980) and Hallgren and Tauer (1989), preplanned orthogonal contrasts were used to examine specific effects of lift date and storage length on RGP and survival. Midseason (January) lifting, when seedlings should be most dormant, was contrasted to the early (December) and late (February) lifts; and the early and late lifts were compared with each other. Storage for ≤ 3 days (considered not stored) was contrasted with storage, and the 21-day versus 38-day storage contrast was tested. Differences at $p \leq 0.10$ were considered statistically significant.

Results

Morphological attributes of the January-lifted seedlings varied between nurseries and among sources from each nursery (table 1). In general, seedlings from the Magnolia Nursery were shorter and had larger diameters than seedlings from the Ashe Nursery. Seedlings that are relatively short but have large stem diameters tend to grow better after outplanting than do tall, spindly seedlings (Brissette and Carlson 1992).

Root Growth Potential

The W.W. Ashe Nursery. There was considerable variation among the individual seedlings from the Ashe Nursery; sample error accounted for 63 percent of the total variation in RGP, leaving 37 percent explained by the experimental treatments. Among the factors studied, lift date accounted for the most variation (10 percent), essentially due to the contrast between midseason lift (RGP = 18 new roots) versus the early and late lifts combined (mean RGP = 9) (mean squared error [MSE] = 24.4; $F_{1,2} = 9.8$; $p = 0.09$).

The contrast between the unstored (RGP = 14) and stored (mean RGP = 11) seedlings was significant (MSE = 5.4; $F_{1,6} = 4.5$; $p = 0.08$). When cold storage treatments were contrasted, seedlings stored for 21 days had less RGP (a mean of 9 new roots) than those stored for 38 days (RGP = 13) ($F = 5.3$; $p = 0.06$). Higher RGP with longer storage has also been observed in loblolly pine (Barnett and others 1988, DeWald and Feret 1988, Feret and others 1985).

Table 1. *Morphological attributes of shortleaf pine seedlings from three geographic sources grown at two nurseries and lifted in January. Mean values (μ) and coefficients of variation (CV) of a 50-seedling sample are presented.*

Nursery/ Source	Attribute[1]						
	Ht (mm)		Dia (mm)		RV (cm^3)		Bud (%)
	μ	CV	μ	CV	μ	CV	
USDA Forest Service							
W.W. Ashe Nursery							
Kentucky	169	23.9	4.6	18.5	5.6	35.4	58
Ouachita & Ozark Mts.	208	17.5	4.0	14.7	2.8	35.9	90
Texas	209	18.5	4.3	17.4	3.9	37.8	72
Mean	195	20.0	4.3	17.4	3.9	37.8	73
Weyerhaeuser Company							
Magnolia Forest							
Regeneration Center							
Kentucky	174	17.4	4.4	19.4	4.4	33.4	52
Ouachita & Ozark Mts.	182	18.1	4.9	18.7	4.3	39.5	72
Texas	176	16.0	4.5	16.6	3.6	35.7	42
Mean	178	17.2	4.6	18.2	4.1	36.2	55

[1] Ht = stem height, Dia = stem diameter, RV = root volume, Bud = percentage of seedlings with an overwintering terminal bud.

There was an interaction between lift date and storage length ($F_{4,6}$ = 6.6; p = 0.02). Among December-lifted seedlings, RGP gradually declined in storage; after the January lift, RGP increased with time in storage; and for the February lift, RGP declined after 21 days storage, then increased (fig. 1).

Seed sources differed in RGP (MSE = 5.8; $F_{2,18}$ = 6.0; p = 0.01). The Texas seedlings had fewer new roots (RGP = 10) than the Kentucky (RGP = 14) or Ouachita (RGP = 13) seedlings.

The Magnolia Nursery. The experimental treatments explained 47 percent of the variation in RGP among the seedlings from the Magnolia Nursery. As among seedlings from the Ashe Nursery, lift date accounted for more variation (22 percent) than any of the other factors in the model. Seedlings from the January lift had twice as many new roots (RGP = 41) as seedlings lifted either earlier or later (mean RGP = 20) (MSE = 3.0; $F_{1,2}$ = 172; p = 0.006). Furthermore, seedlings lifted in February (RGP = 24) had more ($F_{1,2}$ = 47.5; p = 0.02) new roots than those lifted in December (RGP = 15).

Seedlings that were not stored had a greater (MSE = 6.3; $F_{1,6}$ = 8.5; p = 0.03) number of new roots (RGP = 32) than the seedlings that were stored (mean RGP = 24). As at the Ashe Nursery, seedlings that were stored 38 days had more ($F_{1,6}$ = 13.3; p = 0.01) new roots (RGP = 30) than seedlings stored 21 days (RGP = 19). There was also a significant ($F_{4,6}$ = 5.6; p = 0.03) interaction between lift date and storage length. The RGP of seedlings lifted in December was essentially the same, regardless of the storage duration; but for seedlings lifted in January or February, RGP declined after 21 days in storage, then increased after 38 days (fig. 1).

Among seedlings from the Magnolia Nursery, there was a lift date by seed source interaction for RGP (MSE = 3.9; $F_{4,18}$ = 7.2; p = 0.001). Lift date had minimal impact on the RGP of seedlings from the Ouachita and Ozark Mountains, but the RGP of the other two sources clearly peaked after the January lift (fig. 2).

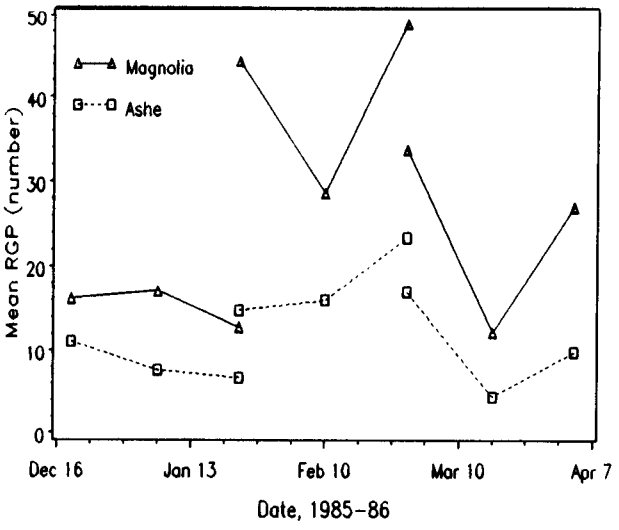

Figure 1. *The interactive effect of lift date and storage duration on the RGP of shortleaf pine seedlings grown at the Weyerhaeuser Company Magnolia Forest Regeneration Center and the USDA Forest Service W.W. Ashe Nursery.*

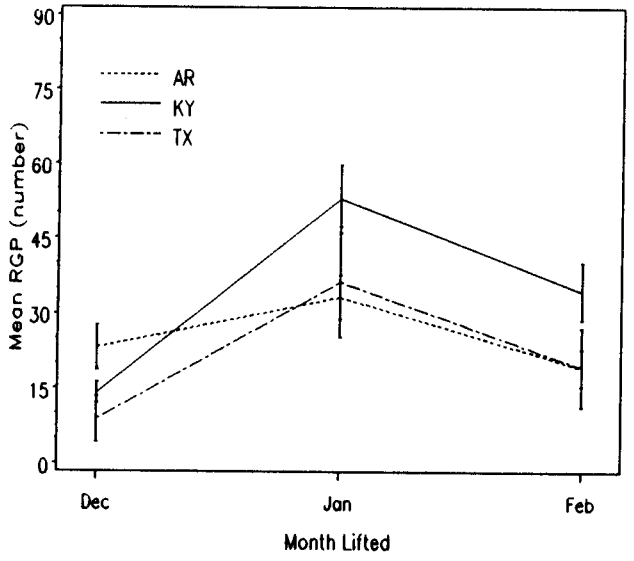

Figure 2. *The interactive effect of seed source and lift date on the RGP of shortleaf pine seedlings grown at the Weyerhaeuser Company Magnolia Forest Regeneration Center. The vertical bars represent ± 1 standard error of the mean.*

Field Survival

The W.W. Ashe Nursery. Survival of seedlings from the Ashe Nursery was very good, averaging 96 percent at the end of the first growing season. However, there were some significant differences due to the factors studied in this research. The one missing plot in the model resulted in an unbalanced design, thus the Type III sums of squares do not add up to the total sums of squares. Consequently, the percentages of variation explained by this model are only approximate. Nevertheless, lift date and storage length together accounted for about 31 percent of the variation in survival of the seedlings from the Ashe Nursery.

With only 1 percent mortality, seedlings lifted in January survived better (MSE = 0.015; $F_{1,6}$ = 32.4; p = 0.001) than seedlings lifted in December or February, which both had 95 percent survival.

Without storage, overall survival was 99 percent, which was statistically better (MSE = 0.011; $F_{1,18}$ = 16.8; p = 0.0007) than the 94 percent average survival of the stored seedlings. Furthermore, seedlings stored for 21 days had greater ($F_{1,18}$ = 32.1; p = 0.0001) survival (98 percent) than seedlings stored for 38 days (92 percent). The interaction between lift date and storage duration was important ($F_{4,18}$ = 5.1; p = 0.006) because storage had no effect on survival of the January-lifted seedlings, whereas 38 days storage resulted in a marked decrease in survival of seedlings lifted in December or February (fig. 3).

There was an interaction between lift date and seed source (MSE = 0.020; $F_{4,53}$ = 2.3; p = 0.07). Survival of seedlings from Kentucky was lower than the other sources after the December and January lifts, but was the best after the February lift (fig. 4).

The Magnolia Nursery. Plot survival of seedlings from the Magnolia Nursery ranged from 88 to 100 percent, with an overall average of 98 percent. None of the preplanned contrasts, experimental treatments, or interactions were significant.

Data from a nearby electronic weather station indicated that the lowest soil water potential recorded during the first growing season was −0.07 MPa. Thus, the seedlings did not encounter even a moderate drought during that year (field capacity ≈ −0.03 MPa). Such high survival is not uncommon for carefully planted research seedlings that are not stressed during establishment.

Discussion and Conclusions

The goal of nursery management is to produce a uniform crop of high quality seedlings. Thus, the amount of variation in an attribute such as stem diameter or RGP is an aspect of the quality of those seedlings. Although there were differences in mean height and diameter of seedlings from the two nurseries, the amount of variation among morpho-

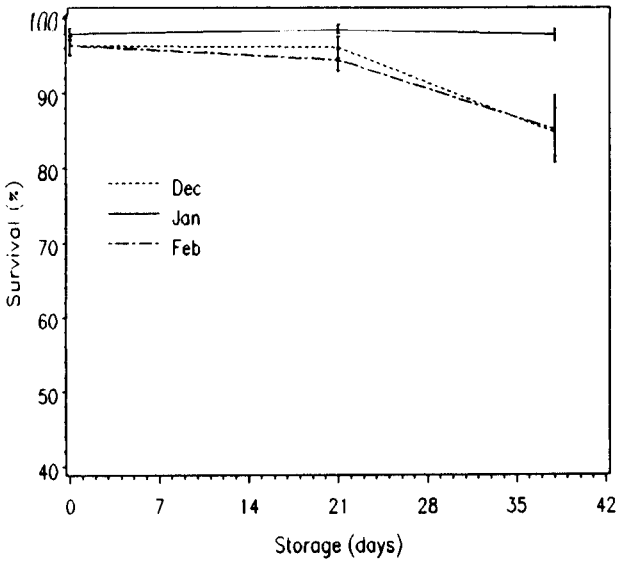

Figure 3. *The interactive effect of lift date and storage duration on the survival of shortleaf pine seedlings grown at the USDA Forest Service W.W. Ashe Nursery. The vertical bars represent ± 1 standard error of the mean.*

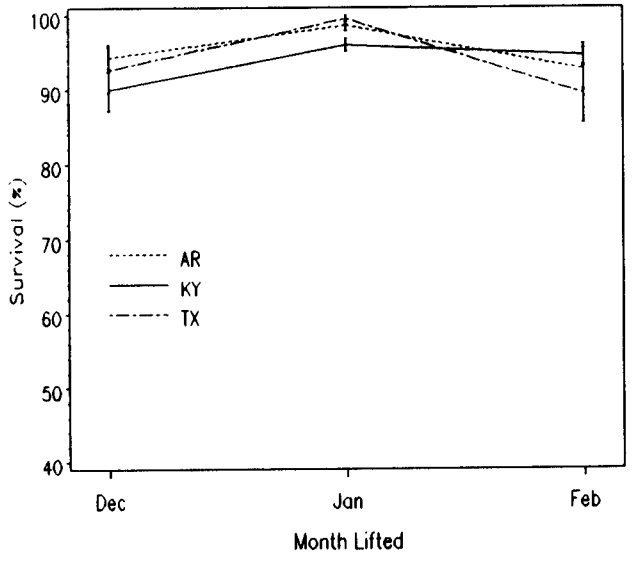

Figure 4. *The interactive effect of seed source and lift date on the survival of shortleaf pine seedlings grown at the USDA Forest Service W.W. Ashe Nursery. The vertical bars represent ± 1 standard error of the mean.*

logical attributes was similar at both locations. However, seedlings from the Magnolia Nursery had less variation in RGP than did seedlings from the Ashe Nursery. Furthermore, mean RGP was higher among seedlings from the Magnolia Nursery. Accumulated chilling affects RGP of shortleaf pine seedlings (Brissette and others 1988). Consequently, being farther north may partially explain why Magnolia Nursery seedlings had greater RGP. However, other factors, such as soil fertility and physical properties, water availability, and nursery culture, can impact RGP.

Although RGP has been shown to be a good predictor of survival (Ritchie 1985), in this study, survival was generally high, regardless of RGP. Among seedlings from the Magnolia Nursery, where the lowest treatment mean RGP was 12 new roots, there were no treatment effects on survival. Some of the differences in survival of Ashe Nursery seedlings did reflect differences in RGP. For example, survival was best among the January-lifted seedlings, which also had the highest mean RGP. Similarly, both survival and RGP were greater among nonstored seedlings than among seedlings that were stored. The relationship between survival and RGP broke down, however, when seedlings stored 21 days were compared with seedlings stored 38 days. Mean RGP was higher after 38 days, but field survival declined, especially among seedlings harvested early or late during the lifting season.

Among cold stored seedlings, a decline in RGP followed by an increase has also been observed in loblolly pine (Barnett and others 1988, DeWald and Feret 1988, Feret and others 1985). Feret and others (1985) speculated that such a "burst" in RGP may be caused by internal plant rhythms or a response to periods of anoxia, which might occur in the root tissues of stored seedlings. It may also be an artifact of the favorable, often constant, conditions under which RGP tests usually are conducted. Studies investigating the relationship between RGP measured under such laboratory conditions and root growth after outplanting into more variable, often harsher, field conditions have not been reported for southern pines. Thus, the burst of RGP among seedlings stored for 38 days may not have occurred in the field, or it may have been delayed until after some early mortality.

Although the effect of seed source was most pronounced for Magnolia Nursery seedlings, ranking of the sources was the same at both nurseries. That pattern--declining RGP along a northeast-southwest transect--suggests a clinal trend in the dormancy induction and release requirements for shortleaf pine. This is an interesting result that warrants further investigation using more geographic seed sources.

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SURVIVAL AND GROWTH RESPONSE OF MESIC AND DRY-SITE SOURCES OF LOBLOLLY PINE SEEDLINGS TO CYCLIC SOIL MOISTURE DEFICIT [1]

Kamran K. Abdollahi, M.V. Bilan, and Z.H. Ning [2]

Abstract. A growth chamber study compared height, biomass, and mortality rate of 4 to 12 month-old loblolly pine (*Pinus taeda* L.) seedlings of mesic and dry-site seed sources to 7 cyclic soil moisture stress levels, averaging between −0.3 to −2.4 MPa. Soil moisture stress was monitored gravimetrically throughout each dry-down cycle until a predetermined soil moisture potential was reached; soil was then rewatered. Shoot height was measured at two-month interval, from 4 to 12 months after the emergence of the seedlings. The oven dry weight of the seedlings and their roots were used for biomass determination. Mortality was recorded every 2 months throughout the experiment.

Dry-site seedlings outgrew mesic seedlings in every soil moisture stress levels. Height growth declined with increasing moisture stress for both seed sources. The most abrupt reduction in height growth occurred between the nonstressed (−0.3 MPa) seedlings and those that grew under −0.6 MPa. Dry-site source produced more shoot biomass in all soil moisture stress levels.

Introduction

Water is one of the most important elements in plant growth and development. As described by Kramer and Kozlowski (1979), water is the solvent in which gases and salts are transported within the plant; it is a principal reagent in photosynthesis and it is necessary for maintaining turgidity of cells. Kramer (1983) mentioned that water deficits, in the long-run can reduce plant growth more than all other stresses combined. As soil moisture decreases, trees are subjected to prolonged internal water stresses which inhibit vital processes of growth. However, many plants seem to survive or grow well in regions where water is often inadequate. Such plants survive either because they avoid drought due to morphological or physiological modification which allows them to avoid or postpone desiccation or because these plants can tolerate some desiccation of their tissue.

Loblolly pine (*Pinus taeda* L.) ranges from south centeral Texas to Southern Delaware, a testimonial to its ability to adapt to widely differing environments. The isolated western-most limit of this natural range, Known as the "Lost Pines", receives 10-20 inches of rainfall a year less than the continuous range 200 miles to the east. Somehow, the "lost Pines" of semi-arid Bastrop, Caldwell, and Fayette counties, Texas survive on about one-half the rainfall of the main population (Wahlenberg 1960). It has also been shown that Lost Pines has several morphological and anatomical modifications which should tend to conserve moisture under droughty conditions (Knauf and Bilan, 1974; Knauf and Bilan, 1977). The physiological basis for such differences is poorly understood, however (Bongarten and Tesky 1986).

It is shown that Lost Pines seedlings have lower rate of transpiration and higher needle moisture potential under moisture stress conditions. signifying moisture conserving ability and tolerance features (Abdollahi, 1991). The search for a "drought-hardy" strain of loblolly pine is important because moisture stress imposed by drought, adverse sites, and competing vegetation largely determine the early performance of outplanted Southern pines (Ursic, 1961).

Experimental Methods

The experimental soil, a fine sandy loam, was collected from the surface 20 cm of a Psammentic Paleudult, in the Stephen F. Austin Experimental Forest. A Ceramic Pressure Plate Extractor was used to determine soil moisture retention. Soil moisture content was measured for pressure from 0.05 to 2.4 MPa. A curve was constructed to fit the obtained data (Figure 1). One hundred and sixty four-inch plastic pots were assembled for filling with the air dried

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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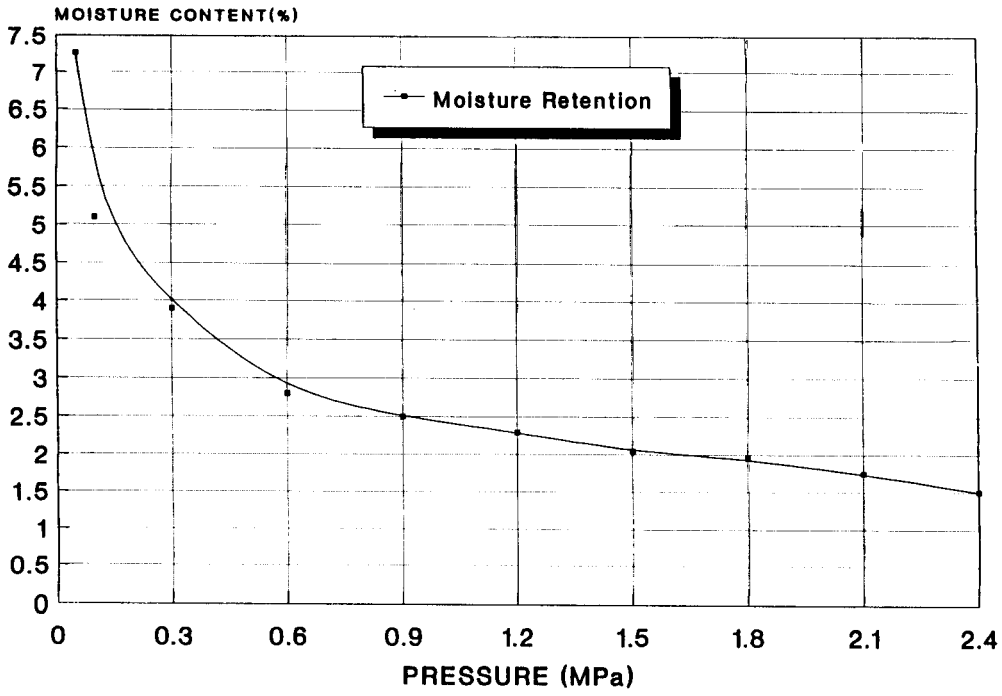

Figure 1. *Soil moisture retention curve for the experimental soil.*

experimental soil. Each pot was fitted with two 20 mesh, nylon screens to prevent soil from being lost through drainage; prewashed pea-size gravel was added to the pots until the combined weight of the pot, screen, and gravel reached 300 grams. An equal amount of oven dried soil was then added to bring the total weight of the pot, screen, gravel and soil to 720.0 grams.

Loblolly pine seeds from both East Texas (mesic) and Lost Pines (dry-site) seed sources were obtained from the Texas Forest Service. The seeds were stratified, and planted in the assembled pots. Each pot contained both seed sources. The experimental plants were grown for two months under favorable moisture conditions in a growth chamber. When the seedlings were two month old, each pot was randomly assigned to one of eight moisture regimes (3, 6, 9, 12, 15, 18, 21, 24 representing −0.3, −0.6, −0.9, −1.2, −1.5, −1.8, −2.1, −2.4 MPa). Throughout the study, soil moisture potential was estimated by weighing the pots each day and correlating soil moisture content with soil moisture potential. Watering weight was also adjusted for the increase in fresh weight of seedlings. All pots were subjected to cyclic moisture stress when plants were two month old. Each pot was weighed daily; and the number of drying cycles to which it had been subjected was recorded. When a pot reached the weight corresponding to its assigned moisture regime, it was watered with 150 milliliters of distilled water to bring the soil moisture to field capacity.

Shoot height was measured at two-month interval, from 4 to 12 months after the emergence of the seedlings. The oven dry weight of the seedlings and their roots were used for biomass determination. Mortality was recorded every 2 months throughout the experiment.

Results and Discussions

Height Growth

Cyclic soil moisture stresses of −0.6 to −2.4 MPa which were imposed on two month old seedlings of East Texas (mesic) and Lost Pines (dry-site) reduced subsequent height growth of both provenances. By the age of twelve months, height growth for both seed sources combined was reduced by 28% in −0.6 MPa regime and by 43% in −2.4 MPa regime (Table 1).

Although height growth declined with increasing moisture stress, the most abrupt reduction in height growth was found between the nonstressed seedlings (−0.3 MPa) and those growing under soil moisture stress of −0.6 MPa. The reduction in height growth between the control and −0.6 MPa constituted 28 %, while the additional reduction between −0.6 MPa and −2.4 MPa amounted only to 15%.

Table 1. *Results of t-test for the height growth (cm), shoot & root biomass of 12 month old loblolly pine seedlings grown in 8 soil moisture regimes for ten months.*

Moisture Regimes (MPa)	Seed Source	Height Mean±S.E.	Biomass	
			Shoot Mean±S.E.	Root Mean±S.E.
−0.3	ET	16.39±0.41	2.50±0.13	1.10±0.078
	LP	18.61±0.47***	2.89±0.12**	1.31±0.093*
−0.6	ET	11.70±0.40	1.70±0.14	0.60±0.056
	LP	13.62±0.33***	2.06±0.12*	0.84±0.031***
−0.9	ET	10.56±0.48	1.45±0.08	0.78±0.167
	LP	11.74±0.40*	1.75±0.10**	0.86±0.056*
−1.2	ET	10.46±0.54	1.60±0.16	0.59±0.096
	LP	10.58±0.57	1.78±0.12	0.91±0.123*
−1.5	ET	9.03±0.38	1.28±0.09	0.58±0.300
	LP	11.58±0.41*	1.91±0.23**	0.82±0.073***
−1.8	ET	8.31±0.43	1.31±0.10	0.52±0.036
	LP	9.92±0.50**	1.75±0.16**	0.71±0.045***
−2.1&-2.4	ET	8.82±0.23	1.17±0.12	0.39±0.031
	LP	11.15±0.14***	1.98±0.17***	0.67±0.063***

*: Significant at alpha .10 level; **: Significant at .05 ; ***: at .01 level. ET: East Texas seed souce (mesic); LP: Lost Pines seed source (dry-site).

Lost Pines (dry-site) outgrew East Texas (mesic) pines in every moisture regime and they exhibited a slightly lower rate in growth decline with an increase in moisture stress. The height growth reduction in −2.4 MPa moisture regime was 40% forlost pines as compared with 46% for East Texas seedlings.

Figure 2 demonstrates the trend in average height growth of loblolly pine seedlings from four to twelve month old regardless of the regimes. Average height growth of Lost Pines are higher than East Texas for all ages except four month old.

Biomass Accumulation

The results of t-test (Table 1) indicate significant differences between the shoot biomass of seed sources at regime −0.3 MPa, −0.9 MPa, −1.5 MPa, −1.8 MPa ($p \leq 0.05$); −0.6 MPa, −2.4 MPa ($p \leq 0.1$), and −2.1 MPa ($p \leq 0.01$). The Lost Pines seedlings had significantly greater shoot biomass than East Texas seedlings. The results (Table 1) also revealed significant differences between the seed sources at regimes −0.3 MPa, −0.9 MPa, −1.2 MPa ($p \leq 0.1$), −0.6 MPa, −1.5 MPa, −1.8 MPa, and

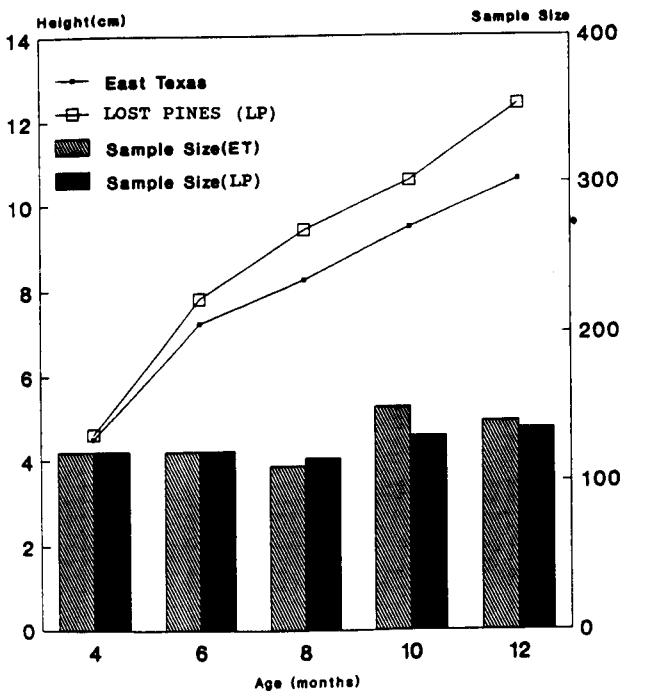

Figure 2. *Average height growth of loblolly pine seedlings from 4 to 12 month old by seed source for combined soil moisture regimes.*

−2.4 MPa ($p \leq 0.01$). Roots of seedlings from Lost Pines had significantly higher biomass than that of East Texas seed source for all the regimes (eg. 19% at regime −0.3 MPa, 40% at regime −0.6 MPa, 16% at regime 0.9 MPa, 54% at regime −1.2 MPa, 41% at regime −1.5 MPa, 36% at regime −1.8 MPa, and 71% at regimes −2.1 MPa & −2.4 MPa).

Seedling Mortality

Percent mortality for both seed sources during 12 months (Figure 3) increased as soil moisture stress increased, however, Lost Pines seedlings had a lower percentage mortality in all stress regimes. The highest mortality (51%) was exhibited by East Texas seed source under regime −2.4 MPa. The highest mortality exhibited by Lost Pines was 25.5% under stress level of −1.8 MPa.

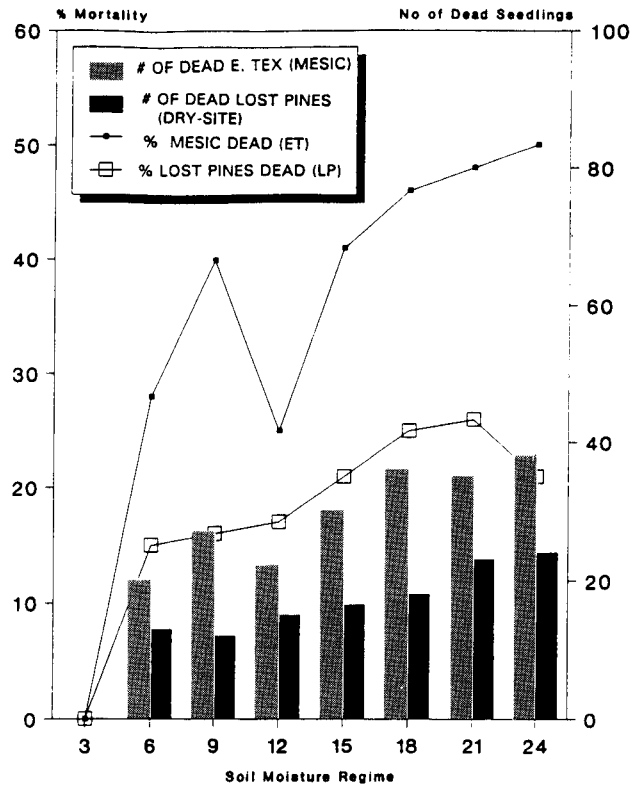

Figure 3. *Mortality of loblolly pine seedlings grown under 8 soil moisture regimes for twelve months.*

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USE OF RAPD TECHNOLOGY TO IDENTIFY MAST POTENTIALS IN HARDWOOD SPECIES [1]

B.S. Crane, L. Pearson, D.D. Hook [2]

Abstract. It is generally recognized that within a hardwood species population some individuals consistently produce heavy mast (acorn, nut, seed) crops while other individuals will not. Identification of an individual's masting characteristics could potentially be accomplished using molecular markers. Use of the random amplified polymorphic DNA (RAPD) marker system, based on polymerase chain reaction (PCR), is suited to this system. RAPDs are useful for distinguishing different individuals in a population.

Leaf samples were collected from 128 individuals of twelve hardwood tree species. Field observations at the time of collection showed these trees to vary widely in mast production. Species included five oaks and two hickories, as well as sugarberry, dogwood, persimmon, blackgum and swamp tupelo. Eight years of recorded mast production data are available for samples from three oak species collected on one site.

DNA was successfully extracted from the leaf material of each species and amplified using random primers. Both heavy and light mast producing tree DNAs were initially evaluated individually. We then used bulk segregant analysis experimental methods to evaluate the potential of this approach to identify mast production traits. DNAs of the heavy mast producers were combined in one aliquot and the DNAs of the light mast producers in a separate aliquot. These two groups were compared using various primers to detect distinguishing RAPD markers. Markers specific for only one bulk, either heavy or light, could correlate with the masting trait. These methods have potential for the early identification of good mast producers for selection, breeding and seed orchard use for these hardwood tree species.

Introduction

Sustaining a mixture of heavy-seeded hardwood tree species in eastern deciduous forests is a desirable but sometimes difficult task to accomplish. Poor natural regeneration often results from inherently low mast (acorn, nut, seed) productivity of individual trees, cyclic crop production, poor germination, foraging by wildlife (Gosselink and Muir, 1990), defoliation, shade and competition (Lorimer, 1992), or losses of heavy-seeded species due to disturbances that favor light-seeded species (Hook, unpublished data). When artificial regeneration is used, seedlings improved through breeding for increased mast production could be outplanted. Unfortunately breeding orchards for most of these species do not exist. In a few isolated areas individual trees are being monitored for mast production, but this process is time consuming and expensive, and the trees are not easily accessible. If techniques could be developed that would allow quick and inexpensive identification of potentially good mast producers, existing individuals in the field could be identified and special precautions could be taken to maintain them. In addition, seedlings at the nursery could be screened for good masting potential and planted in desired locations.

Identification of an individual's masting characteristics could potentially be accomplished using DNA markers. Random amplified polymorphic DNA (RAPD) markers, based on the polymerase chain reaction (PCR), have been used to follow traits in other species (Grattapaglia et al., 1992). The DNA polymorphisms identified by the markers show up as bands on an agarose gel and are relatively simple to screen based on their presence or absence. The RAPD system offers several advantages; RAPDs are capable of distinguishing different individuals in a population (Williams et al., 1990), they are not species specific, only a small amount of DNA is required, protocols and data collection are less time consuming than restriction fragment length polymorphism (RFLP) or isozyme analysis, RAPDs

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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can be combined with RFLPs to increase efficiency of genetic marker analysis (Anderson and Fairbanks, 1990), and DNA libraries, known DNA sequences and radioisotopes are unnecessary, making RAPDs ideal for small research studies.

In woody plants isolation of DNA of an adequate purity to successfully perform RAPD reactions is often difficult. Secondary compounds such as polyphenols and polysaccharides are released during tissue grinding, copurify and interact with the DNA (Katterman and Shattuck, 1983, Rogers and Bendich, 1988, Loomis, 1974) and can inhibit PCR-type reactions (Demeke and Adams, 1992).

We isolated DNA from leaf tissue of different hardwood species using a CTAB extraction method (Doyle and Doyle, 1990). We used the DNA in RAPD reactions to screen individuals separately, then in bulks for bulk segregant analysis experimental methods.

Methods and Materials

Leaves were collected in September 1991 and May 1992 from the most recent growth flush at the canopy top of 128 mature trees. Species studied included: *Quercus alba* L. (white oak); *Q. falcata* Michx. var. *falcata* (southern red oak); *Q. falcata* var. *pagodifolia* Ell. (cherrybark oak); *Q. lyrata* Walt. (overcup oak); *Q. michauxii* Nutt. (swamp chestnut oak); *Carya aquatica* (Mich. f.) Nutt. (water hickory) and *C. tomentosa* (Poir.) Nutt. (mockernut hickory), *Celtis laevigata* Willd. (sugarberry), *Cornus florida* L. (dogwood), *Diospyros virginiana* L. (persimmon), *Nyssa sylvatica* Marsh. (blackgum) and *N. sylvatica* var. *biflora* (Walt.) Sarg. (swamp tupelo). Samples represented a range of habitats across coastal and piedmont regions of South Carolina. Trees varied widely in mast production based on visual observations at the time of collection. The fall of 1991 was a bumper crop year for mast production in the southeast (Beck, 1992) representing a peak in a mast cycle. Because both extremes of the spectrum (inherently low or high mast production) would be more apparent during a peak in the mast cycle, we collected leaves from each extreme. We feel that they would more closely reflect the true genetic nature of a tree's masting potential because of this particular time in the mast cycle.

Field samples were stored on ice during collection and transit (24-48 hours), immediately frozen in liquid nitrogen when returned to the lab and stored at −30°C until being processed further. To extract the DNA 500 mg of frozen tissue[3] was placed in a prechilled (−20°C) crucible. It was ground to a fine powder under liquid nitrogen with insoluble polyvinylpolypyrrolindone (PVP). The powder was transferred into a Kontes tissue grinding tube (#21) to which five milliliters (mls) of preheated (65°C) CTAB extraction buffer was added. The mixture was homogenized for 1-2 min[4] then incubated in a 65°C water bath for 30 min. It was then transferred to a centrifuge tube to which an equal volume of 24:1 chloroform:isoamyl alcohol (CIA) was added. The solution was mixed thoroughly but gently to achieve a good emulsion. After centrifugation for 10 min at 19,000 × g, the upper aqueous layer[5] was transferred to a new tube and CIA was again added and mixed thoroughly. Following another centrifugation the upper aqueous layer was transferred to a new tube to which 1/10 vol 3M sodium acetate (NaAc, pH 6.0) was added. After mixing, an equal vol of −20°C isopropanol was added and mixed, precipitating the DNA. The DNA pellet was then transferred[6] to a new tube, washed twice with 70% ethanol and air dried. It was then dissolved[7] in 1 ml TE buffer.

Additional extractions of the DNA solution with phenol:chloroform:isoamyl alcohol (PCIA, pH 8.0) were necessary to further remove contaminants and secondary compounds which otherwise inhibited amplification in RAPD reactions. Two-hundred and fifty microliters (μl) of the DNA solution were mixed with an equal vol of Tris/NaCl buffer. An equal total vol of PCIA was added and mixed. Following centrifugation for 5 min at 16,000 × g the upper aqueous layer was transferred to a new tube.

An equal vol of PCIA was again added and mixed. Following another centrifugation, the upper

[3] Do not allow the tissue to thaw as oxidation of polyphenols will occur which can interact with the DNA (Couch and Fritz, 1990).

[4] Homogenization time depends on species. Oaks and hickories took longer to grind and homogenize than the other species.

[5] Amount of upper phase varies with species.

[6] DNA may be transferred either by pelleting in a centrifuge 10 min at 16,000 × g and carefully pouring off the supernatant, or grasped with glass pipette hook (bend tip of a glass pipette over ethanol flame to form a hook) and transferred to a new tube.

[7] Alternatively incubate one hour at 37°C to facilitate dissolving.

aqueous layer was transferred to a new tube to which 1/10th vol 100 mM NaAc (pH 6.0) was added. After mixing, an equal vol −20°C isopropanol was added and mixed to precipitate the DNA. After a final centrifugation the supernatant was carefully poured off, and the DNA pellet was washed twice with 70% ethanol and air dried. The DNA was then dissolved in 250 μl TE and samples were stored at 4°C. The DNA concentrations were measured (before and after PCIA) using a fluorometer.

Following extraction procedures, individual DNAs were amplified using up to 100 primers (University of British Columbia, primers 201-300). To prepare the DNAs for RAPD reactions, aliquots from each PCIA-cleaned DNA sample were diluted to a concentration of 12.5 μg/ml in 100 μl of water. Samples were boiled for 10 min and immediately placed on ice. Two μl of each DNA sample were transferred to separate PCR tubes. The RAPD-reaction solution[8] was mixed and 23 μl were added to each PCR tube containing DNA. Each solution was overlaid with mineral oil and tubes were placed in a thermal cycler. Amplification took place over 45 cycles: denaturation 1 min at 94°C, annealing 1 min at 35°C, ramp at a rate of 1°C per 2 sec to 72°C, extension 2 min at 72°C (final cycle with a 5 min incubation at 72°C) and an indefinite 4°C after 45 cycles were completed. Loading dye buffer (Sambrook et al., 1989) was added to each sample, vortexed and centrifuged for 5 min at 16,000 × g. Samples were separated electrophoretically on a 1.5% agarose gel at 150 volts. The gels were stained with ethidium bromide and photographed.

Solutions

CTAB extraction buffer: 2% hexadecyltrimethylammonium bromide (CTAB), 1.4 NaCl, 20 mM ethylenediamine tetraacetic acid (EDTA), 100 mM Tris, pH 9.5, 0.2% 2-mercaptoethanol, 1% soluble polyvinylpolypyrrolidone (PVP), 0.1 mg/ml protease

TE buffer: 10 mM Tris, pH 8.0, 1 mM EDTA

TRIS/NaCl buffer: 200 mM NaCl, 100 mM Tris, pH 8.0, 10 mM EDTA

RAPD reaction solution: 10X buffer, 1.9 mM MgCl, 2.5 mM each of deoxynucleotide triphosphate (dATP, dCTP, dGTP, dTTP), 4 μM oligonucleotide primer, 1 unit Taq DNA polymerase, 2 μl of 12.5 ng/μl DNA (add separate from reaction solution, see protocols for details), volume to 25 μl with water. Chemicals used were obtained from Perkin Elmer and Promega.

Results and Discussion

The protocol of Doyle and Doyle (1990) worked effectively for isolation of DNA from twelve species of mature hardwoods trees. We obtained DNA from 99% of the samples with less than 1% being recalcitrant. DNA concentrations varied, shown by the following average concentrations (μg/ml) of all samples within each species: white oak 144, southern red oak 78, cherrybark oak 158, overcup oak 69, swamp chestnut oak 88, water hickory 81, mockernut hickory 77, sugarberry 117, dogwood 49, persimmon 36, black gum 79 and swamp tupelo 34. Variations could be attributed to species, variability in leaf texture, developmental stage of the leaf, and presence of secondary compounds (Guillemaut and Marechal-Drouard, 1992).

A PCIA wash of the DNAs was a critical step in our protocols. Without it DNA extracted from late-summer leaves did not amplify successfully. Additional organic extractions have been shown to remove contaminants from DNA (Honeycutt et al., 1992). We used PCIA to clean the DNAs further. Pink and brown discoloration commonly displayed in late-summer DNAs disappeared after two to three PCIA extractions, suggesting the removal of polyphenols and other contaminants. Repeatable and consistent results were then observed for PCIA-purified DNA when tested with several primers. DNAs extracted from spring-collected samples showed no discoloration and amplified without the additional PCIA extraction. However this treatment was used on these samples to see if any changes in amplification occurred. Results revealed more bands following PCIA treatment. Therefore, PCIA purification was adopted as a routine part of the protocols for all tissues. For unknown reasons this treatment resulted in over 50% of the DNA concentration being lost. However ample DNA was still present for use in RAPD reactions.

[8] This reaction solution should be made up on ice and the DNA amplified directly thereafter.

Bulk segregant analysis (BSA) has been used to screen polymorphisms in bulked groups of individuals having the same trait (Michelmore et al., 1991). By bulking the DNAs, common polymorphisms are revealed while individual and novel polymorphisms are not. Thus when an unusual polymorphism does show up in the bulk it may be informative. This method facilitates analysis because an entire genomic region, rather than an individual locus, is being evaluated for correlated markers. This in turn expedites their placement on a genetic map. BSA ideally should be done on samples derived from segregating populations that have a known genetic history. This prerequisite does not exist for the hardwood species with which we were working. The oaks with long-term mast data were the best available samples to study.

Following the completion of amplification of individual samples, we evaluated BSA experimental methods. We bulked the two groups of DNAs from each of the three species of oak trees having long-term mast data. The trees were located on one site in the coastal region of South Carolina, avoiding any differences in allelic expression due to geographic variation. For each species, DNAs from three trees being heavy mast producers were combined in one aliquot, and DNAs from three trees being light mast producers were combined in another aliquot, all in equal volumes. These two aliquots were compared, using a number of primers in RAPD reactions, to detect polymorphisms that may be present in one bulk and not in the other. When a distinguishing polymorphism was found the primer was then run with the individuals in that bulk to see if the same polymorphic band was present in each of the individual samples. With only three individuals per bulk the BSA method was not successful. We were unable to identify any informative polymorphic bands. Individual polymorphisms rather than unusual bulked polymorphisms were revealed. The BSA method is more efficient with a larger number of samples in each bulk (Michelmore et al., 1991). The dogwood species had the highest number of samples with eight per bulk. We tested these bulks using the BSA method with 12 primers. The bulks gave identical patterns except for one distinguishing marker. This primer was tested on the individual DNA samples in that bulk, but only six of the eight individuals showed the polymorphism. In evaluating our other species' bulks, none had a sufficient number of samples to continue with the BSA method. In theory the BSA method should work with greater numbers of samples.

The sensitivity of this method was tested using two swamp chestnut DNAs, one of which contained a marker that was absent from the other sample. We ran reciprocal dilutions of the DNA samples which scored for the presence and absence of a particular marker (at 1, 2, 4, 5, 10, 20, 33 and 50%). It was found that markers present in less than 25% of the bulk samples were not detected, but above that they were. This suggests that only markers that are less than 25% recombination from a gene of interest would be detectable in this species using this method.

In conclusion, our data indicates that RAPD markers can be used for these species. Additional PCIA extractions of leaf DNA are critical for successful amplification using random primers. For the bulk segregant analysis approach however, greater numbers of individuals, preferably within a genetically defined cross or population would probably be required. The techniques presented here could provide a better understanding of hardwood tree species biology and the masting phenomenon.

Acknowledgements

We would like to thank Dr. Carlyle Franklin, NC State University Forestry Department for his permission and assistance in collecting leaves from the three species of oak trees having long term mast data.

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ROOT-SHOOT RELATIONSHIPS OF COPPICED SYCAMORE AND SWEETGUM [1]

Karen Kuers, Klaus Steinbeck, and Lawrence A. Morris [2]

Abstract. Core root biomass (heartroot and lateral roots within a 12 inch radius) was measured on twelve-year-old coppiced sweetgum (*Liquidambar styraciflua* L.) and sycamore (*Platanus occidentalis* L.) rootstocks. Core root mass was compared to both groundline diameter and the total basal area at breast height of dominant sprouts using logarithmic transformations of the data. Predictions of core root mass based on groundline diameter accounted for 91 and 81 percent, respectively, of the variation in the sweetgum and sycamore rootstocks. Sycamore core root mass was correlated to total basal area of the dominant sprouts (r^2 = 0.68), whereas the equation for sweetgum was improved by including number of sprouts as a second variable (r^2 = 0.90). Equations predicting aboveground mass from groundline diameter of the rootstock accounted for 85% of the variation in sweetgum and 58% in sycamore.

Sweetgum produced three times the core root biomass of sycamore. Average mass was 8.12 and 2.45 kg/stump for sweetgum and sycamore, respectively. Predictions of aboveground mass indicated that the sweetgum also produced three times greater sprout biomass. Although the sweetgum were significantly larger than the sycamore, analysis of covariance did not indicate that the above to belowground relationships differed significantly between the two species.

Introduction

The relationships between shoot and root biomass of trees are of interest because they represent interdependent, yet competing sinks for photosynthate and nutrients. Internal controls, often mediated through hormonal balance, tend to maintain relatively stable size relationships of roots to shoots (Kozlowski, et. al., 1991; Waring and Schlesinger, 1985). Büsgen and Münch (1929) reported that the roots of trees grown in closed stands constituted about 25% of the total tree biomass. In a review of root biomass studies, Santantonio et. al. (1977) found that the portion of total tree biomass in roots ranged from 14 to 29% for temperate deciduous trees, 15 to 45% for coniferous forests, and 6 to 44% for tropical and subtropical forests. Bray (1963) noted that estimates of root-shoot ratios for temperate forests were very uniform. They ranged from .15 to .33 with a mean value of .21. Fogel (1983) reported a somewhat larger range of .09 to .44 for root-shoot ratios in coniferous forests. Variations among root-shoot ratios are due to numerous factors such as light, soil bulk density (Kozlowski et.al., 1991), night temperature (Hellmers and Rook, 1973), water and nutrient availability (Axelsson and Axelsson, 1986; Waring and Schlesinger, 1985), age (Ovington, 1961), and species.

The effects of coppicing on root systems vary with the tree species, length of cutting cycle, and site quality (Cotta, 1845). For example, rootstocks of American sycamore, which had been coppiced annually, weighed 16 tons/ha, whereas others harvested on 2 and 7 year cycles weighed significantly more, 23 and 25 tons/ha, respectively (Steinbeck and Nwoboshi, 1980). Reidacker (1972) compared the root biomass of 30-year-old stands of coppiced and high forest Eucalyptus, and found an average increase of 40% in high forest root biomass over the coppiced stand (114 vs. 81 kg/tree).

Due to the difficulty of excavating and measuring root systems, equations which predict belowground biomass of trees using easily measured parameters such as dbh and height are in common use (Santantino et. al., 1977; Whittaker et. al., 1974). Most equations are of the form:

$$\log Y = a + b (\log X)$$

where a and b are regression coefficients, Y = ovendry weight of the component of interest, and X is the diameter at breast height.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Graduate Research Assistant, Professor and Associate Professor, respectively, University of Georgia, Athens.

Direct comparison of equations from different studies are difficult because various portions of the root biomass have been measured by different investigators. Some studies do not specify the portion of the root obtained (Baskerville, 1965), some are based only on roots above a specified diameter (Ovington et. al., 1967), while others attempt to correct for root sampling losses through estimates based on relationships between broken root diameters and individual root biomass (Santantonio et. al., 1977; Whittaker et. al., 1974). An alternate approach, the one taken in this study, is to determine the root biomass within a specified radius of the stump (Harris et. al., 1973). This study compares the root-shoot relationships of coppiced sweetgum and sycamore, and determines the relationship between the central mass of the large, structural roots of coppiced stands and more easily obtained above-ground measurements.

Materials and Methods

This study was conducted in a portion of a large, short-rotation species trial located in Tattnall County in the lower Coastal Plain of Georgia. Mixed species plots of American sycamore, European black alder (*Alnus glutinosa* L.), and sweetgum were planted with alternating rows in 1978 and 1979 at a 4 x 8 feet spacing. The alder survived very poorly and was eliminated by disking three years later. This left the remaining sweetgum and sycamore trees at a spacing of 4 x 16 feet.

The soils on this site were of the loamy, silicaceous thermic family of Arenic Plinthic Kandiudults (Fuquay soil series) and Plinthaquic Paleudults (Leefield soil series). Both soils were formed in thick marine sediments. The Leefield was the more poorly drained of the two, having a high water table within 18 to 30 inches of the surface, and in many years above the surface during the late winter or early spring months (USDA 1980). This high water table limited rooting depth for both tree species.

The trees used in this study developed as follows: Bare rooted, 1-0 seedlings grew for five years after transplanting into the field and then were cut about 6 inches above ground. Their stumps resprouted and the resulting coppice was harvested in late January, 1989. At this time the rootstocks were 12 years old, and the sprouts growing on them six years old.

Random rows of rootstocks were harvested one month later, in February, 1989. A subsoiler, pulled by a farm tractor, pruned lateral roots on two sides of the stools about 3 feet from the center of a row to a depth of about 24 inches. Some ropelike laterals near the soil surface, the largest of which averaged 0.8 inches in diameter for sycamore and 1.6 inches for sweetgum, were thus cut. The stools were loosened with tractor and cable, then picked up with a fork lift and shaken to remove most of the adhering soil. A total of 52 sycamore and 48 sweetgum stools were collected in this manner.

Rootstocks were trucked to Athens, GA. Remaining soil was washed off with a garden hose. The basal diameters of the sprouts on each stump were measured, as were the basal area of each rootstock at groundline and its rooting depth.

After air drying for a month, the rootstocks were weighed. At this point they consisted of the stumps of the aboveground sprouts, a well defined heart root, and shallow lateral roots. The number of lateral roots larger than 0.5 inches in diameter were counted and the cross sectional area of the largest lateral root was determined. Most fine roots (less than 2 mm in diameter) became brittle upon drying and were lost.

Aboveground biomass was estimated from measurements of the sprout diameters on each harvested stump. Sprouts had been cut approximately 6 inches above groundline. The relationship between sprout diameter at 6 inches and at breast height was determined by measuring 45 sprouts of sycamore and 44 sprouts of sweetgum (Fig. 1). Sprout dry weight was predicted from dbh using equations developed by Park et. al. (unpublished data) for sycamore and sweetgum. Total aboveground dry weight included the weights of the sprouts and the portion of the rootstock above groundline.

In order to determine the root mass in a consistent volume, each rootstock was first cut at groundline to separate the stump (6 inches to groundline) from the heartroot. All laterals were cut off 12 inches from the centerline of the taproot, leaving a cylindrical core of root containing the heartroot and up to 12 inches of lateral roots. This central core of heartroot and inner laterals was weighed and will be referred to as the core root.

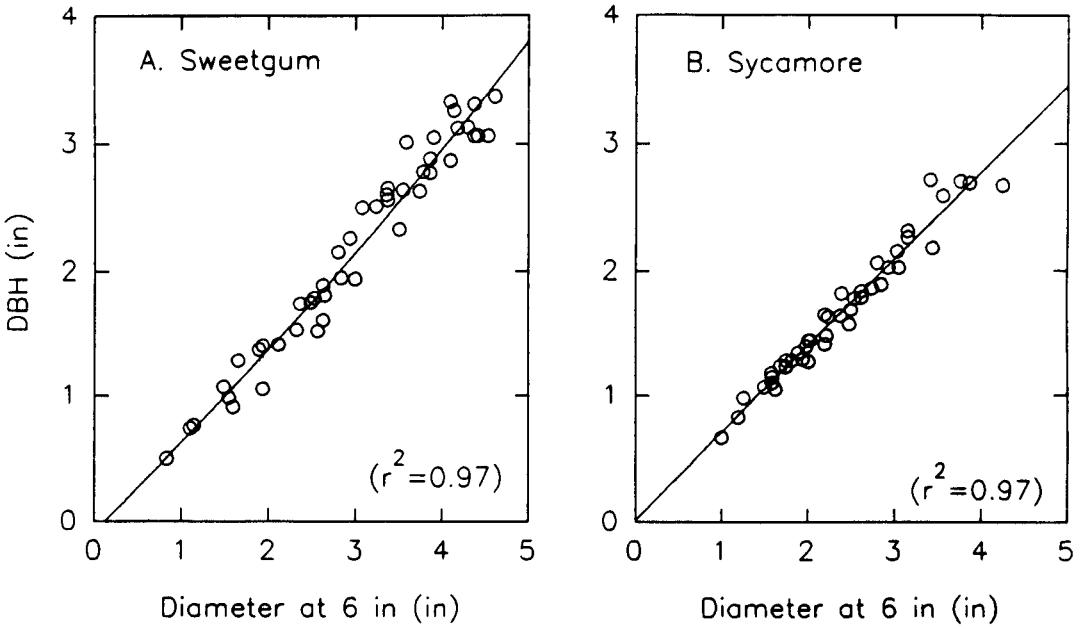

Figure 1. *Relationship of sprout dbh to the diameter of the sprout 6 inches above groundline. A. Sweetgum: $\log_{10}(Y) = -0.198 + 1.112\log_{10}(X)$; B. Sycamore: $\log_{10}(Y) = -0.150 + 0.985\log_{10}(X)$.*

Subsamples of the air-dried root systems were collected and dried to constant weight at 158°F. All root weights were converted from an air-dry to oven-dry weight on this basis.

Differences in mass and root morphology between species were evaluated using a t-test. Relationships among core root mass, rootstock groundline diameter, aboveground dry weight, and basal area of the sprouts were determined by regression analysis (SAS Users Institute, 1990). The slopes and intercepts of these relationships were compared between species using analysis of covariance.

Results and Discussion

Sweetgum rootstocks were significantly larger than those of sycamore (Table 1). Although sweetgum taproots penetratated 13.4 inches deeper into the soil in spite of the high water table, the depth of the first major branching of the taproots was the same for both species. Sycamore had smaller, and at their base somewhat more elliptical, lateral roots than sweetgum.

The rootstocks of sweetgum weighed more than three times as much as those of sycamore (Table 2). The total dry weight of sweetgum core roots ranged from 2.4 to 42.9 lbs, with an average of 17.8 lbs. The total dry weight of sycamore core roots averaged 5.4 lbs, with a range of 1.5 to 18.0 lbs. Sycamore also had significantly fewer lateral roots than sweetgum.

Core root mass was strongly related to the groundline diameter of the rootstock for both sweetgum and sycamore (Fig. 2). The best relationship was obtained using logarithmic transformations of both the dependent (core root mass) and independent (groundline diameter) variables. The equation for sweetgum explained somewhat more of the variation in core root mass (r^2 = 0.91) than did the equation for sycamore (r^2= 0.81). However, the range of rootstock diameters was much greater in sweetgum than in sycamore. As noted by Whittaker et. al., (1974), high correlation coefficients are obtained when a wide range of tree sizes are used in samples, and therefore are of limited value in interpretation of the regressions. Analysis of covariance did not indicate that the slope or intercept of the equations differed significantly between the two species ($p < 0.05$).

Total aboveground mass (sprouts plus stump) was strongly correlated with groundline diameter of the rootstock as illustrated in Fig. 3 (r^2 = 0.85 in sweetgum, 0.58 in sycamore). The total sprout basal area at breast height was also correlated with groundline diameter (data not included). Larger rootstocks supported greater sprout mass for both sweetgum and sycamore. Although regrowth of sweetgum was significantly greater than that of

Table 1. Average dimensions of 12-year-old sweetgum and sycamore rootstocks grown in the Georgia Coastal Plain and coppiced at age 6.

Species	Dimensions[1]				
	Basal Area at Groundline (in^2)	Taproot Branching depth (in)	Taproot Total Depth (in)	Diam. Largest Lateral	
				Horizontal (in)	Vertical (in)
Sweetgum	50.1	9.4	46.5	2.4	3.1
Sycamore	18.9	10.2	33.1	1.4	2.0

[1] Except for the depth at which taproots branched, all dimensions varied significantly (.0001) between species (t-test).

Table 2. *Average rootstock mass and number of large, lateral roots of 12-year-old sweetgum and sycamore grown in the Georgia Coastal Plain and coppiced at age 6.*

Species	Dry weights (lbs) [1]			Number of [1] laterals > 0.6 in diameter
	Core Root	Heart Root	Laterals within 12 in	
Sweetgum	17.84	11.77	6.07	11.5
Sycamore	5.39	4.55	0.84	7.4

[1] All values varied significantly (.0001) between species (t-test).

sycamore, analysis of covariance did not indicate a significant difference in the slope or intercept of the equations relating aboveground growth to groundline diameter for the two species ($p < 0.05$). This is most valid for rootstocks 8 inches or less at groundline because of the lack of large diameter sycamore rootstocks in the sample.

Core root mass was also related to the total sprout basal area at breast height (Fig. 4). The regression for sweetgum ($r^2 = 0.87$) was significantly improved by including the number of dominant sprouts ($r^2 = 0.90$), whereas sprout number did not improve the equation for sycamore ($r^2 = 0.68$). From Fig. 4 it is apparent that the effect of sprout number is more evident for large rootstocks than for smaller ones. Since the sycamore roots were generally smaller than the sweetgum roots, it seems likely that sprout number would also be significant in sycamore equations that included larger rootstocks. Santantonio et. al. (1977) found that the relationship between root system biomass and dbh of trees less than 4 inches dbh displayed considerable variation among species and sites, whereas root systems of larger trees (4 to 20 inches) from a wide variety of species and habitats were relatively constant. Analysis of covariance did not indicate a significant difference ($p < 0.05$) in the relationship of core root mass to sprout basal area for the sweetgum and sycamore in this study.

The percentage of the root system contained in the sampled core root is not known. Leaf et. al, (1971) found 74.2% of the total root weight of 39-year-old plantation grown red pine (*Pinus resinosa* Alt.) within 24 inches of the root collar, and Deans (1981) found 50% of all roots >0.5 cm within 20 inches of 16-year-old Sitka spruce (*Picea sitchensis*). The radius of 12 inches used in this study likely measured substantially less than 50% of the roots. Therefore, estimates of total root-shoot biomass relationships are not possible. However, the percent of total harvested biomass (sprouts, stump, and core root) found in the core root ranged from 20 to 42% in sweetgum and 11 to 50% in sycamore with an average of 29 and 30% for the two species (Table 3). There was no significant difference between the two species ($p < 0.05$).

In summary, it is possible to predict the large root mass of coppiced stands using logarithmic regressions similar to those used for trees with

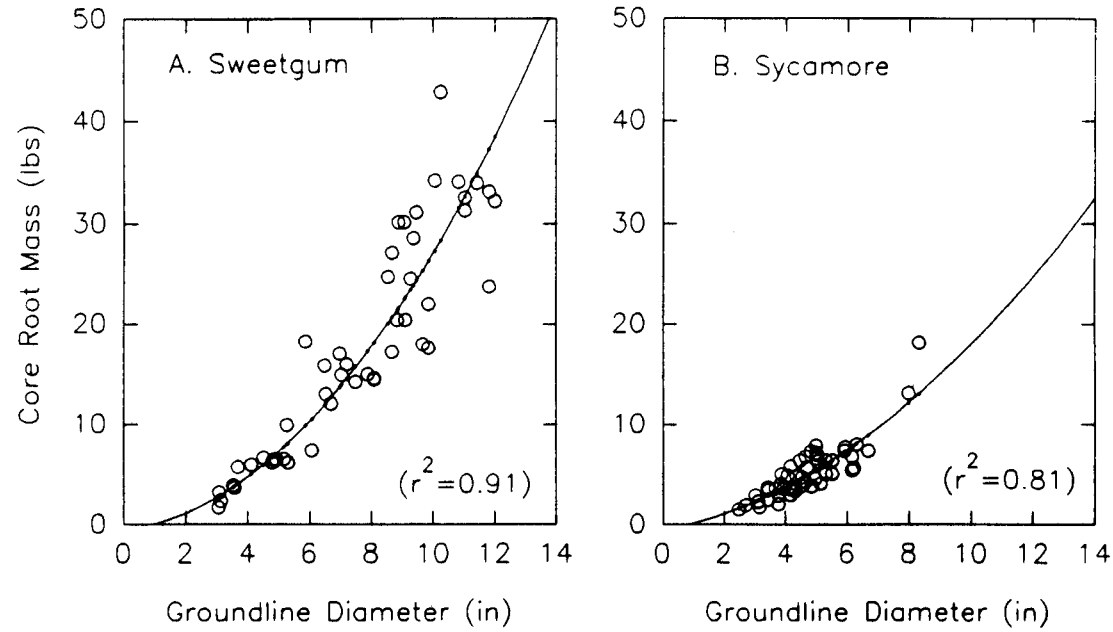

Figure 2. *Relationship of core root mass to the groundline diameter of the rootstock. A. Sweetgum: $\log_{10}(Y) = -0.468 + 1.903\log_{10}(X)$; B. Sycamore: $\log_{10}(Y) = -0.442 + 1.693\log_{10}(X)$.*

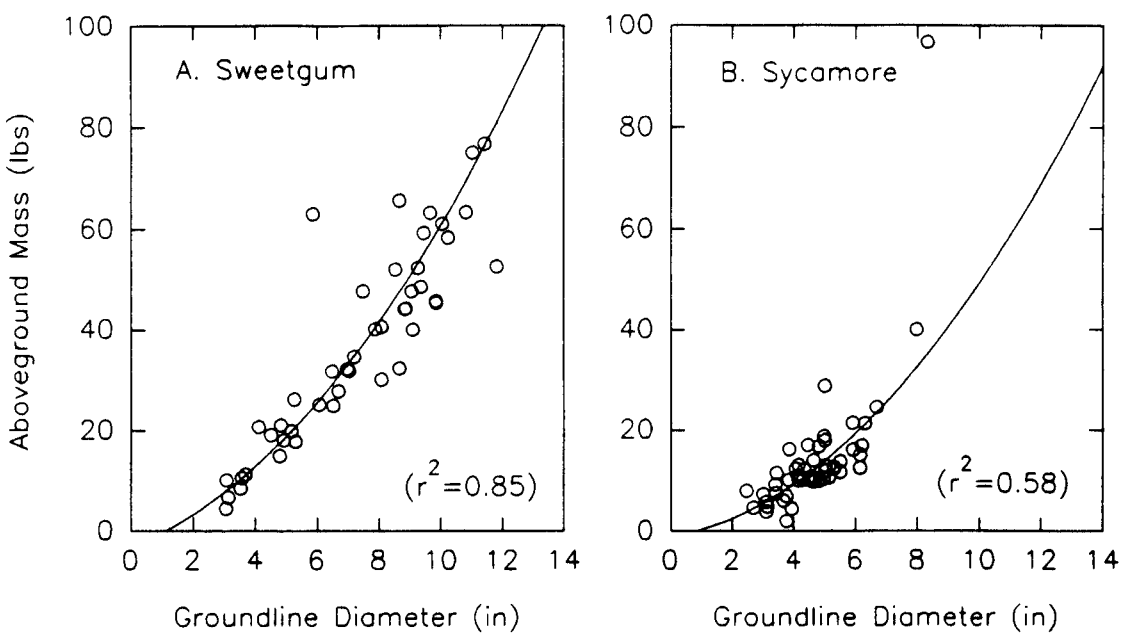

Figure 3. *Relationship of aboveground mass (sprout + stump) to the groundline diameter of the rootstock. A. Sweetgum: $\log_{10}(Y) = 0.078 + 1.706\log_{10}(X)$; B. Sycamore: $\log_{10}(Y) = -0.122 + 1.811\log_{10}(X)$.*

single stems. The relationship may vary among sites, elapsed time since the last harvest, and overall age of the rootstock. In this study, the relationships between above and belowground components were quite similar for sweetgum and sycamore, and may indicate that site factors and cultural practices affect these relationships more than species differences. When trees have multiple stems, regressions based upon basal area of the sprouts are better than those based upon dbh, and inclusion of number of sprouts as a second variable may improve the correlation.

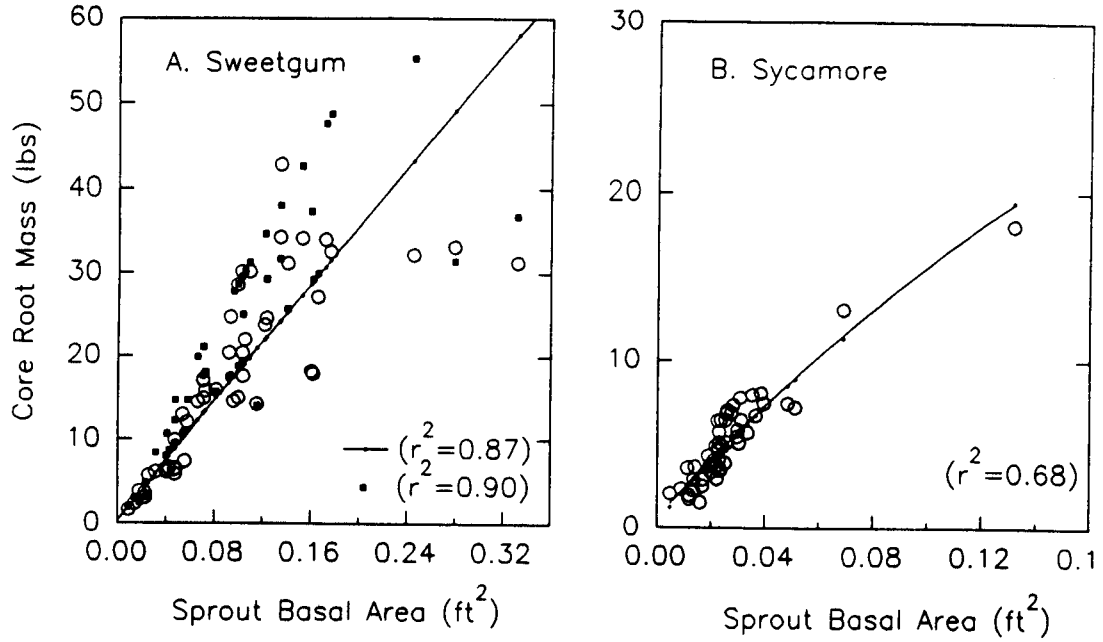

Figure 4. *Relationship of core root mass to the totalsprout basal area at dbh. A. Sweetgum: -•- $log_{10}(Y) = 2.226 + 0.966 log_{10}(X)$; ▪ $log_{10}(Y) = 2.004 + 0.915 log_{10}(X) + 0.621$(number of sprouts); B. Sycamore: $log_{10}(Y) = 2.022 + 0.833 log_{10}(X)$.*

Table 3. *Average core root, stump, sprout and total harvest weight of 12-year-old sweetgum and sycamore grown in the Georgia Coastal Plain and coppiced at age 6.*

Species	Dry Weight (lbs) [1]				Core Root [2] % of Total Harvest
	Core Root	Stump	Sprout (Predicted)	Total	
Sycamore	5.4	2.0	12.8	20.2	28.7
Sweetgum	17.8	5.6	36.2	59.6	29.7

[1] All dry weights varied significantly (.0001) between species (t-test).
[2] Values were not significantly different (.0001) between species (t-test).

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COMPARISONS OF BIOMASS AND NUTRIENT ACCUMULATIONS IN LOBLOLLY AND SHORTLEAF PINES FROM AN UNEVEN-AGED PINE FOREST IN ARKANSAS [1]

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Abstract. Two shortleaf and two loblolly pines from each of the eight 2-inch diameter classes, ranging from 4 to 18 inches, were randomly selected and harvested from a natural, uneven-aged, mixed loblolly-shortleaf pine stand located in Hope, Arkansas. Destructive essay for each of the 32 trees were conducted and partitioned into 7 components: 1- and 2-year-old needles, branch wood, branch bark, dead branches, bolewood, and bole bark. Regression models to predict biomass and nutrient accumulations were developed for each species. In comparison, shortleaf pine accumulated 19% more biomass, 19, 20, 37, and 19 per cent more N, P, Ca, and Mg, respectively, but 12% less K than loblolly pine for trees of equal sizes.

Introduction

A long-term research project to study the site productivity of southern pine forest, a joint effort between campuses of the University of Arkansas System, was initiated in 1975. The study site is located at the Southwest Research and Extension Center Experiment Forest near Hope, in a natural, uneven-aged stand of mixed loblolly (*Pinus taeda* L.) and shortleaf (*Pinus echinata* Mill.) pines. Portions of the area were harvested by clearcutting and planted with genetically improved seedlings. At the same time, undisturbed areas were maintained as control for comparison purposes.

The forests were intensively instrumented in order to obtain quantitative data in soil water chemistry (Wheeler, Ku and Colvin, 1989) and nutrient budget of the ecosystem. Biomass production and nutrient accumulation of the stand has been reported elsewhere (Ku, Wheeler and Colvin, 1991). This paper will report the differences in biomass and nutrient accumulations between the two component species, loblolly and shortleaf pines, in the natural, uneven-aged portion of the research area.

Climate and Physiographic Characteristics

The study area is located at latitude 33°45'N and longitude 93°35'W, 5 miles northeast of Hope, in Hempstead County, southwestern Arkansas. The area has long, hot, humid summers and mild winters. The growing season is long with at least 7 months of the year frost free. The Gulf of Mexico provides a year-round source of moisture with an average annual precipitation of 52 inches.

The soil of the study area, Sacul loam, a Clayey, mixed, thermic Aquic Hapludult was formed in materials derived from unconsolidated sediments of the Upper Western Gulf Coastal Plain. The soil is deep, moderately well-drained that has a slowly permeable clayey subsoil (USDA 1979). Natural fertility of the soil is low but the available water capacity is high. The site index for the soil is fairly good, about 80 feet for loblolly pine at 50 years of age.

Stand Characteristics

This natural, uneven-aged loblolly-shortleaf pine stand had been managed for approximately 30 years on a selection silvicultural system with a five-year cutting cycle to a residue basal area of 70 ft^2/acre. The last harvest occurred three years prior to the commencement of this study in 1977. Prior to the harvest cut in September 1977, the stand inventory revealed the following characteristics: There were 191 stems (4-inch DBH and over) per acre with well developed hardwood understory, 95 ft^2/acre of basal area, and the largest trees were 77 years old. The ratio of loblolly to shortleaf pines in the stand was 2.67:1 in number of stems and 2.57:1 in basal area. This unequal proportionality in species composition was the result of a biased marking system that favored the loblolly over shortleaf pines. Diameter distribution of the stand had a q-value (Daniel, Helms

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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and Baker 1979) of 1.30 with the q-values of loblolly at 1.32 and the shortleaf at 1.27 (Table 1).

Table 1. *Stand Characteristics.*

	Loblolly Pine	Shortleaf Pine	Total	Ratio (L/S)
	——— per acre ———			
Stems	139	52	191	2.67
B.A.(ft^2)	68.67	26.70	95.37	2.57
q-Value	1.32	1.27	1.30	-
Biomass	36.04	15.73	51.77	2.29

Methods and Procedures

Biomass Determination

The aboveground biomass and nutrient contents of the overstory components were determined by destructive sampling. Two trees from each of the two species in each of the eight, 2-inch diameter classes (4 to 18 inches DBH) were randomly selected and cut for total tree analysis. Each of these 32 trees was felled and green weights were obtained in field with a hanging scale for each biomass component of the tree: The crown of each tree was delimbed and separated into upper, middle and lower portions, needles were removed and separated into one-and two-year-old needles, and the entire bole was cut into 1-meter bolts. After gross weighing, a 2-inch disk was cut from the basal portion of each bolt, taken into laboratory and separated into bolebark and bolewood. Subsample of live branches were likewise separated into branch-bark and branch-wood. The above samples of branch-wood and branch-bark, bolewood and bolebark, together with subsamples of dead branches, and 1-year-old and 2-year-old needles from each tree, formed the seven biomass partitions in this study. Since total green weight of each component was obtained in field, subsample from each component was used to determine their moisture contents by drying at 70°F in a walk-in kiln, and then the biomass dry weight of each component was calculated. Subsample from each dried component was used for chemical analysis of the five nutrient elements: Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg).

Chemical Analysis of Biomass

Subsamples from each oven-dried component of the tree were pulverized in a Wiley mill to pass through a 40-mesh screen. These plant tissue samples were dry ashed at 450°C in a muffle furnace and dissolved in 3N HCl, dried on a hot plate, redissolved in 5 ml of 1N HCl and brought up to volume with distilled water. After dilution, concentrations of K, Ca and Mg were determined by atomic absorption spectrometry, and P was determined colorimetrically by the molybdate-vanadate method (Jackson 1958). Nitrogen fractions were determined by the Kjeldahl steam-distillation method (Bremner 1965a).

Statistical Analysis

The least squares method was used to determine the relationship between tree component biomass dry weight and D^2H, a "volume index". Analyses of variance (SAS Institute Inc., 1988) showed significant differences between species in all of the component parts except in the 1-year-old needles and the branch-bark of the sample trees. Regression equations were then developed to predict biomass weights of each component part and the combined weights of crown, bole, and total tree, in the general form,

$$\text{Biomass Dry Weight} = A + B(D^2H)$$

where biomass dry weight was in pounds, DBH (D) in inches, and total height (H) in feet of the sample trees.

In a similar manner, analyses of variance in nutrient concentrations of N, P, K, Ca and Mg showed no significant differences between the various biomass partitions of the two species. However, when nutrient content of each component and the total tree were computed from their respective biomass dry weights and the corresponding nutrient concentration values, various statistical differences were found. Regression equations were then developed to account for the nutrient accumulation in each component and the total tree of the two species.

Results and Discussion

Biomass Accumulation

Regression analysis indicated significant differences between biomass accumulations for the two species in the following attributes: Total tree, bolewood, bolebark, and the bole at $p < 0.01$; 2-year-old needles, live branch-wood and the crown at $p < 0.05$; dead branches at $p < 0.10$ levels of significance; and there were no differences in 1-year-old needles and branch-bark.

Shortleaf pine accumulated a greater amount of biomass: 32% in crown, 13% in bolewood, 41% in bolebark, 15% in bole, and 19% in total tree than

loblolly pine for the entire range of diameter classes (Table 2). These values were derived from an integration procedure across the entire range of DBH classes based on regression equations of the biomass component parts of the two species, assuming that one tree was present in each diameter class for each species.

The stand dry weights of the component parts in 1-year, and 2-year-old needles, branch-wood, branch-bark, dead branches, bolewood, and bolebark were 0.35, 0.38, 1.22, 1.18, 0.76, 10.72 and 1.12 for shortleaf and 0.93, 0.64, 2.80, 3.09, 0.75, 25.44, and 2.39 t/ac for loblolly pine, respectively (Table 3). These in turn amounted to 2, 2, 8, 8, 5, 68, and 7 percent of biomass in loblolly trees; and 2, 2, 8, 8, 2, 71, and 7 percent of biomass in shortleaf trees, respectively. A greater proportion of dead branches and a lesser proportion of bolewood were accumulated in shortleaf than in loblolly pines. Total aboveground merchantable biomass accumulations of stems larger than 4-inch in DBH were 36.04 t/ac for loblolly pine and 15.73 t/ac for shortleaf pine. This amounted to a biomass ratio of 2.29:1, a much reduced value than he 2.67:1 ratio in number of trees or the 2.57:1 ratio in basal area between the two species (Table 1).

Nutrient Accumulations

There were no differences in nutrient concentrations in any of the five elements. However, the 19 per cent greater biomass accumulation for the entire tree in shortleaf pine led to a greater accumulations of N, P, Ca, and Mg at 19, 20, 37, and 19 per cent, respectively, than the loblolly. It is interesting to note that a reversed situation existed in the K accumulations of the two species, as shortleaf accumulated 17% more K in the crown but 27% less in the bole that resulted in a 12 percent less potassium for the entire tree (Table 2).

Nutrient accumulations of the stand in N, P, K, Ca and Mg were 60, 5, 18, 31, and 16 lbs/ac for shortleaf, and 160, 24, 73, 110 and 59 lbs/ac for loblolly pines, respectively (Table 4). The greatest accumulation of each element was found in the bolewood which may easily be explained by its overwhelming mass. On the other hand, the higher concentration of elements in the crown components (branches and needles) would account for the proportionally greater accumulation of those elements in the crown (Table 5).

Impact of Harvest on Nutrient Removal

As in conventional practice today, logging operations to harvest the boles only and to leave the tree tops on site would conserve considerable amount of nutrients in these ecosystems as compared to the whole tree harvest. For the most critical nutrient element, N, a greater amount were accumulated in the crown, 58% for shortleaf and 55% for loblolly pine, than in the bole portion of the trees. Since the crown portion amounted to only 25% of the total aboveground biomass for shortleaf and 23% for loblolly pines, this twenty-five per cent gain in biomass from whole tree harvest would actually be obtained at the expense of more than 31 percent (as in P, K, Ca and Mg) to more than 55 per cent (as in N) additional nutrient removal from the site (Table 5).

Conclusion

The aboveground merchantable biomass production of an uneven-aged, mixed southern pine forest ecosystem in Arkansas was 15.73 for shortleaf and 36.04 t/ac for loblolly pines, with about 25 percent produced in the crown portions and 75 percent in boles for the two species. From regression analysis, shortleaf pines accumulated more biomass: 32% in crown, 15% in bole and 19% in total tree for the trees of equal diameter size classes. Because of this, the ratio between loblolly and shortleaf pines were reduced from 2.67:1 in number of stems and 2.57:1 in basal area to 2.29:1 in biomass accumulation.

There were no significant differences in nutrient concentrations between species. However, nutrient accumulations did differ on account of differences in biomass components between the two species. Shortleaf pine accumulated 19, 20, 37, and 19 per cent more N, P, Ca, and Mg, respectively, but 12 per cent less K than the loblolly pine.

Conventional harvest of boles only would remove about 31-60 percent of the accumulated nutrient elements from site.

Table 2. *Comparison of Biomass and Nutrient Accumulations between Species.*

		Biomass	N	P	K	Ca	Mg
		lbs					
Crown	Sh.L.	9635	44.71	3.56	8.84	20.19	6.69
	Lob.	7324	35.02	2.60	7.54	15.05	6.08
	%	32	28	37	17	34	10
Bolewood	Sh.L.	26119	24.37	2.43	8.58	16.46	11.89
	Lob.	23111	23.26	2.40	12.25	14.18	9.81
	%	13	5	1	−30	16	21
Bolebark	Sh.L.	2562	7.97	0.74	1.85	7.91	2.27
	Lob.	1822	6.65	0.58	2.13	3.30	1.59
	%	41	20	28	−13	140	43
Bole	Sh.L.	28681	32.34	3.17	10.43	24.38	14.15
	Lob.	24933	29.91	2.99	14.38	17.47	11.40
	%	15	8	6	−27	40	24
Tree	Sh.L.	38316	77.06	6.73	19.27	44.56	20.84
	Lob.	32257	64.93	5.59	21.91	32.52	17.48
	%	19	19	20	−12	37	19

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Table 3. *Stand Biomass Accumulation (lbs/acre) by DBH Class and Species.*

DBH (in)	D^2H	No. Trees	1-yr Needles	2-yr Needles	Branch Wood	Branch Bark	Dead Branch	Bole wood	Bole bark	Total
					Shortleaf Pine					
4	686	11	38	23	59	56	36	405	83	700
5	1131	10	43	31	88	85	54	681	106	1088
6	1715	4	22	18	54	51	33	436	58	672
7	2450	2	14	12	38	37	24	322	39	486
8	3353	2	17	17	52	50	32	449	51	668
9	4437	3	32	33	104	100	64	901	97	1331
10	5716	2	26	28	89	86	55	781	82	1147
11	7205	3	47	52	169	162	104	1485	153	2172
12	8918	3	57	64	209	200	129	1846	185	2692
13	10869	2	45	52	170	163	105	1505	150	2190
14	13073	3	81	93	306	294	189	2722	269	3954
15	15543	2	63	74	243	233	150	2162	212	3137
16	18295	2	74	87	286	274	176	2549	249	3695
17	21342	1	42	50	167	160	103	1489	145	2156
18	24699	1	49	58	193	185	119	1725	167	2496
19	28380	1	56	67	222	213	137	1983	191	2869
SUM	---	52	706	759	2449	2349	1510	21441	2239	31453
Tons	---	---	0.35	0.38	1.22	1.18	0.76	10.72	1.12	15.73
					Loblolly Pine					
4	651	30	159	111	186	53	132	1749	372	2761
5	1084	23	137	95	207	122	114	1928	327	2931
6	1655	11	75	52	140	110	62	1294	183	1917
7	2381	10	80	55	175	159	66	1605	197	2337
8	3279	9	84	59	210	209	69	1922	211	2765
9	4363	9	99	69	274	289	81	2498	252	3564
10	5649	7	91	63	272	299	74	2475	234	3509
11	7153	7	108	75	341	385	87	3098	279	4372
12	8891	7	127	88	420	485	102	3816	330	5368
13	10879	5	106	73	365	427	85	3313	278	4648
14	13132	5	123	85	439	520	99	3979	325	5571
15	15666	5	143	99	521	623	115	4728	379	6609
16	18498	2	66	46	246	296	53	2226	175	3107
17	21642	2	76	52	287	347	61	2598	202	3622
18	25114	3	130	90	498	606	104	4512	347	6287
19	28931	1	49	34	191	233	39	1730	132	2408
20	33108	1	56	39	218	268	45	1976	149	2750
21	37660	1	63	43	248	305	50	2245	168	3123
24	53731	1	88	61	353	436	70	3195	236	4439
SUM	---	139	1860	1289	5592	6172	1511	50888	4777	72089
Tons	---	---	0.93	0.64	2.80	3.09	0.75	25.44	2.39	36.04

Table 4. *Stand Biomass and Nutrient Accumulations (lbs/acre) by Components and Species.*

	Biomass	N	P	K	Ca	Mg
	---------- Shortleaf Pine ----------					
1-yr. Needles	706	11.04	0.81	2.35	0.67	0.91
2-yr. Needles	759	10.65	0.77	2.41	0.84	1.01
Branch-Wood	2449	4.51	0.16	1.94	1.20	0.80
Branch-Bark	2349	7.03	0.77	0.59	8.86	1.83
Dead Branches	1510	1.29	0.09	0.88	1.54	0.29
Crown	7773	34.54	2.60	8.16	13.11	4.83
Bolewood	21441	18.41	2.13	9.98	11.04	8.95
Bolebark	2239	6.77	0.64	1.82	7.05	1.94
Bole	23680	25.19	2.77	9.61	18.09	10.89
Total Tree	31453	59.72	5.37	17.76	31.20	15.73
	---------- Loblolly Pine ----------					
1-yr. Needles	1860	29.26	1.93	6.65	1.65	2.35
2-yr. Needles	1289	18.19	1.19	3.89	1.30	1.59
Branch-Wood	5592	11.14	0.50	1.51	3.50	2.61
Branch-Bark	6172	27.14	2.70	8.85	28.98	7.20
Dead Branches	1511	2.70	0.28	0.22	0.75	0.42
Crown	16424	88.42	6.60	21.12	36.18	14.16
Bolewood	50888	52.70	9.63	28.40	32.44	25.38
Bolebark	4777	19.21	1.73	5.88	9.96	4.19
Bole	55665	71.91	11.66	34.28	42.40	29.57
Total Tree	72089	160.33	18.26	55.39	78.58	43.74
SUM	103542	220.05	23.63	73.15	109.78	59.47

Table 5. *Stand Biomass and Nutrient Accumulations in Bole and Crown by Species.*

	Shortleaf Pine				Loblolly Pine			
	Bole		Crown		Bole		Crown	
	lbs/ac	%	lbs/ac	%	lbs/ac	%	lbs/ac	%
Biomass	23680	75	7773	25	55665	77	16424	23
N	25	42	35	58	72	45	88	55
P	2.8	52	2.6	48	11.6	64	6.6	36
K	10	54	8	46	34	62	21	38
Ca	18	58	13	42	42	54	36	46
Mg	11	69	5	31	30	68	14	32

COMPARATIVE FUSIFORM RUST SEVERITY IN LOBLOLLY, LONGLEAF, AND SLASH PINES [1]

C.H. Walkinshaw, R.L. Bryant, and J.P. Barnett [2]

Abstract. Fusiform rust, *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme*, is the most severe disease problem in the southern pine forests. For years, silviculturists have recognized that longleaf pine (*Pinus palustris* Mill.) is less infected by the disease than loblolly (*P. taeda* L.) or slash (*P. elliottii* Engelm. var. *elliottii*) pines. In areas of heavy rust infection, longleaf pine may become infected. In these cases, mortality of longleaf pine is higher than that of either loblolly or slash pine. Both loblolly and slash pine may be severely infected by the disease, but these species differ remarkably in their response. This difference is greatest when a single branch gall grows into the stem of a tree. Loblolly pine usually adapts to such infection and grows productively until the end of the stand rotation. Rust-associated mortality (RAM) in loblolly pine does not rise until four or more galls grow into the stem. In contrast, slash pine may succumb to rust from a single branch gall that has grown into the stem. Data documenting these conclusions are presented and discussed with related greenhouse and microscopic findings.

Introduction

Loblolly (*Pinus Taeda* L.), longleaf (*P. palustris* Mill.), and slash (*P. elliottii* Engelm. var. *elliottii*) pines are the predominant hard pine species in the Southern United States. Loblolly and slash pines are highly susceptible to fusiform rust, *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme*, whereas longleaf pines are rarely infected. Waves of fusiform rust infection occur in the Southern forest from time to time and damage large numbers of loblolly and slash pines (Peterson and Jewell 1968). Weather conditions affect the susceptibility of the developing pine shoots and the production, dissemination, and germination of infecting basidiospores of the pathogen (Froelich 1989).

A disease such as fusiform rust creates major changes in the forest. These changes are the result of large-scale mortality of some species and survival of millions of infected but degraded trees of other species. The wave of infection that occurred during the latter half of the 1970's coincided with large plantings of susceptible slash pines (Goddard and Wells 1977, Shoulders 1976). Shortly thereafter, the species of choice for planting throughout the South shifted to loblolly pine. The shift from slash to loblolly may be altering the natural balance in the pathogen:host relationship. These two species differ in their tolerance to the rust and their capacity to serve as possible reservoirs for rust spores that can initiate new waves of the disease.

The objective of this study was to compare the effects of fusiform rust infection in loblolly, longleaf, and slash pines. The hypothesis was that these pines have different tolerances to fusiform rust and may differ in the number and variety of isolates of the rust fungus that they harbor for 100 years or more.

Materials and Methods

Longleaf Pine

Longleaf pines that were in their second to sixth year of height growth were observed in central Mississippi and northwest Florida. One hundred infected trees were studied in Mississippi and 500 were studied in Florida. Planting spacing was approximately 6 X 6 feet at each location. Observations were made of mortality, presence of galls, gall height, and origin of galls (infected terminal or infected branch). Trees were considered dead when dieback included the lowest branch.

Seedlings of longleaf pines were inoculated with composited field isolates of fusiform rust spores at Gulfport, MS and Asheville, NC. Six months after inoculation the seedlings were read for multiple buds, galls, and mortality. Histological specimens (100 total) were taken from galls, fixed, and processed for

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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light microscopy according to published techniques (Walkinshaw 1978, Walkinshaw and Roland 1990).

Slash Pine

A Jackson County, Florida, planting of slash pine was chosen for this study because fusiform rust infection levels were 95 to 97 percent in nearby commercial pines. The slash test contained five replications of 43 open-pollinated families in 10-tree row plots . Observations were made of mortality, presence and origin of galls (see longleaf), and stem form (straight trees with a single dominant terminal). Other observations were reported earlier (Walkinshaw 1987). Readings in this planting were made yearly between ages 5 and 13. Slash pine seedlings from 21 of the 43 open-pollinated families plus a large number of USDA Forest Service families were inoculated with rust spores and sampled as described for longleaf pines.

Loblolly Pine

The loblolly pine planting is adjacent to the slash pine test in Jackson County. The loblolly test contained four replications of 49 control-pollinated crosses among 22 parents in 10-tree row plots. Observations were made of mortality, presence and origin of galls, and number of galls growing into stems. Observations were made between ages 4 and 17.

Seedlings were inoculated with rust spores, sampled, and read in greenhouse tests. A variety of symptoms were used to characterize the disease in these seedlings.

When it became apparent that infected loblolly pine responded differently from longleaf and slash pines, a number of commercial stands were observed. The results from stands were based on random rows of 25 trees sampled along secondary roads in Florida and Mississippi.

Results

Responses Common to the Three Species

Infection of terminal shoots in field or greenhouse seedlings killed seedlings of all three species by girdling stems within two growing seasons. These seedlings decayed rapidly in the field and left little residue after 3 to 5 years. Approximately 2 to 5 percent of the seedlings in the slash and loblolly pine tests died from this early rust-associated mortality (RAM).

Mortality of pines that are older than 3 years is influenced by availability of inoculum from oaks, weather, shoot physiology, and location of galls in the tree. Approximate mortality rates at some steps in the pathway are given in figure 1.

Longleaf Pine

More than 68 percent of the galls on longleaf pine in the field originated in the large-diameter terminal shoot. There was an average of 2.2 galls per tree with as many as 8 on some. On infected branches 90 percent of the galls were within 12 inches of the stem. Stems on trees with galls were straight, and no multiple stems were observed. Galls on stems grew to 16 to 36 inches long and killed the tree by dieback within 2 to 4 years. Breakage of stems at the gall left the residual stems without foliage. When galls grew from branches to stems, cankers formed with little swelling in the stem.

Field infections in longleaf pine accompanied heavy infections of slash and loblolly pine. The percentages of trees with galls in the Florida site were 92 and 95 for slash and loblolly pine, respectively.

Longleaf pine seedlings that were inoculated in the greenhouse formed large galls at the soil line and multiple buds. Mortality was approximately 20 percent at time of observation. Necrosis, tissue disorientation, and numerous rust hyphae were seen under the microscope. Some galls had a greatly enlarged cortex. These tissue changes were noted in both select and wild open-pollinated families.

Slash Pine

The large variation in susceptibility of slash pine families was useful to sort out response to the rust at the Jackson County site. The relationship between infection at 4 years and rust associated mortality at 9 years is important ($r^2 = 0.69$, Table 1). The association between infection and healthy trees is $r^2 = 0.79$. These values are highly significant ($P = 0.001$).

An equally valuable inverse relationship for the 43 families existed between mortality and normal stems ($r^2 = 0.65$). Family means of normal stems ranged from 31 to 97 percent.

Mortality was not related to the number of branch galls that entered the stem. One gall appeared adequate to kill the tree.

Greenhouse seedlings that were inoculated with a composite of spores had numerous areas of necrosis in their cortex. Bark that was normally

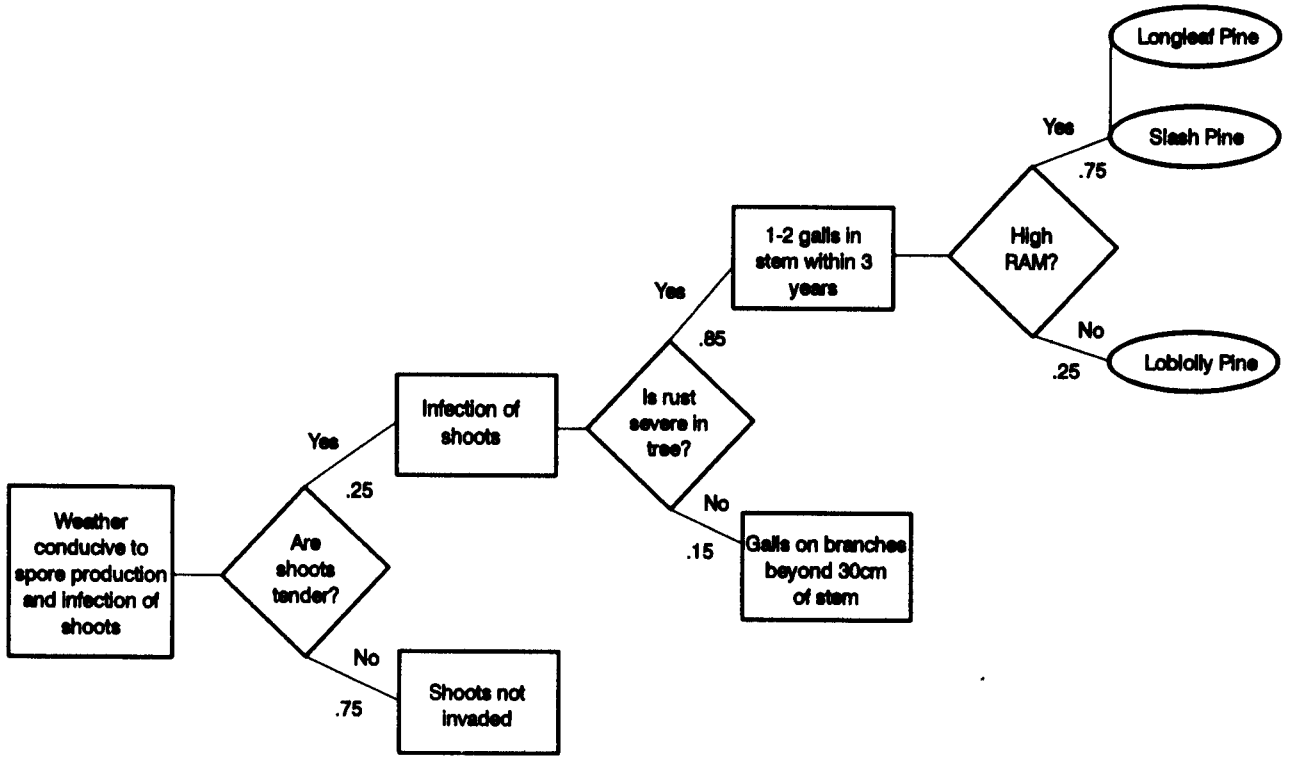

Figure 1. *Estimated proportions for events leading to mortality of hard pines to fusiform rust.*

absent in healthy seedlings was plentiful in galled seedlings. Seedlings had high mortality after 1 year in a shadehouse.

Loblolly Pine

Mortality in loblolly pine was lower than in adjacent slash pine and was not related to infection at age 4 (r^2 = 0.24, table 2). The 49 crosses were significantly different in the percentage of trees that died by 12 years (P = 0.009).

Of the 90 percent infection in this test, nearly all was due to branch galls that grew into the stem 3 to 6 feet from the soil line. The range of values across replications for families was 2.4 to 10 galls per tree. Intact dead trees in the stand had 4 to 15 branch galls that grew into the stem.

Loblolly pine seedlings in greenhouse inoculations had galls that were fat (twice the normal diameter), lacked bark, and produced adventitious shoots at the gall. Nearly all the families had a high percentage of seedlings with galls. Specimens from these galls contain numerous fungal hyphae and a minimum of disorganized tissue.

Discussion

Results presented in this paper support our hypothesis that the response of loblolly pine differs from that of longleaf and slash pine. Moveover, our results confirm and extend the findings of Powers (1975), Sluder (1977), and Wakeley (1969). Sluder's recent studies on crosses of loblolly and slash pine further stress the differences in the performances of these two species in plantations (Sluder 1989). Also, it is interesting to note that slash pine had high rust mortality in the Southwide Pine Seed Source Study (Henry 1959). Longleaf and slash pine galls degenerate within a few years and fail to produce spores. Many dead longleaf and slash pines had a single gall in their stem. Histological observations showed the tendency for infected tissues of these species to die. This response of longleaf and slash pines weakens the pathogen's chance to survive in the absence of infected loblolly pines.

Prediction of slash pine mortality from a number of traits is not difficult (Walkinshaw 1987). A model has been published (Nance and others 1982).

Table 1. Percentage of infection and rust-associated mortality (RAM) in slash pines Jackson County, FL.*

Pine family	Infection at age 4 (%)	RAM at age 4 (%)	RAM at age 9 (%)	Healthy at age 13 (%)
C-71	44	0	15	60
25-61	34	13	16	58
M-601	61	19	39	40
C-213	55	16	27	40
C-108	67	34	44	28
UC	70	20	30	27
262-55	85	50	79	21
282-55	94	52	68	21
32-59	79	25	29	14
26-61	84	0	55	14
100-57	68	32	46	12
121-56	100	55	84	8
317-56	97	45	68	7
M305	91	39	50	5
14-56	86	33	48	0
103-60	91	23	48	0

* Means of five replications of 10 trees. Healthy values were means of only two or three replications due to the poor condition of replications four and five.

Table 2. *Percentage of infection and rust-associated mortality (RAM) of loblolly pines in Jackson County, FL.@*

Pine cross	Infection at age 4	RAM at age 12	Healthy at age 12
	- - - - - - - Percentage of the trees that survived planting - - - - - -		
3-2 X 1-14	77	28	12
3-2 X 1-64	84	26	10
3-2 X 7-2	78	21	3
3-2 X 7-34	79	24	3
3-2 X 7-56	76	16	5
3-2 X 12-13	78	22	6
3-8 X 1-14	56	14	6
3-8 X 1-64	69	31	10
3-8 X 7-2	64	6	11
3-8 X 7-34	76	18	10
3-8 X 7-56	78	10	8
3-8 X 12-13	78	20	0
3-36 X 1-14	63	17	13
3-36 X 1-64	53	15	23
3-36 X 7-2	50	11	19
3-36 X 7-34	67	16	17
3-36 X 7-56	60	5	14
3-36 X 12-13	67	24	8

@ Means of four replications of 10 trees. Infection rose to 100 percent for many crosses after 12 years. RAM was not significant at age 4.

Such models appear to function because there is a direct relationship between the event of infection and mortality. This was not the case for loblolly pine.

Loblolly pines can tolerate as many as four galls that grow to the stem (Walkinshaw 1989). Trees in the Jackson County test lived almost 10 years with

4 to 15 such galls. This ability to tolerate the pathogen was evident in the large greenhouse galls with limited necrosis. Planting loblolly pines on sites where the rust hazard is high appears to ensure the survival of the host and pathogen. Adult trees in most loblolly sites have one gall per stem. These galls can remain active for decades.

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EFFECT OF GENETIC IMPROVEMENT AND VEGETATION CONTROL ON LOBLOLLY AND SLASH PINE PLANTATIONS AFTER THREE GROWING SEASONS [1]

Barry D. Shiver and John W. Rheney [2]

Abstract. A study was established in 1986-87 to evaluate the effect of genetic improvement and vegetation control on growth and yield of loblolly (*Pinus taeda* L.) and slash (*Pinus elliottii* Engelm.) pine plantations from large plots rather than from progeny tests. Separate studies were established for coastal plain loblolly, piedmont loblolly, and coastal plain slash pine. Gains in both dbh and total height from genetic improvement were statistically significant ($\alpha = .05$) for loblolly pine for both regions. Gains from genetic improvement were not significant for slash pine for either variable. Vegetation control resulted in significant increases in dbh and total height for all species and regions. In addition, use of vegetation control with genetic improvement resulted in a synergistic effect so that the total gain from this treatment was more than the additive effect of genetic improvement or vegetation control alone. The synergism was particularly evident in slash pine where no gains from genetics were obtained without vegetation control. There were only small differences in average cronartium infection across treatments.

Introduction

Foresters have been intrigued for decades with the idea of breeding trees with superior growth, form, wood quality, and disease resistance characteristics. State and federal agencies and private companies have cooperated since the 1950's with the goal of developing "super trees" which would increase yields per acre for the southern pines. Evidence from progeny test results indicates that this effort has largely been a success for loblolly and slash pines (Hodge et al 1989, Talbert et al 1985) with volume gains ranging from 7% to 19%.

As first generation seed orchards and rogued first generation seed orchards came into full production in the 1970's, virtually all seedlings planted on corporate lands were genetically improved. Unfortunately, most of the growth and yield models in use were developed from plantations planted with either unimproved or marginally improved seedlings. Growth and yield models are used extensively by forest industry to plan for future wood supplies. Progeny tests are typically planted as single row plots and concerns have been raised regarding the appropriateness of using percentage gains from progeny tests to adjust growth and yield models. In addition, progeny tests often receive different cultural treatments such as mowing and fertilization than operational plantations and these treatments may affect yields (Cooper and Ferguson 1977, Duba et al, 1984). Finally modern growth and yield systems produce outputs of stand structure from which yields by product class can be estimated. It is impossible to obtain stand structure estimates from row plots.

In an attempt to answer some of these questions, the Plantation Management Research Cooperative[3] (PMRC) of the Daniel B. Warnell School of Forest Resources at the University of Georgia installed a study in 1986-87 with the following objectives:

(1) evaluate the impact of genetic improvement on yields for planning purposes.
(2) evaluate the impact on yields of combining genetic improvement and vegetation control.
(3) evaluate single family genetically improved plantations versus bulk lot genetically improved plantations.

Yields as used here refers not only to total volume or weight, but also to stand structure and variability. Of particular interest will be the product breakdown and the range and skewness of the diameter distribution.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Associate Professor and Research Coordinator, University of Georgia, Athens, GA.

[3] 1992 Members include Boise Cascade, Champion Internaitonal Corp., Gilman Paper Co., Inland-Rome Inc., ITT Rayonier Inc., James River Timber Corp., JSC/CCA, Kimberly-Clark Corp., MacMillan-Bloedel Ind., Packaging Corp. of America, Procter & Gamble Cellulose, Union Camp Corp., University of Georgia Daniel B. Warnell School of Forest Resources.

Results of the study should indicate how to develop yield models for genetically improved planting stock.

Methods

The study was established over Georgia, Alabama, western South Carolina and north Florida. The study area was divided into two physiographic regions, piedmont and coastal plain. The overall study actually consists of three separate studies -- piedmont loblolly, coastal plain loblolly, and coastal plain slash. The PMRC membership was polled to determine each of their top 10 families from their tree improvement programs by species and region. Those results were compiled and the top six families were tentatively scheduled for inclusion in the study. The loblolly families were checked by North Carolina State University-Industry Cooperative Tree Improvement Program personnel who evaluated the rankings and provided input. Slash families were similarly evaluated by Cooperative Forest Genetics Research Program personnel at the University of Florida. The families[4] chosen for inclusion in the study by species and region are presented below:

Coastal Plain Loblolly	Piedmont Loblolly	Coastal Plain Slash
7-34	12-12	106-56
10-5	5-5	6-56
17-5	12-9	35-60
10-25	12-7	56-56
7-56	1-14	261-56
7-2	15-42	187-57

In addition to these genetically improved families, unimproved seed was obtained from International Forest Seed in Birmingham, AL. This unimproved seed was obtained in the same regions encompassed by the study and was not obtained from either seed orchards or seed production areas. There were three separate lots of unimproved seed corresponding to the three regions/species combinations included in the study.

Six treatments were included in the study:

(1) Unimproved stock, No vegetation control
(2) Unimproved stock, complete vegetation control
(3) Bulk lot improved stock, no vegetation control
(4) Bulk lot improved stock, complete vegetation control
(5) Single family improved stock, no vegetation control
(6) Single family improved stock, complete vegetation control

Each cooperator contributed open pollinated seed for each of the families included in their region. Seedlings were all grown in the Union Camp Corporation nursery at Belleville, GA. For each species/region combination a portion of the seed from families included were mixed together to form an improved bulk lot. In addition a portion of each family was held back and grown in the nursery beds as single family plantings.

Fifty locations of the study were established with 15 piedmont loblolly, 16 coastal plain loblolly, and 19 coastal plain slash pine locations. At each location, treatments 1-4 were established and one of these treatments was randomly selected for replication. In addition treatments 5 and 6 were established and one of these two treatments was randomly selected for replication. In total there were 8 plots at each location. Locations were treated as reps in the experiment. The replication at a location represented an attempt to quantify the within location error.

Each plot was 0.4 acres in size with a 0.2 acre measurement plot. Seedlings were hand-lifted in January and planted the same week they were lifted at a density of 700-750 per acre. The vegetation control treatments (2, 4, and 6) were imposed over whatever operational site preparation treatments were chosen by the cooperator. Control was maintained by killing woody vegetation with herbicides before planting and by spraying Oust in early spring of each growing season followed by directed sprays of glyphosate as needed during the growing season. The necessity for these treatments declined markedly after the second growing season as planted pines captured the site.

After three growing seasons, every other pine on the measurement plots was tagged and measured for dbh (0.1 in.) and total height (ft.). Evidence of stem galls of fusiform rust (*Cronartium fusiforme* Hedge. and Hunt) were noted.

Results and Conclusions

Genetic improvement resulted in an average height of 6.1 ft. as compared to 5.3 ft. for unimproved planting stock for piedmont loblolly pine.

[4] Family identification numbers are those of their respective cooperative.

Vegetation control resulted in an average height of 7.1 ft. versus 5.3 ft. for no vegetation control. Both genetic improvement and vegetation control were statistically significant factors (α = .05) for average height.

For coastal plain loblolly pine both genetic improvement and vegetation control were again statistically significant factors. Genetic improvement resulted in an average height of 6.5 ft. versus 6.1 for unimproved and vegetation control resulted in an average height of 8.1 compared to 6.1 for no vegetation control.

Genetic improvement was not a statistically significant factor for average height of slash pine (6.4 ft. versus 6.3 ft.). Vegetation control (7.7 ft.) was a statistically significant factor for average height compared to no vegetation control (6.3 ft.).

For both species and in all three regions there was a significant interaction between genetic improvement and vegetation control for average height (Table 1) and average dbh (Table 2). The reason for the interaction is that the effect of using both vegetation control and genetic improvement is always larger (average height and average dbh) that the sum of either treatment in isolation. There is a synergistic effect of genetic improvement and vegetation control.

These plots are still very young (three years old) to evaluate the impacts of treatments on stand structure. The only treatment which had any impact on variability as measured by coefficient of variation was vegetation control. Single family plots had coefficients of variation similar to bulk lot improved for both average height and average dbh.

In addition, the average of single family plots by species and region was virtually identical to the average of bulk lot improved plots for average height and average dbh. There were no clear trends in cronartium infection percentage across any treatments.

These plots are only three years old, but already they are increasing our knowledge of how genetically improved plots should compare to unimproved plots. Even though future generations of genetically improved plots will probably increase growth rates and disease resistance over current improved stock, the methodology of how to handle improved planting stock in our growth and yield models should still be applicable.

Table 1. *Increase in third year average height (ft.) from genetic improvement, vegetation control, and both genetic improvement and vegetation control.*

	Piedmont Loblolly	Coastal Plain Loblolly	Coastal Plain Slash
Genetic Improvement	0.8	0.4	0.1
Vegetation Control	1.8	2.0	1.4
Sum	2.6	2.4	1.5
Both	2.8	2.7	2.5

Table 2. *Increase in third year average dbh (in.) from genetic improvement, vegetation control, and both genetic improvement and vegetation control.*

	Piedmont Loblolly	Coastal Plain Loblolly	Coastal Plain Slash
Genetic Improvement	0.17	0.08	0.02
Vegetation Control	0.47	0.49	0.41
Sum	0.64	0.57	0.43
Both	0.74	0.67	0.64

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Regeneration

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USE OF SUPPLEMENTAL CO_2 FOR GREENHOUSE PRODUCTION OF CONTAINER LOBLOLLY PINE SEEDLINGS: APPRAISAL OF COSTS AND SEEDLING GROWTH [1]

G.A. Hernandez and A.E. Miller [2]

Abstract. Carbon dioxide enriched air was used during growth of young loblolly pine seedlings at the State Forestry Commission greenhouse container production facility near Wedgefield, SC. One greenhouse received 1,000 ppm CO_2 from commercial generators (propane fuel) and was compared with another adjacent alike greenhouse having ambient CO_2 in outdoor air (340 ppm control). During the first winter crop, climatic factors (low light and warm temperatures) and a manually operated CO_2 generator system reduced potential treatment by 65 percent. Still, treated seedling stem height and diameter, and root, shoot, and total dry weight ranged from 5 to 20 percent greater than control seedlings at the end of the 24 week growth period. Final size of the untreated seedlings showed that crop production time could be reduced 4 weeks sooner with CO_2 enrichment when the same size occurred earlier in the treated seedlings. Marginal cost for CO_2 enrichment were recovered if greenhouse operation was reduced by four weeks. Growth response and costs were similar for the second winter trial. A third winter growth trial is planned.

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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INTEGRATION OF NURSERY PRACTICES WITH SITE PREPARATION [1]

Philip D. Schrock, David B. South, and Robert J. Mitchell [2]

Abstract. Successful regeneration of pine plantations should be defined by the economic returns on the investment rather than on how clean, uniform, or fast growing (per se) the stand appears at a particular age. Many foresters now realize that maximum volume production does not equate to maximum return on investment. However, the practice of efficiently spending a limited budget on the most economical regeneration practices requires a basic understanding of important biological interactions. Unfortunately, researchers in the past have usually concentrated on main effects.

We propose that studies be established to investigate the potential interactions among seedling diameter, weed control and other silvicultural practices. This may provide a better understanding of the opportunities for reducing regeneration costs by substituting competitive seedlings rather than applying a high level of site preparation with marginal seedlings. It may be possible to reduce the total amount invested while maintaining acceptable growth. Secondly, seedling size may play an important role in realizing acceptable rates of return on those sites in which intensive management is economically feasible.

Introduction

Some have suggested that improvements in seedling morphology will result in interactions between the planted seedling and the site (Fry and Poole 1980). In New Zealand, researchers have examined interactions between seedling size and site preparation methods (Albert et al. 1980; Balneaves 1989; Baker and Ledgard 1991). Seedling morphology in New Zealand is often defined using root-collar diameter (RCD). Conifer seedlings with RCDs as large as 10 mm have been tested (Baker and Ledgard 1991).

In the southern United States (US), researchers have conducted numerous site preparation studies or seedling quality studies but only a few have been aimed at predicting the relationship between seedling size and site preparation treatments (Mitchell et al. 1988; Britt et al. 1991). In many cases, seedling quality studies were conducted with just one site preparation treatment. Likewise, researchers in the South often fail to document the mean RCD used in site preparation studies. In many studies with loblolly pine, the mean RCD at planting would be approximately 3.5 mm.

This paper gives the authors' perspective regarding some important questions that need to be addressed if pine regeneration is to be viewed as an entire process rather than a series of steps in isolation. We believe that optimizing regeneration systems will require that the economic performance of the stand be the criterion by which systems are evaluated rather than examining the additional costs of certain items. Furthermore, we believe there is an opportunity to improve the financial performance of investing in regeneration (largely by reducing costs while maintaining growth). Costs may be reduced by investing in seedling morphology in ways that have yet to be adequately addressed in the southern US.

Seedling Quality

Willen and Sutton (1980) defined the quality of planting stock as "the degree to which that stock realizes the objectives of management (to the end of the rotation or achievement of specified sought benefits) at minimum cost." Although this definition is often cited, many researchers do not define the objectives of management nor do they discuss costs involved in increasing seedling performance. Minimum performance standards are rarely mentioned when researchers describe the attributes of a quality seedling. An exception is one study where minimum standards for survival and growth were set for longleaf pine (Hatchell and Muse 1990).

In general, the criteria for the optimum seedling will depend on the standards set by management. When the goals of management are

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minimal, the criteria for what is an acceptable seedling will also be low. Minimum characteristics for a plantable seedling will be low if the goal is only to produce seedlings that will survive transplanting and are easily hand planted. For example, in the past, good survival of longleaf pine was the primary basis for evaluating seedling quality. Therefore, due to differences in survival, seedlings with 10 mm RCDs were judged "inferior" to seedlings with 5 mm RCDs (Wakeley 1949). As a result, the minimum RCD for a plantable bare-root seeding was set at only 4.7 mm (Wakeley 1954). In contrast, when the goal of management was increased to include growth after outplanting, the criteria for an acceptable longleaf pine seedling was increased to 10 to 12 mm RCD (White 1981; May 1984). Therefore, the definition of a quality seedling can depend on whether or not management sets a standard for acceptable growth after transplanting.

In some cases, the characteristics of an optimum seedling are determined by opinion rather than on field performance. For example, presence of a winter bud is often listed as a characteristic for the optimum slash pine seedling. The reason why a terminal bud is considered important for slash pine is unclear but can be traced back to the 1930's (Wakeley 1935). However, Wakeley was unable to show any effect on either survival or early growth when he tested the hypothesis that, independent of seedling diameter, the terminal bud of slash pine affects field performance (Wakeley 1949). Despite these results, some researchers still contend that a terminal bud for slash pine is an important seedling characteristic. As a result, one nursery in 1991 lost over $150,000 in revenue because they were told to cull plantable slash pine seedlings that did not have a terminal bud. The reason we mention this is to illustrate that in the southern US seedling quality, is to some extent, in the eye of the beholder.

The objectives of pine management differ between the southern US and New Zealand. In the southern US, a common management objective is to produce a high volume of pulpwood in a 25 year rotation. In order to reduce the risk of a planting failure, a high number of seedlings are planted per hectare (often more than 1,500 trees per hectare (TPH)). Some researchers have suggested that when initial survival is 85%, 3,200 seedlings can be planted per hectare (Bailey 1986; Borders et al. 1991). When planting this many seedlings per hectare, there is not much economic justification to improving seedling performance (Caulfield et al. 1992; South 1993). This may help to explain why the RCD limit for culling bareroot slash pine and loblolly pine seedlings is only 3 mm (Mexal and South 1991).

In contrast, management in New Zealand is mostly for solid wood production. Therefore, a greater emphasis is placed on obtaining high seedling survival. For clear wood regimes, the national average initial stocking is now less than 1000 TPH (Arnold and New 1991). To make efficient use of valuable genetic stock, some suggest planting as low as 500 to 800 TPH (Wilcox and Carson 1991; Arnold and New 1991). As a result, seedlings with RCDs below 4 mm are usually culled (FRI 1988). It is generally believed that a RCD of at least 5 mm should guarantee good survival on most sites in New Zealand. However, harsher, frosty sites may require seedlings with diameters greater than 6 mm (FRI 1988). On mountain sites, Douglas-fir seedlings with diameters of 8 to 10 mm are recommended (Baker and Ledgard 1991). In addition to the management objective of achieving high survival, there is the belief that seedling size at planting influences the time required for a tree to reach a merchantable size (Fry and Poole 1980). Some estimate that use of large-diameter seedlings can shorten stand development of southern pines by one to two years (South 1993).

Due to differences in management objectives, "large" diameter bareroot seedlings are favored in New Zealand but not by many managers in the southern US. In the South, some managers consider 6 mm RCD seedlings as being "too large" or too expensive to plant. Since there are no studies with slash pine seedlings greater than 6 mm RCD, we wondered how seedlings up to 12 mm would perform under a variety of site preparation alternatives.

Economic Justification

Data with Douglas-fir suggest that 6.5 mm seedlings reach a height of 8 m approximately 0.6 to 3.7 years ahead of 3.5 mm seedlings (Blake et al. 1989). If a 1 to 4 year gain in stand development could also be achieved with the use of large diameter pine seedlings, then the potential economic value can be calculated with a growth and yield program. The NCSU plantation management simulator was used to determine the volume gain achieved with a 1 to 4 year stand advance and no reduction in rotation age. Data presented in Table 1 suggest that the economic gains are greater when the additional volume is captured early and if the plantation is on a high quality site.

Table 1. *Projected merchantable volume gains by achieving a one to four year advance in stand development and subsequent gains in present value from planting stock capable of achieving such gains.*

Site index 25 yr	Stand age	Year Advance							
		1	2	3	4	1	2	3	4
m		----------m^3/ha----------				$ gains/1000 seedlings			
15									
	15	8.4	17.5	27.3	37.1	30	62	97	133
	20	9.8	18.9	28.7	37.8	26	50	77	101
	25	8.4	16.8	24.5	32.2	17	33	49	64
	30	6.3	11.9	17.5	22.4	9	18	26	33
18									
	15	13.3	27.3	41.3	55.3	47	97	148	198
	20	13.3	26.6	38.5	50.4	35	71	103	134
	25	10.5	20.3	30.1	38.3	21	40	60	77
	30	7.0	14.0	20.3	25.2	10	21	30	37
21									
	15	18.2	37.1	55.3	72.8	65	132	198	260
	20	16.8	32.9	46.9	62.3	45	88	127	166
	25	12.6	24.5	35.0	45.5	25	49	70	91
	30	8.4	16.1	22.4	28.7	12	24	33	43

Volume gain calculated from the North Carolina State University Plantation Management Simulator for 1,235 trees per hectare. Economic gains assume a 6% real interest rate and a stumpage value of $10.60 per m^3.

Although not exact, the volume gain resulting from a 4 year advance is about 4 times that of a 1 year advance. If we assume the relationship between seedling diameter at planting and volume production/ha in 15 to 30 years is linear, then one might assume that a 2 mm increase in average diameter would equate to a 1 year advance in stand development and an 8 mm increase would equate to a 4 year increase. Assuming an average seedling size of 3.5 mm (Boyer and South 1988), a 5.5 mm seedling would advance stand development one year. If the effect was linear, we would also expect a 4 year gain from a 11.5 mm seedling. One study suggests that the relationship is linear for loblolly pine seedlings up to 7 mm (South et al. 1989). However, there are no reported studies with either loblolly or slash pine that use seedlings with RCDs as large as 11.5 mm (Table 2). Therefore, we need to establish studies to determine if the relationship will be linear or curvilinear over a sufficiently wide range of seedling diameters.

If it costs $30/thousand to produce seedlings averaging 3.5 mm in diameter, then we could expect to pay no more than $164/thousand ($30 + $134 from Table 1) for 11.5 mm seedlings (assuming these seedlings would give a 4 year gain and would be machine planted on a site [site index 18 m; base age 25] that received the same level of site preparation as 3.5 mm seedlings; and the final harvest would be at age 20). However, to date, there are no reported studies for loblolly or slash pine to demonstrate that planting 11.5 mm seedlings will result in a growth equivalent to a 4 year jump ahead of that resulting from planting 3.5 mm seedlings.

Edward Munns recommended to "Always extend your experimental treatments beyond the extremes of present economic feasibility, in both directions. That's the way to get the essential biologic facts, and to be informed in time to cope with economic change" (Wakeley 1978). Nursery researchers in the southern US have been reluctant to follow these recommendations. Seedling grade studies usually involve a narrow range of diameters (Table 2). This results because a large number of seedlings with 7 mm RCD or greater are usually not available from nurseries in the southern US. An exception is for longleaf pine where seedling diameters as large as 21 mm have been tested (Lauer 1987).

Despite the fact that 10 to 14 mm seedlings of longleaf pine are machine planted each year, some researchers suggest that pine seedlings with 10 mm or 11 mm diameters would be too difficult to plant with

most tree planting machines and therefore would not be practical on an operational scale. The economical justifications often cited for using small diameter seedlings include lower costs for seedling production, transportation, and planting. However, the potential economic gains from improving growth are usually ignored.

Many believe that 4 mm slash pine seedlings will survive and grow as well as 10 mm seedlings. This belief has not been challenged and therefore research in the southern US has been aimed at increasing growth with other silvicultural treatments such as mechanical site preparation, fertilization, and weed control. However, these practices may be more expensive when compared to improving seedling morphology as a means of increasing the rate of stand establishment.

Site Preparation

A number of silvicultural options are used to encourage pine production including bedding, herbaceous weed control, and fertilization. Each practice has unique effects on plantation performance. Some researches have investigated interactions among certain silvicultural treatments (Jokela et al. 1991). Such interactions can stem from a number of mechanisms. For instance, if nitrogen is limited, adding nitrogen to the site may result in increased pine growth. However, due to the extensive root system of herbaceous plants and their rapid and vigorous response to fertilization, nitrogen additions without control of herbaceous competitors may result in capturing only a small portion of the potential response. In other examples, there may be no interaction between treatments, and the gains from fertilization with phosphorus and bedding may simply be additive (Gent et al. 1986).

Little work has looked into the efficacy of single versus double bedding. Mann and McGilvray (1974) reported that at age 8, single bedding increased slash pine height growth by approximately 0.3 m on wet sites. However, double bedding on the same site resulted in a 4.2 m increase. Furthermore, as the sites become drier, the gains due to bedding diminished. Thus the interaction among treatments may be a function of the site. Before these considerations can be integrated into management in a rational, and predictive sense, a fundamental understanding of the manner in which silvicultural options influence growth and development of pine is needed.

This is equally true for the interaction of nursery management and silviculture. Although some have speculated that an inherent interaction between silviculture, site quality and seedling quality is to be expected (Sutton 1979; Fry and Poole 1980), in the few studies that have looked into this aspect, the effects appear to be additive (Mitchell et al. 1988, Britt et al. 1991, Balneaves 1989). When RCD is the basis for evaluating seedling quality, we have not observed any changes in seedling rank due to differences in site or site preparation treatment. However much work is yet to be done.

The influence of nursery and silvicultural treatments may be manifested in either survival and/or growth responses. Yet, these two attributes may respond to treatments differently. For instance, before mortality is realized, a threshold level of stress, particularly during seedling establishment, is required. Thus on some sites growth responses to a particular treatment may always be found, but survival would only be found during dry years. This may be a particularly important observation when one attempts to anticipate potential responses of various seedling types to fall planting.

Planting Date

Planting in early fall (October and November) may increase pine growth during the following year. The growth response to early fall planting appears to be much stronger in the southern portion of the range of loblolly than in northern areas such as Virginia. This may be due to differences in soil temperatures during winter months. Dramatic root growth can occur between October and March if the soil is warm and moist. However, October is the time of the year in which frequent drought periods are encountered. Due to this constraint, most southern pines are operationally planted during the winter months (January and February) when the probability of favorable soil moisture is high, and the risk of failure due to poor survival is sufficiently low. However, seedling mortality is not equally distributed among seedling types. As seedlings diameter increases, probability of survival is likely to increase (South et al. 1989). Thus, large diameter seedlings are likely to have greater probability of success in fall plantings but may not have any influence on survival in winter plantings (i.e. all seedlings survive well). The extent to which this hypothesis (Figure 1) holds true awaits field testing.

Table 2. The range of root-collar diameters of southern pine seedlings tested by various researchers.

Study	species	diameter range (mm)
		1 2 3 4 5 6 7 8 9 10 11 12
Meekins 1964	taeda	<------->
Silker 1960	elliottii	<---------->
Bethun and Langdon 1966	var densa	<---------->
Wakeley 1949	elliottii	<---------->
Clark and Phares 1961	echinata	<------->
Blair and Cech 1974	elliottii	<--------->
South et al. 1985	taeda	<--------->
Burns and Brendemuehl 1971	elliottii	<---------->
South et al. 1989	taeda	<---------->
Shiver et al. 1990	taeda	<---------->
Bacon et al. 1979	elliottii	<---------->
Shoulders 1961	elliottii	<---------->

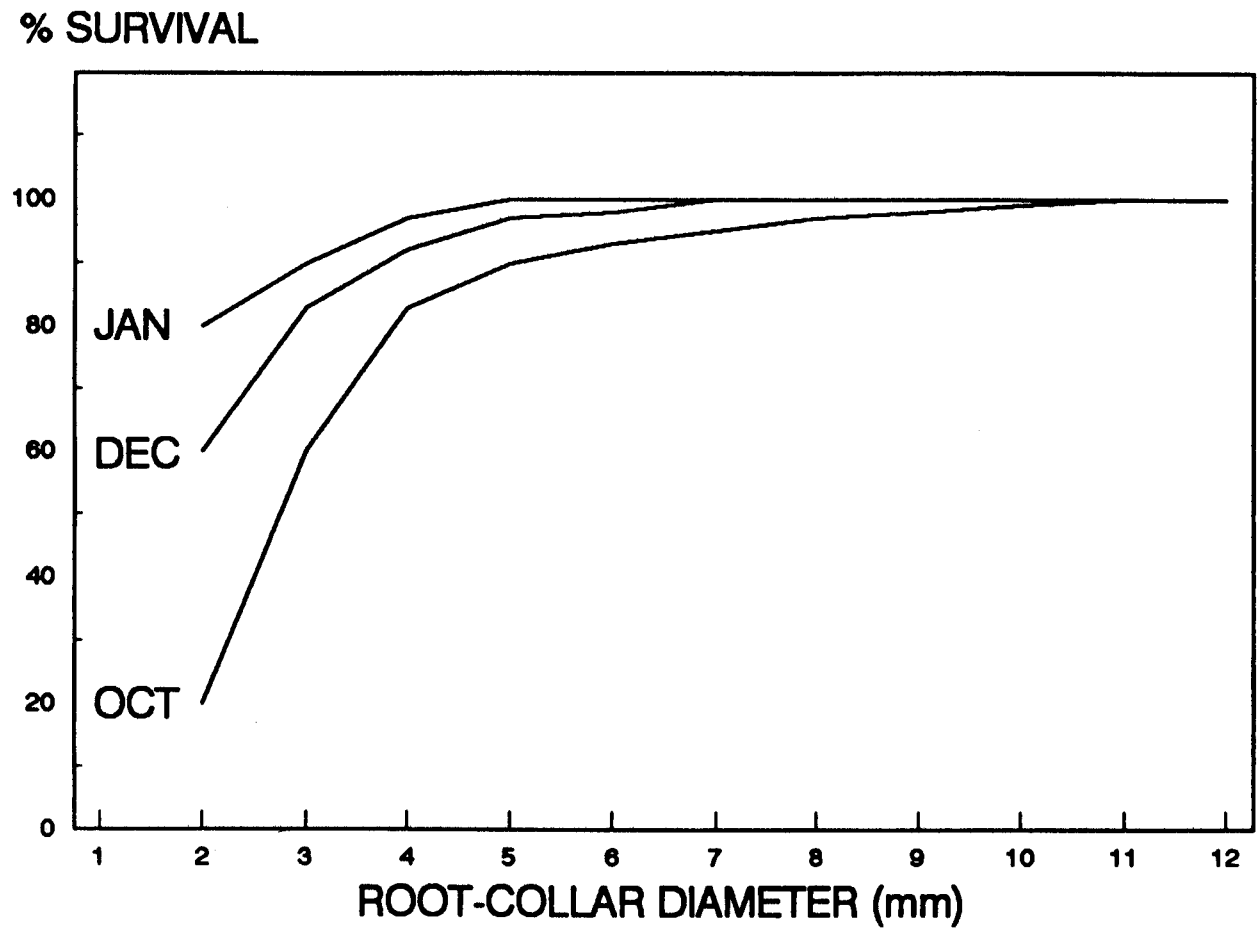

Figure 1. *Hypothesized interaction between planting date and root-collar diameter for bare-root slash pine seedlings.*

Costs of Site Preparation

Costs involved in establishing a pine plantation can vary widely. For an old-field site in Alabama, regeneration costs for loblolly pine can be as low as \$95/ha (\$23 for planting stock and \$72/ha for machine planting 750 TPH). In contrast, when planting white pine in central Ontario, the costs could be as high as \$2,262/ha (\$466 for purchasing and planting 2,000 seedlings and \$1,796 for scarification, brush control and fertilization (Brand 1991)). Approximate costs of various soil cultivation, fertilization, and weed control treatments for the southern US (Dubois et al. 1991) and Ontario (Brand 1991) are presented in Table 3. Also listed are the additional volume gains required to "break-even" using a 6% real interest rate (Fox 1988). For example, if one invests \$280/ha in double chopping, then an additional 140 m^3/ha would be needed at harvest (age 25 for loblolly pine). If the treatment produced less than this amount (when compared to planting on land with no site preparation), then the investment would earn less than 6%.

Table 3. *Estimated costs and break-even yields from different pine establishment practices for Alabama, USA and central Ontario, Canada.*

Location	Treatment	Cost	Break-even yield
		- \$/ha -	m^3/ha
Alabama			
	Spot application of herbicides	90	45
	Fertilization at planting	100	50
	Single Chop	162	81
	Chop-bed	222	111
	Double chop	280	140
	Shear-Rake-Pile	308	159
	Shear-rake-pile-bed	412	206
	Shear-rake-pile-disk	432	216
Ontario			
	Scarification	310	155
	Brush control	996	498
	Brush control-scarification-fertilization	1,796	898

For this analysis, the discounted value of wood is assumed to be \$2/m^3. At a 6% interest rate, this is equivalent to a harvest value of \$8.58/m^3 for a 25 year rotation or \$49.30/m^3 for a 55 year rotation.

In the past, the primary goal of management of lands owned by pulpwood companies was to increase volume production at harvest. Land managers in the southern US often would use tractors, shears, tree crushers, rakes, disks, and bedding plows for site preparation. However, as energy and equipment became more expensive, managers became more critical of suggested cultural treatments and their effects. Today, treatments are evaluated on their effect on cost of production as well as their influence on volume growth. Figure 2 examines the relationship between regeneration costs and per unit cost of wood production.

The key to understanding Figure 2 is determining the present value of a cubic meter of wood. If the stumpage value of pulpwood at harvest (at age 25) is estimated to be \$8.58/m^3, then at a 6% real interest rate, the discounted value at planting would be \$2.00/m^3. In other words, if regeneration costs are more than \$2.00/m^3, then the investment would have a negative net present value.

Four theoretical regeneration options are given on Figure 2. Each involve planting loblolly pine on a 25 year rotation. Option #1 involves investing \$150/ha in planting an old-field with 1000 TPH. Although this option is the least productive in terms of volume production (175 m^3/ha at harvest), it has an acceptable net present value (NPV = \$200/ha). Option #2 is the same as #1 with an additional expenditure of \$100/ha in herbaceous weed control. Although both volume and cash flow are increased, the NPV is decreased to \$150/ha. In contrast, Option #3 involves investing \$750/ha for mechanical site preparation (shear-rake-pile-bedding), herbaceous weed control, fertilization, and planting 3,000 TPH. Although this option produces the most volume after 25 years, the NPV is no longer positive (NPV = -\$150/ha). Option #4 is the best alternative and has the highest NPV (\$250/ha): the cost of establishment is only \$250/ha and the volume growth production is relatively high. The challenge for land managers is to identify the combination of nursery and silvicultural practices that will produce results like option #4. We believe that option #4 can be achieved more easily by planting competitive, large-diameter seedlings than by planting marginal seedlings (which may require a high level of site preparation).

Summary

In the past, size recommendations for bareroot pines in the southern US have concentrated on achieving adequate survival and have generally ignored potential growth gains. If the objectives of management evolve to include rapid early growth, and producing a low cost/m^3, then we need to install studies to examine potential interactions among seedling diameter, planting date, and intensity of site preparation. Studies in the past have involved a

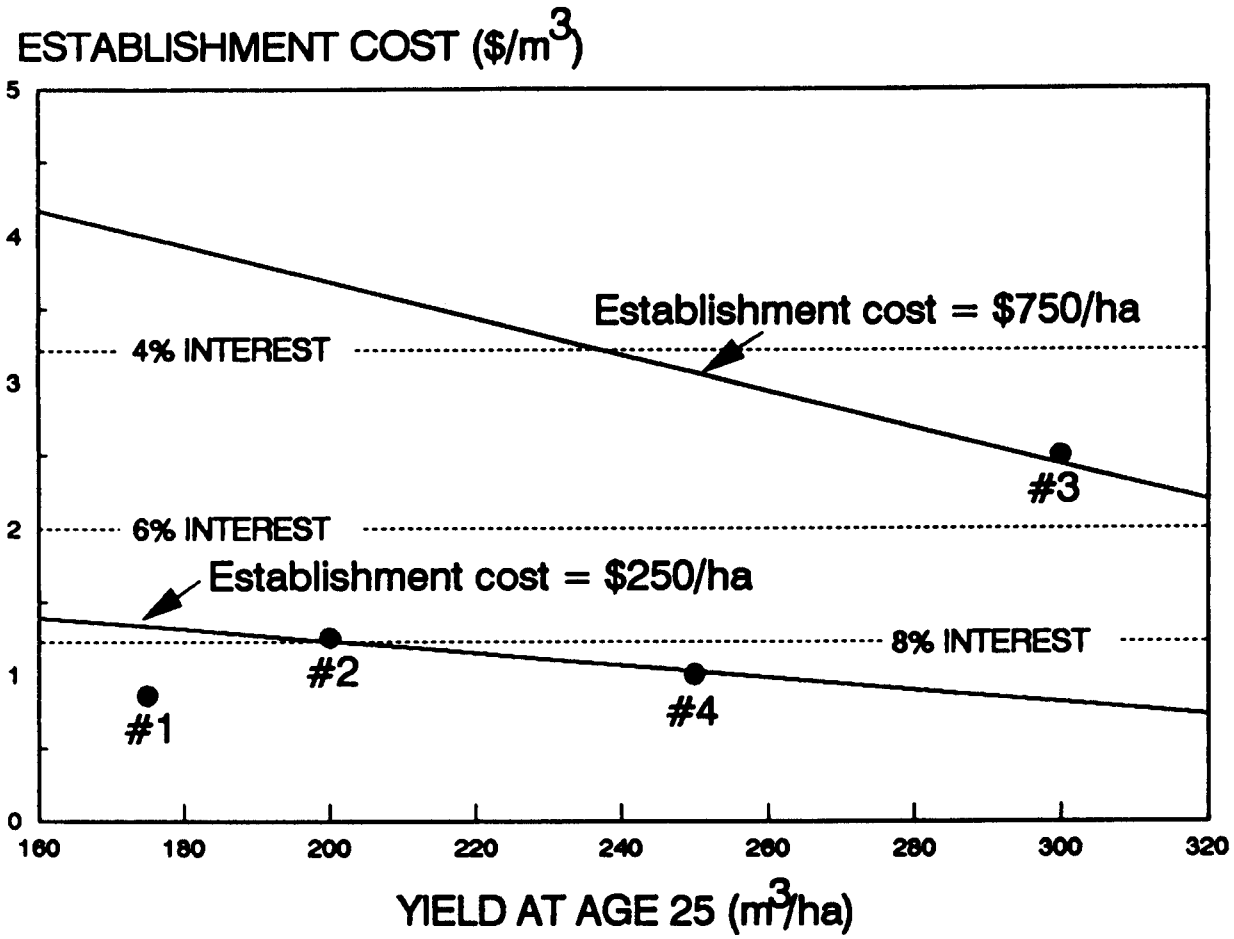

Figure 2. *Relationship between harvest yield and unit costs for wood production for four different regeneration regimes. For this analysis, the discounted value of wood is assumed to be $2/m³. At a 6% interest rate, this is equivalent to a stumpage value of $8.58/m³ when harvesting at age 25.*

relatively narrow range of seedling size and often seedlings larger than 6 mm RCD were not tested. Studies with 7 to 12 mm seedling need to be established in order to understand the essential biological facts regarding potential interactions with tree size.

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FIRST-YEAR RESPONSE OF DIRECT-SEEDED SHORTLEAF PINE AND HARDWOOD SPROUTS TO THREE METHODS OF HARDWOOD CONTROL IN THE ARKANSAS OZARKS [1]

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Abstract. The establishment and development of shortleaf pine regeneration and hardwood regrowth in relation to the method used for hardwood control were monitored in a demonstration of uneven-aged shortleaf pine (*Pinus echinata* Mill.) management using single-tree selection on the Ozark National Forest in northwest Arkansas. Untreated checks were compared to three hardwood control treatments: (1) hardwood injection with herbicide; (2) once only manual hardwood control with chain saws; and (3) manual hardwood control with chain saws, repeated annually as needed to control resprouts. Because of a seed crop failure during the winter after hardwood control, shortleaf pine seeds from an Ozark Mountain source were broadcast onto study plots. One year after treatment, hardwood control plots had 24 percent better milacre pine stocking and 70 percent more free-to-grow pine seedlings than check plots. For pine regeneration, there were no significant differences between the three hardwood control treatments. Sprouts from treated hardwoods exhibited significantly more ground coverage on manual control plots than on herbicide injected plots. Cost of the once only manual hardwood control treatment was about half the cost of the hardwood injection treatment.

Introduction

For regulated uneven-aged management of shortleaf pine (*Pinus echinata* Mill.), the majority of stems in a stand should be in the seedling, sapling, and poletimber size classes to allow for a continuous progression of trees into more valuable sawlogs. To accomplish that objective, the hardwood component must be periodically controlled; otherwise, intolerant shortleaf pine seedlings that develop in the understory will most likely be shaded out.

Alternatives for vegetation management include prescribed fire, mechanical methods, manual methods, herbicide treatments, and biological methods. In the "Final Environmental Impact Statement for the Ozark/Ouachita Mountains" (USDA FS 1990), the preferred alternative for vegetation management specified an increase in the use of manual methods and a decrease in the use of herbicides and soil-disturbing mechanical methods. When herbicides are used, priority is to be given to chemicals and application methods that pose minimum risk to humans, wildlife, and nontarget plants.

This study is part of a larger effort to demonstrate uneven-aged management of shortleaf pine by conversion of mature even-aged stands using single-tree selection. Objectives were (1) to compare the cost and effectiveness of hardwood control by manual methods with that of stem-injected herbicides and (2) to monitor the establishment and development of shortleaf pine regeneration and hardwood regrowth following manual and herbicide hardwood control.

Materials and Methods

Study Area

The study is located in Johnson County, Arkansas, on the Bayou Ranger District of the Ozark National Forest. Plots are situated on a south-facing slope, and the elevation ranges from 760 to 920 ft. Soils are Nella (Typic Paleudult) and Mountainburg (Lithic Hapludult), gravelly or stony, fine sandy loam (USDA 1977). Annual precipitation averages 46 inches with extremes being wet winters and dry autumns.

The south-facing slope contained a mature stand of shortleaf pine averaging 85 ft^2 of basal area per acre in trees larger than 4.5 inches in d.b.h. Most pines were from 14 to 18 inches in d.b.h., and the understory was devoid of pine regeneration. Overstory and midstory hardwoods (larger than 4.5 inches in d.b.h.) averaged 32 ft^2 of basal area per acre and exhibited a classic uneven-aged structure. There had been no apparent forest management activity during the last 20 years. Site indices at 50 years for

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[1] Paper presented at the Seventh Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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shortleaf pine were determined by slope position in accordance with USDA FS (1976): upper slope = 59 ft, midslope = 64 ft, and lower slope = 69 ft.

Study Installation

Twelve plots of 0.5 acre (147.6 ft by 147.6 ft) each, with interior subplots of 0.25 acre (104.4 ft by 104.4 ft), were established in the summer of 1990. The experimental design is a randomized complete block with three replications of four treatments. Blocking was based on topographic position--upper (22 percent slope), middle (26 percent slope), and lower (10 percent slope). Within each interior plot, 25 systematically spaced sample points were permanently established to serve as centers of circular quadrats for monitoring pine seedling and sapling development, nonpine competition, and seedbed disturbance.

All merchantable-sized pines (4.6 inches in d.b.h. or larger) were inventoried by 1-inch d.b.h. classes on a plot-by-plot basis. These data were used to determine the allowable cut based on the basal area-maximum diameter-quotient (BDQ) technique (Farrar 1984). The BDQ technique was applied according to three guidelines, in order of importance: (1) A basal area of 60 ft^2 per acre was to be left in merchantable-sized pines after harvest. (2) All pines larger than a maximum d.b.h. of 18 inches were to be cut, but some larger pines were retained to achieve the desired basal area. (3) The residual diameter distribution should approach a balanced uneven-aged structure, characterized by a constant ratio (q) between the number of trees in succeeding diameter classes (q = 1.22 for 1-inch d.b.h. classes).

Pine harvesting was completed in late June 1990. Cut pines were removed tree-length using an articulated rubber-tired skidder.

Treatments

Hardwood control was accomplished in early September 1990, by an independent contractor. An untreated check is being compared to three methods of postharvest hardwood control as follows:

Check. No hardwood control, but there was disturbance from logging.

Hardwood Injection. All hardwood trees and shrubs that were 1.0 inch or larger in groundline diameter (g.l.d.) were stem injected near the root collar with Garlon® 3A (triclopyr) at the rate of 0.5 ml of undiluted herbicide per incision and one incision per inch of g.l.d. This treatment was accomplished with Jim-Gem® tree injectors.

Manual Hardwood Control, Once Only. All hardwood trees and shrubs that were 1.0 inch or larger in g.l.d. were manually cut using chain saws. Stump heights averaged less than 1.0 ft.

Manual Hardwood Control, As Needed. This was accomplished using the same method as the previous treatment, but it is repeated each year, as needed, to minimize hardwood sprouts.

In order to assess the initial cost of herbicide and manual treatments for controlling hardwoods, the time required to inject or manually fell the hardwoods was recorded. The volume of injected herbicide was measured. Six 0.5-acre plots were assessed for injection cost and six plots were assessed for chain saw felling cost. Hardwoods on plots that were assigned *manual hardwood control* as needed were first injected using clean Jim-Gem tree injectors filled with a dye solution to determine time and herbicide volume requirements for an injection treatment. Following the simulated injection, hardwoods were then felled with chain saws. The other three plots used in the cost comparison of each hardwood control treatment (injection vs. chain saw felling) were the three that had been assigned as *hardwood injection* or *manual hardwood control.* For labor cost, the minimum wage was doubled to $8.50 per hour to account for vendor contract fees. The cost of Garlon herbicide was based on the retail price in 1991 ($169 for 2.5 gallons). The cost of chain saw operation was based on dollar amounts taken from Miller (1984) with an addition of simple interest at 5 percent for inflation over 6 years; it was figured to be $2.76 per hour of chain saw use.

Pine Seed Crops

Natural pine seedfall was monitored from October 1990 through January 1991, using 4 seed traps on each of the 12 plots. The four interior plot corners were used as monumentation points for the seed traps. Individual seed traps had an opening size of 0.92 ft^2. Between October of 1990 and February of 1991, only 2,959 potentially viable seeds per acre were collected in the traps. Since 40,000 viable shortleaf pine seeds per acre are purported to be necessary for adequate regeneration under natural conditions (Liming 1945), the 1990-91 seed crop was judged to be a complete failure.

To ensure regeneration of the area, Bayou Ranger District personnel obtained shortleaf pine

seeds (Ozark Mountain source) from the USDA Forest Service's W.W. Ashe Nursery in Brooklyn, MS. Using cyclone hand-seeders, district personnel broadcast the seeds onto the 12 study plots at the rate of 3 pounds per plot (6 lb/acre) in mid-February 1991. Seeds were held in cold storage at 36 °F between the day of receipt and the day of sowing. These seeds were reported to contain 28,100 seeds per pound, had a germination rate of 86 percent, and were not treated with repellents nor stratified before sowing in the field. The recommended rate for broadcast sowing of repellent-treated, stratified shortleaf pine seeds is 0.48 lb/acre (Ezell 1988).

Measurements and Data Analysis

Following harvest and hardwood control, seedbed conditions were ocularly estimated to the nearest 10 percent on each of the 25 sample quadrats per plot. Eight disturbance codes were used in that assessment: mineral soil exposed, but no soil displaced; mineral soil exposed and displaced; forest floor disturbed but not down to mineral soil; forest floor undisturbed, no apparent logging activity; forest floor covered by logging debris that was less than 2.0 inches in diameter; forest floor covered by logging debris that was greater than 2.0 inches in diameter; forest floor covered by manually-cut hardwood slash; and forest floor occupied by tree stumps, decaying logs, or rock outcrops.

One year after hardwood control (fall 1991), first-year pine seedlings were counted within the 25 1-milacre sample quadrats on each interior plot. The two tallest (dominant) pine seedlings (stems ≤ 0.5 inch in d.b.h.) within each milacre were measured for total height to 0.1 ft and g.l.d. to 0.04 inch (1.0 mm). These dominant seedlings were assessed as being overtopped or free-to-grow. Within a 2-milacre radius on even-numbered quadrats, pine saplings (stems >0.5 inch but <4.6 inches in d.b.h.) were measured, but only 2 saplings were present across all 12 plots, 1 year after treatment and harvest. Within the 25 1-milacre quadrats per plot, percent ground cover was ocularly estimated to the nearest 10 percent for merchantable and submerchantable pines and hardwoods, and for herbaceous vegetation (forbs, grasses, semiwoody plants, and vines).

During the fall measurement, hardwood rootstocks of seedling size were counted within each of the 25 1-milacre quadrats per plot. The tallest seedling-sized hardwood was identified by species and measured for total height to 0.1 ft and for crown width at the widest axis and perpendicular to that axis to 0.1 ft.

Within 2-milacre quadrats on even-numbered sample points, hardwood saplings were counted by 1-inch d.b.h. classes. Where rootstocks were disturbed by harvesting or hardwood control, within the 2-milacre quadrats, rootstock g.l.d.'s were measured to 0.1 inch, each rootstock was identified by species, sprouts were counted on each rootstock, and the tallest sprout per rootstock was measured for total height to 0.1 ft.

A 100 percent inventory was conducted within each 0.5-acre check plot and herbicide injection plot to count residual hardwoods larger than 4.5 inches in d.b.h. Residual stems were tallied by 1-inch d.b.h. classes. These hardwoods were categorized into four groups: red oaks (principally *Quercus falcata* Michx., *Q. rubra* L., and *Q. velutina* Lam.), white oaks (*Q. alba* L. and *Q. stellata* Wangenh.), hickories (*Carya* spp.), and other hardwoods.

Analysis of variance was used to evaluate treatment effects on measured variables. Percent values for quadrat stocking, free-to-grow condition, and ground cover were compared following arc sine transformation. Statistically significant differences were tested by orthogonal contrasts. Regression analyses were used to determine the relationship of number and height of hardwood rootstock stump sprouts to g.l.d. for eight species groups on manual hardwood control plots. These eight species groups included: white oak (*Quercus alba* L. and *Q. stellata* Wangenh.); red oak (*Q. falcata* Michx., *Q. marilandica* Muenchh., *Q. nigra* L., *Q. rubra* L., and *Q. velutina* Lam.); hickory (*Carya* spp.); flowering dogwood (*Cornus florida* L.); blackgum (*Nyssa sylvatica* Marsh.); red maple (*Acer rubrum* L.); shrubs (*Amelanchier arborea* [Michx. f.] Fern., *Callicarpa americana* L., *Crataegus* spp., *Rhus copallina* L., *R. glabra* L., and *Vaccinium* spp.); and other hardwoods (*Diospyros virginiana* L., *Fraxinus* spp., *Ostrya virginiana* [Mill.] K. Koch, *Prunus serotina* Ehrh., *Rhamnus caroliniana* Walt., and *Ulmus* spp.). Sprout data from check plots and hardwood injection plots were too few for use in these regression analyses.

Results and Discussion

Initial Cost of Hardwood Control

Averaged over an area of 3 acres for each method of hardwood control, the initial cost of manually felling the hardwoods was about half the cost of tree injection (table 1). On plots where both

methods of hardwood control were compared, the same number of hardwood stems were treated, and that permitted calculation of the cost per treated stem. Chain saw felling was accomplished at a cost of $0.07 per treated stem as compared to $0.14 per stem for herbicide injection.

In the present study, all hardwoods larger than 1.0 inch in g.l.d. were treated, even if they were of merchantable size. On an operational scale, merchantable hardwoods should be sold and removed from the site, which would reduce the cost of postharvest hardwood control.

Table 1. Per acre costs of hardwood control by tree injection and manual felling.

Cost factor	Hardwood control treatment	
	Tree injection	Manual felling
	----------(dollars/acre)----------	
Labor	13.60	24.65
Herbicide	47.58	-
Chain saw operation	-	6.49
Total	61.18	31.14

Postharvest Seedbed Condition

Cut-and-leave hardwood control techniques result in too much detritus being left on the site, and slash cover has been shown to impede natural pine regeneration (Trousdell 1950). In the present study, a preliminary analysis of posttreatment seedbed conditions indicated that, on the six plots subjected to manual hardwood control, 88 percent of sampled milacres contained hardwood slash, and ground coverage from felled hardwoods averaged 62 percent of the area within those milacres. Since such heavy slash restricted accessibility and was considered to be unacceptable for pine seedling establishment, the slash was removed from within plot boundaries if larger than 4.0 inches in diameter.

Exposed mineral soil is considered to be the most desirable seedbed for natural pine regeneration (Trousdell 1950). In the present study, the forest floor was assessed as being disturbed on only 31 percent and 27 percent of sample milacres within check plots and hardwood injection plots, respectively. Obviously, selection cutting resulted in minimal site disturbance for these two treatments. In contrast, on manual hardwood control plots, 66 to 72 percent of sample milacres had forest floor disturbance, but not mineral soil exposure. The greater incidence of forest floor disturbance on the latter plots is attributed to hardwood removal after chain saw felling.

Tree stumps, decaying logs, rock outcrops, and logging slash greater than 2.0 inches in diameter (nonstockable) comprised only 6 percent of sampled milacres, across all 12 plots, and were considered to be no impediment to pine seedling establishment.

Pine Regeneration

In uneven-aged management, 200 submerchant-able-sized pines/acre are considered to be the minimum for adequate density, with 50 percent milacre stocking being optimum (Cain 1991). The preharvest inventory revealed no pine seedlings, but one growing season after direct seeding, pine seedling density averaged 1,733 stems/acre across all treatments. Thus, with direct seeding, the study area was successfully regenerated. Statistically, there was no significant difference in seedling density between treatments (table 2). For milacre stocking, however, all plots that received hardwood control had significantly better milacre stocking of first-year pine seedlings, averaging 48 percent, compared to untreated check plots that averaged 24 percent (table 2).

Based on potentially viable seeds, the seeds-per-seedling ratio was about 133 to 1 on check plots, 55 to 1 on hardwood injection plots, and 91 to 1 on manual control plots. For comparison, Yocom and Lawson (1977) investigated natural shortleaf pine regeneration on seed tree areas in the Ouachita Mountains of Arkansas for 9 years and reported average seeds-per-seedling ratios that ranged from 70 to 1, up to 217 to 1, from potentially sound seeds.

Density of sapling-sized pines (0.6 to 4.5 inches in d.b.h.) declined from 45 trees/acre, before harvest, to only 6 trees/acre, 1 year after harvest. The loss of 39 sapling pines/acre is attributed to logging activity. For 200 submerchantable-sized stems/acre in a well-stocked, uneven-aged shortleaf pine stand, using a q-factor of 1.2, the percentage of trees by d.b.h. class would equal the following: seedlings = 32 percent, 1-inch class = 27 percent, 2-inch class = 23 percent, and 3-inch class = 18 percent. Another 16 trees/acre should be in the 4-inch d.b.h. class (Reynolds 1959).

Even though first-year results indicated pine regeneration success on the Ozark study area, stand structure is a long way from a well-regulated condition. Results from uneven-aged management of

Table 2. *Status of first-year pine seedlings by method of hardwood control.*

Treatment	Density (stems/acre)	Milacre stocking[1] (percent)	Total height (feet)	G.l.d.[2] (inches)	Free-to-grow (percent)
Check	1,093	24a[3]	0.30	0.05	12a
Hardwood injection	2,653	49 b	0.34	0.05	77 b
Manual hardwood control	1,587	44 b	0.34	0.04	91 b
Manual hardwood control, as needed	1,600	51 b	0.37	0.05	78 b
Mean square error	1,312,222	40.60	$0.57x10^{-2}$	$4.14x10^{-2}$	238.52
PR>F[4]	0.46	0.05	0.79	0.77	0.01

[1] Based on the presence of at least one pine seedling per milacre quadrat.
[2] Groundline diameter.
[3] Columnar means followed by the same letter are not significantly different at the 0.05 level, according to orthogonal contrasts: Check vs. HI + MHC + MHCAN; HI vs. MHC + MHCAN; MHC vs. MHCAN; where HI = hardwood injection, MHC = manual hardwood control, and MHCAN = manual hardwood control as needed.
[4] The probability of obtaining a larger F-ratio under the null hypothesis.

shortleaf pines in the Ouachita Mountains of Arkansas suggest that old, even-aged sawtimber stands are the most difficult to convert to uneven-aged management and will require the longest conversion period of any existing stand type (Murphy and others 1991).

The size of first-year pine seedlings was not improved by the method of hardwood control in this study (table 2). The lack of differences in mean height and g.l.d. of first-year seedlings for different treatments is not surprising. Bormann (1956) reported that loblolly pine (*Pinus taeda* L.) seedlings can become established under dense forest canopies because of their ability to use low light intensities, but when secondary foliage develops, the seedlings are unable to photosynthesize effectively. Similar physiological responses might be expected in shortleaf pine seedlings. When compared to hardwood control, the presence of midstory and overstory hardwoods has been found to reduce the growth of natural loblolly and shortleaf pine seedlings by about 1.4 ft within 3 years of their establishment on a Coastal Plain site (Cain 1988b). At the end of the first growing season, only 12 percent of dominant pine seedlings were judged as free-to-grow on check plots in the present study, as compared to an average of 82 percent that were free-to-grow on plots receiving hardwood control (table 2).

Nonpine Competition

One year after hardwood control, density of seedling-sized hardwoods averaged nearly 4,800 rootstocks/acre, with no significant differences among treatment means (table 3). Dominant hardwood sprouts were of similar heights on check plots and on manual control plots, but averaged 32 percent shorter on herbicide injection plots.

A more revealing measure of hardwood competition was percent ground cover, which ranged from 3.3 percent on herbicide injection plots to 27.2 percent on check plots for submerchantable hardwoods (table 3). One year after treatment, crowns of dominant seedling-sized hardwood rootstock sprouts occupied significantly more area on manual control plots than on herbicide injection plots (table 3). On manual control plots, seedling-sized rootstocks of blackgums and flowering dogwoods predominated; whereas, on check plots and herbicide injection plots, oaks were the predominant woody stems of seedling size. These data suggest that selection of one hardwood control treatment over another could unwittingly alter future species composition by increasing the dominance of those that are less desirable (blackgums) at the expense of those that are more desirable (oaks).

Table 3. *Status of nonpine competition, 1 year after hardwood control.*

Treatment	Rootstock density[1]	Total height[2]	Relative crown area[2]	Ground cover: Hardwoods <4.5 inches d.b.h.	Ground cover: Hardwoods >4.5 inches d.b.h.	Ground cover: Herbaceous vegetation
	(no./acre)	(feet)	(percent)	(percent)		
Check	4,853	2.30	3.45ab[3]	27.2a	43.6a	16.9
Hardwood injection	4,120	1.64	2.13a	3.3 c	6.1 b	21.9
Manual hardwood control	5,480	2.44	6.51 b	14.6 b	0.3 c	25.9
Manual hardwood control, as needed	4,720	2.50	4.92 b	11.5 b	0.1 c	31.1
Mean square error	1,024x10[3]	0.13	0.79	1.59	49.29	136.95
PR>F[4]	0.49	0.08	<0.01	<0.01	<0.01	0.62

[1]Data from seedling-sized hardwood rootstocks.
[2]Data from dominant seedling-sized hardwood rootstocks.
[3]Columnar means followed by the same letter are not significantly different at the 0.05 level, according to orthogonal contrasts: Check vs. HI + MHC + MHCAN; HI vs. MHC + MHCAN; MHC vs. MHCAN; where HI = hardwood injection, MHC = manual hardwood control, and MHCAN = manual hardwood control as needed.
[4]The probability of obtaining a larger F-ratio under the null hypothesis.

Ground cover from merchantable-sized hardwoods averaged 43.6 percent on check plots but was 6 percent or less on plots where hardwoods were controlled 1 year earlier (table 3). On check plots, the multistoried hardwood cover, in combination with overstory pines, contributed to almost complete shading of the forest floor. Species dominance for residual merchantable-sized hardwoods on check plots was reflected in basal area, which averaged 29 ft^2/acre. Of that total basal area, 19 percent was in red oaks, 55 percent in white oaks, 20 percent in hickories, and 6 percent in other hardwoods.

Ground cover from herbaceous vegetation averaged 24 percent, 1 year after treatment, with no significant differences among treatments. Since these mountain sites do not support the degree of herbaceous vegetation that occurs on Coastal Plain sites, which can approach 100 percent coverage (Cain 1988a), herbaceous vegetation is less likely to be an aggressive competitor of developing pine regeneration.

Hardwood Sprouts

One of the most cited disadvantages of manual hardwood control is the likelihood that stump sprouts will require additional control measures and thereby increase the cost of treatment (Berstein 1978, Lowery 1986, Walstad and others 1987). Where manual or mechanical hardwood control has been assessed, hardwoods have been found to sprout less vigorously when cut in the growing season than when cut in winter (Geisinger and others 1989, McMinn 1989, Zedaker and others 1989). Since hardwood regeneration dynamics are an important consideration in the management of uneven-aged pine stands, it was appropriate to investigate species response to mechanical hardwood control in this study.

For the eight predominant species groups in which sprouting could be assessed, four exhibited statistically significant correlations between g.l.d., at the time of treatment, and the height of rootstock sprouts, 1 year later (fig. 1). For correlation between g.l.d. and number of stump sprouts per rootstock, there was statistical significance for seven of the eight species groups (fig. 2).

White oak was the only hardwood group to exhibit a statistically significant decline in sprout height as g.l.d. increased above 15 inches (fig. 1).

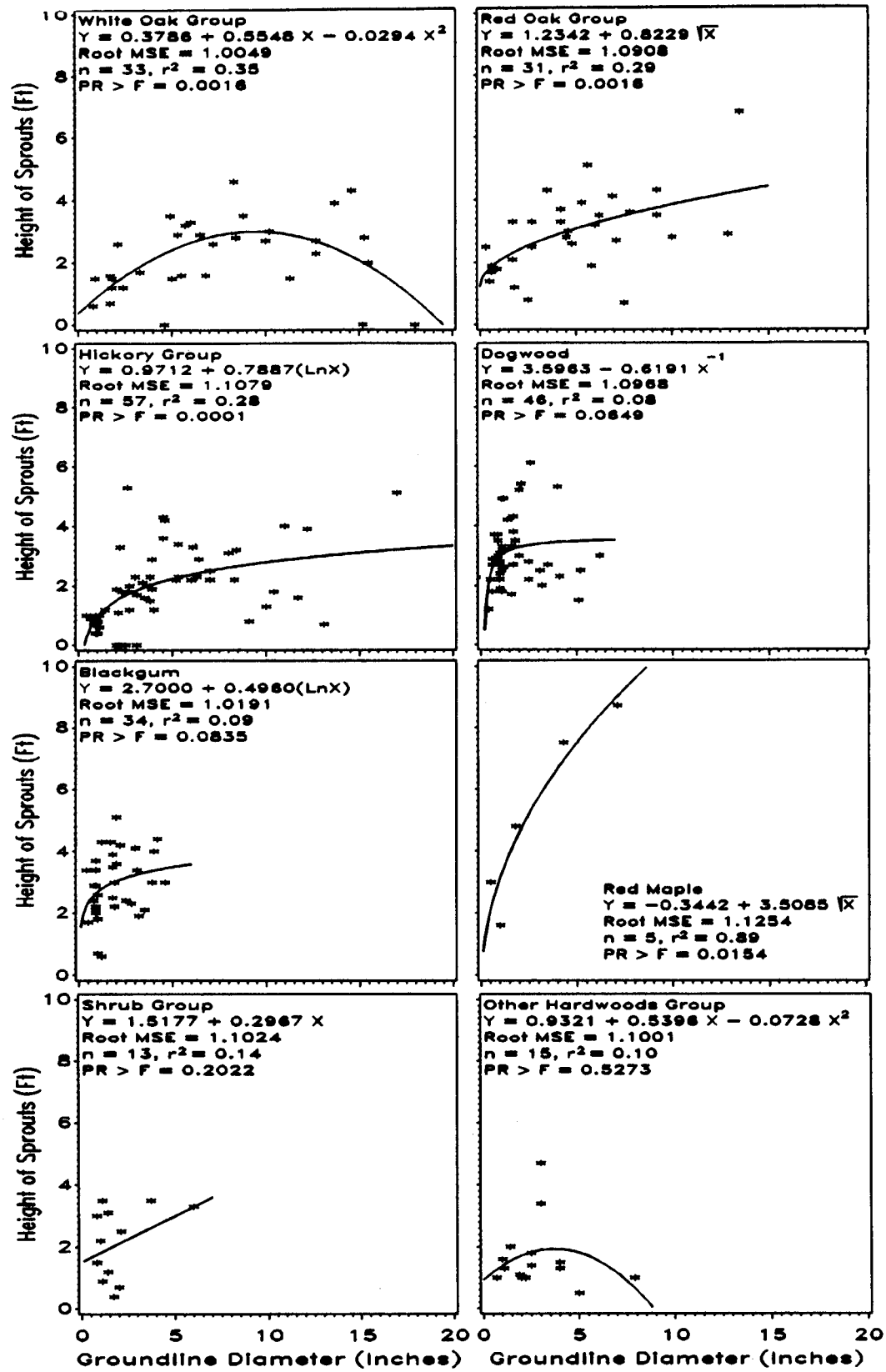

Figure 1. *Stump sprout height in relation to stump groundline diameter by species group, 1 year after manual hardwood control. Four of the eight groups showed significant relationships ($P<0.05$).*

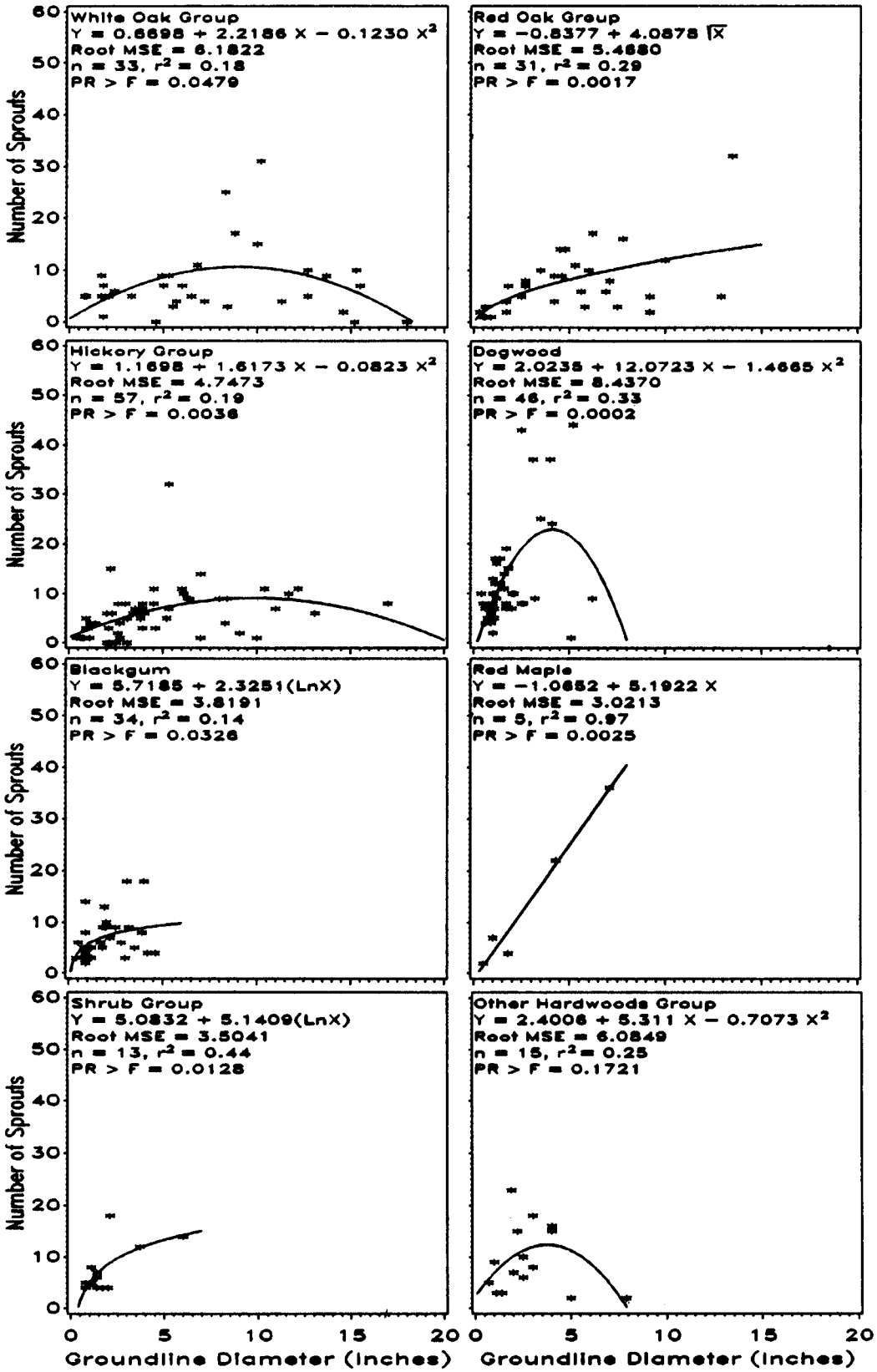

Figure 2. *Stump sprout numbers in relation to stump groundline diameter by species group, 1 year after manual hardwood control. Seven of the eight groups showed significant relationships ($P<0.05$).*

Although the stand had not been disturbed for about 20 years, the g.l.d.'s of most hardwoods were less than 15 inches. In contrast to height, numbers of sprouts per rootstock exhibited a higher propensity to decline as g.l.d. of the rootstock increased for four of the eight hardwood groups (white oak, hickory, dogwood, and other hardwoods) (fig. 2).

Because of these trends in hardwood sprout development, forest managers would be more likely to benefit from manual hardwood control if that treatment was restricted to stems larger than 10 inches in g.l.d. Some studies of hardwood sprout development have indicated that, when small diameter stems (<2 inches in d.b.h.) are prevalent, no control is better than manual felling because competition is likely to be greater after cutting than the competition from the original stems (Liming and Seizert 1943, Meade 1955).

For this study, 1 year after herbicide injection, rootstock sprouts that developed on treated stems were too few in number to allow an assessment of sprout development. Thus, compared to chain saw felling, herbicides provided better control of hardwoods in terms of sprout development during the first year after treatment, even though density of surviving rootstocks was not significantly reduced by any treatment. If herbicide use is not an option on National Forest lands because of public concerns, then manual girdling of the hardwood component is likely to result in fewer sprouts of smaller size than manual felling (Liming 1945, 1946).

Conclusions

First-year results are often tentative, and treatment effects may change as additional measurements are taken. Even so, important differences were found between hardwood control treatments within 1 year after imposing the treatments. Where hardwoods were controlled, milacre stocking of shortleaf pine regeneration was best and more pine seedlings were free-to-grow. The use of herbicides resulted in less ground cover from reinvading hardwood sprouts when compared to chain saw felling. In the latter treatment, the size and number of stump sprouts varied by species but tended to increase as g.l.d. of the parent tree increased to 10 inches.

Acknowledgements

This study was funded by the USDA Forest Service Ozark National Forest. Field support for plot installation and treatment was provided by personnel from the Bayou Ranger District, Hector, Arkansas.

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NATURAL AND ARTIFICIAL PINE REGENERATION IN THE GEORGIA PIEDMONT: HOW SPECIES COMPOSITION IS AFFECTED BY MANAGEMENT AND REGENERATION TECHNIQUES. [1]

Judith A. Fitzgerald, M. Boyd Edwards, and Phillip M. Dougherty [2]

Abstract. A pine regeneration study was established in September of 1990 on the B.F. Grant Memorial Forest of the University of Georgia's Daniel B. Warnell School of Forest Resources. The study objective was to determine the effects of six different regeneration-management regimes on the growth and biological diversity of vegetation species. After harvest in the fall of 1990, five replications of six treatments were applied: (1) Seed tree - intensive management; (2) Seed tree - non-intensive management; (3) Planted Loblolly (*Pinus taeda* L.) pine - intensive management; (4) Planted Loblolly pine - non-intensive management; (5) Hardwood only - intensive management and (6) a Control - no management. The paper summarizes the data collected from immediately after harvest to one year after study establishment.

Introduction

The emphasis placed on planting loblolly pine (*Pinus taeda* L.) in the Southeast has led to many questions about the lack of biological diversity in our forests. With the public's growing awareness of the forests as more than just a timber supply, emphasis is shifting to more unevenaged mixed stands or "natural" looking forests. This includes not only hardwood forests, but a mix of pine-hardwood. Natural regeneration is one way of accomplishing this mixture in a low impact manner. Generally, the public is against clearcuts, so natural regeneration with seed trees and shelterwoods along with coppice sprouting is an alternative that may be a good compromise.

Intensive herbaceous weed control has been shown to increase survival and yields of loblolly pine seedlings (Schoenholtz & Barber 1988, Creighton et al. 1986). With increased use of herbicides, there is concern about the loss of species in the forest stand. Studies on different site preparation intensities have shown that with herbicides such as sulfometuron methyl (Oust®) species richness was reduced by almost 80% (Swindel et al. 1989). The result is pine stands which look like a "monoculture" with very little diversity present. Although, these stands have less competition for nutrients, water, and light than the non-intensively managed stands (Dougherty & Gresham 1988), the species richness declines. Therefore questions arise as to how this loss of diversity affects wildlife habitat. For example, are we intensively managing our forests to the detriment of our wildlife species? Studies have shown that upon conversion to pine plantations, an increase in herbaceous food plants occurs (Felix et al. 1986). While there is a loss of mast, there is an increase in legumes (*Desmodium* spp., *Lespedeza* spp.), woody (*Vaccinium* spp., *Vitis* spp., *Rubus* spp.) and grasses. Felix et al. found that blocks of mixed age plantations near stands of hardwoods provided excellent habitat for wildlife. These young plantations have also been shown to have an increased population of small mammals (Perkins et al. 1988). Mechanically site-prepped stands were shown to have less vegetation than stands that had been chemically site-prepared. Small mammal populations were higher on these chemically site-prepped tracts. Small mammals are important as a food source to a variety of animals such as owls, hawks, snakes, foxes, and coyotes.

Mixtures of pine-hardwood stands provide excellent habitat for fox squirrels (*Sciurus niger*). Decline of the fox squirrels in the Southeast has been attributed to the greater fragmentation and loss of mature pine-hardwood mixed forests (Loeb & Lennartz 1989). New methods have been developed in the Georgia Piedmont to promote mixed stands of pine-hardwood. One such method is the fell and burn technique (Waldrop et al. 1989) which successfully helped established pine-hardwood forest in the southern Appalachian mountains, but does have some draw backs in the Piedmont. The main problem is the thin layer of topsoil and the narrow range of the

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rootmat that leads a hot fire to damage the site intensively through soil exposure and erosion.

Time of harvest also has an effect on what species reinvade the site, because sites harvested during the dormant season showed a higher pine component than the growing season harvest, which resulted in a higher hardwood component (McMinn 1989).

Methods of establishing natural pine stands have long been studied (Wahlenberg 1960). Traditional methods such as seed tree, shelterwood, and clearcutting with seed in place have all been shown to be effective (Edwards 1986). For the most part, the problem with this artificial regeneration is it's either a "feast or famine" type of situation, because there is either too much stocking, or not enough uniform stocking. Further studies are being conducted to determine options for a landowner to economically handle naturally regenerating his land (Edwards & Dangerfield 1989).

Natural regeneration of hardwoods relies heavily on the presence of trees to provide stumps for sprouting (Kays et al. 1988). On sites where pine was the predominant species, and few hardwoods were present, little is known about naturally regenerating these stands.

At present, there are few longterm projects now in progress that are geared to answer not only the economics of growing a natural or artificially planted pine stand, pine-hardwood mixture, or hardwood, but also are looking at the diversity and function of the site under these regimes. Concerns as to the effects of intensive or non-intensive management of a forest on the specie diversity have not been previously stressed in research. Many aspects of site characterization need to be done at the onset of longterm research so changes in the ecosystem under the applied treatments can be demonstrated.

The objective of this study was to characterize the impacts of natural and artificially regenerated stands, which received low and high intensity management, and to study vegetative diversity and biomass production the first two years following establishment. Focus was not only on the trees of these stands, but also the understory vegetation that develops under these management techniques. Under these management schemes three major points were examined: 1)environmental data , 2) soil, and 3) vegetation. Environmental data, quantum, air and soil temperatures, soil moisture, and rain, were monitored to determine trends on the site. Soil aspects were classified in order to form a base from which future measurements can be compared to follow the changes due to management techniques. Vegetation will be quantified to follow the species composition changes due to the different intensities of management. This provides a record of what species enter and exit the ecosystem as the canopy closes in the different treatments.

With the "Ecosystem Management" approach to managing forests, (ie. managing for maintaining the health of the ecosystem rather than for the optimizing production on a single acre), there is much interest in understanding how forest regeneration and management systems affect ecosystem functions and diversity. However, most of previous research was focused on understanding how forestry activities affect tree growth. This study will provide not only documentation of the effects of forest regeneration methods and management on specie diversity and biomass production, but also a foundation for a longterm study of these ecosystems.

Methods

The study is located on the B.F. Grant Memorial Forest outside Eatonton, Georgia (Figure 1). An upland Piedmont site with a Davidson Clay Loam (clayey, kaolinitic, thermic, Rhodic Kandiudult) type soil was chosen. A stand of natural loblolly with an average age of 55, which had been thinned four years prior to establishment of the study, was selected. The stand has a history of prescribed burns and was last burned in March of 1990. In the fall prior to study establishment, a randomized complete block with five replications was mapped out. Six treatments were randomly assigned to each block:

1. Seed tree - intensive management
2. Seed tree - non-intensive management
3. Clearcut - plant with Loblolly - intensive management
4. Clearcut - plant with Loblolly - non-intensive mgt.
5. Clearcut - intensive management for hardwoods
6. Clearcut - Control - no management

Each treatment plot was 0.4 acre, (0.16 ha) in size with an interior measurement plot of 0.25 acre (0.10 ha). Each plot was permanently marked with fence posts with one corner being tagged as the base corner from which all measurements taken are mapped. Intensively managed plots here may be a misnomer. Intensive management in this study stands for the type of management a small landowner may use without spending great sums of money.

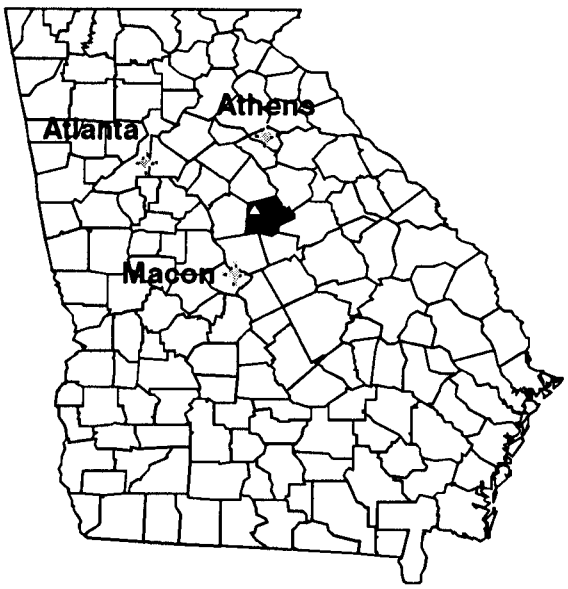

Figure 1. *Location of regeneration study in Putnam County, Georgia. The site is represented by the (▲) in the highlighted county.*

Prior to clearcutting the tract, leave trees of an average 16 inches in diameter at breast height were marked in the seed tree plots. Ten to twelve trees per acre were selected based on dominant crowns, form, and abundance of cones (Wahlenberg 1960). A total cut of approximately 45 acres, around and including the 12 acres of plots, left a wide buffer strip to prevent influence of "outside trees" on the research plots. This buffer strip was planted in the same seed source of loblolly pine that the treatment plots were planted.

In the planted plots, loblolly pine 1-0 bareroot seedlings were planted. The trees were planted on a 10 foot by 7 foot (3m x 2m) spacing (622 trees per acre). In each plot, there are 13 rows of 18 trees per row.

Before seedfall in the seed tree plots, five 1 m^2 seed traps were randomly placed per 0.25 acre plot to collect seed. Seeds were collected once a week during peak seedfall (late October until early February) for the first year after the initial cut.

Permanent sampling points for characterization of soil aspects were established. Five subplots per measurement plot were mapped out in order to sample changes in soil every five years. Soil will be collected in these subplots within a 7.8 foot (2 m) radius of the center of the subplot. For the initial sampling, soil was collected in the 12-2 o'clock quadrant. Thus, no one spot within the subplot will be tested more than once in a thirty year cycle. The soil will be tested to determine macronutrient, micronutrient, pH, and organic matter.

A reconnaissance survey was conducted to determine the vegetative variability. Factors such as species, percent cover, frequency, and amount of whitetailed deer (*Odocoileus virginianus*) browse was recorded. Five 1 m^2 quadrats per 0.25 acre plot were mapped out. Vegetative species found in these quadrats are listed in Table 1. Variability was determined using a standard error of the mean to the mean to determine sample size needed (Mueller-Dombois & Ellenberg 1974). Frequency and an ocular estimate of percent cover will be taken for all species including trees, shrubs, vines, forbs, and grasses. A tally of browsed stems will be kept to determine which species are more favorable for deer consumption. Based on the variability found in the reconnaissance survey, a second survey was performed in September 1991 with 25 1 m^2 quadrats per measurement plot.

On the planted loblolly pine plots, measurements were made in January 1992 as to the percent survival, height, and ground line diameter.

Manipulations

The intensively managed seed tree plots will have the hardwoods removed in the Fall of 1992. The hardwood stems will be basal sprayed using a Solo backpack sprayer and 5 % by volume Garlon 4®. No herbaceous control will be performed in the first two years in order to allow establishment of natural pine. Success of the natural regeneration will be determined if after two years there are 500 uniformly stocked trees per acre. If regeneration is successful, then some type of stand density management will be conducted. On the intensively managed planted plots, herbaceous weed control was performed using a spotgun treatment with 5 oz. active ingredient Oust®. A six foot spot was treated around each pine 2 months after planting. The hardwoods in the plot will be basal sprayed using Garlon 4®. These treatments will be repeated each year as necessary. Non-intensive planted plots will not have any further treatment performed after planting. On the intensive hardwood plots, all pine regenerating within the plot will be removed using Garlon 4® or Round-up®. Hardwood species, important to timber and wildlife, such as oak, sweetgum, and dogwood will be encouraged. On the control plots, there will be no further management after clearcutting.

Table 1. Vegetative species richness and dominant species found by compositional group at B.F. Grant during the June 1991 reconnaissance survey.

WOODY	19 species identified	
	Loblolly pine	(*Pinus taeda* L.)
	Sweetgum	(*Liquidambar styraciflua*)
	Dogwood	(*Cornus florida*)
	Red Maple	(*Acer rubrum*)
	Oaks	(*Quercus* spp.)
VINES	7 species identified	
	Blackberry	(*Rubus* sp.)
	Honeysuckle	(*Lonicera japonica*)
	Muscadine	(*Vitis rotundifolia*)
	Yellow jessamine	(*Gelsemium sempervirens*)
	Poison Oak	(*Toxicodendron radicans*)
HERBACEOUS	61 total species identified	
FORBS	52 species identified	
	Goldenrod	(*Solidago* sp.)
	Asters	(*Asteraceae*)
	Horseweed	(*Conyza canadensis*)
	Rabbit tobacco	(*Gnaphalium* spp.)
	Lespedeza	(*Lespedeza* spp.)
	Desmodium	(*Desmodium* spp.)
GRASSES	9 species identified	
	Broomsedge	(*Andropogon virginicus*)
	Panic grass	(*Panicum* sp.)
	Plume grass	(*Erianthus* sp.)

Results and Discussion

There was no difference in the mean height between the intensive (35.16 cm) and the non-intensively (35.49 cm) managed plots (Table 2). However, there was a significant difference between the two treatments for the ground line diameter (5.79 mm versus 5.01 mm). No difference in survival (86% versus 85%) or the percent of browsed stems (14% versus 15%) was seen (Table 3). However, we did observe a difference in the pattern of browsing. In the herbicided plots, the browse tended to be in straight rows, whereas, the untreated plots tended to be randomly distributed. There was a significant difference between the amount of tip moth (*Rhyacionia frustana*) damage found in the two treatments. The intensively managed plots showed a higher incidence (24%) of tip moth damage as opposed to the nonintensively managed plots (11%). This might account for the non-significant difference in heights between the herbicided and the non-herbicided plots.

Seedfall in the seed tree plots for the first year was highly variable (Figure 2.) Average seedfall per trap from November 1, to December 1 was 4 seeds. One seed in a trap represented 4048 seeds/acre. The maximum seedfall occurred on November 20th, when one trap had 26 seeds located in it. The first year results of the vegetation sampling in the seed tree plots showed an average of 6898 seedlings in the intensive plots and 7060 trees in the non-intensive (Table 3). The average height for the seedlings after the first growing season was 12.8 and 12.2 respectively.

Table 2. *First year planted loblolly pine average height and ground line diameter (GLD) data, first year pine survival, whitetailed deer browse and tip moth damage from B.F. Grant Regeneration study. Means followed by different letters are significantly different at the (p > 0.05) level using the Duncan's Multiple Range Test.*

TREATMENT	HEIGHT MEAN (CM)	HEIGHT STD. ERR.	GLD MEAN (MM)	GLD STD. ERR.	SURVIVAL %	BROWSED %	TIP MOTH %
Intensive	35.16	0.28	5.79A	0.05	86	14	24A
Non-intensive	35.49	0.30	5.01B	0.03	85	15	11B

Table 3. *First year results of natural pine regeneration in the seed tree plots.*

TREATMENT	TREES/ACRE	AVERAGE HEIGHT (CM)
Intensive	6898	12.8
Non-intensive	7060	12.2

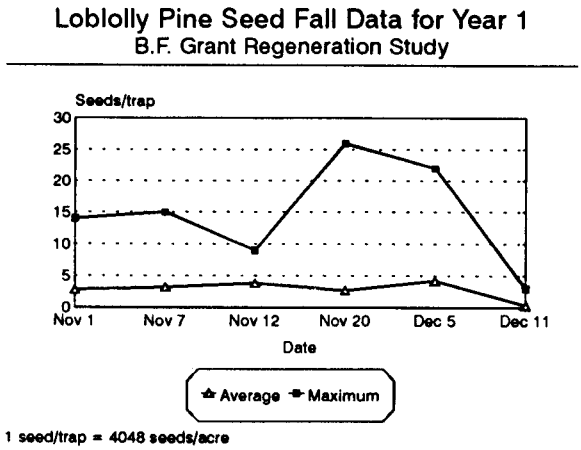

Figure 2. *Graph of average and maximum seed fall per seedtrap on the seed tree plots. Each seed per trap represents 4048 seeds per acre.*

Currently, data from the first year vegetation sampling is being analyzed to establish the first year base line for all further stand management manipulations. Plans to follow this stand during its development are being implemented. This study will provide two years of establishment data for two different regeneration and management intensities and the resulting effects on stand composition.

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PINE REGENERATION AND UNDERSTORY VEGETATION 1 YEAR AFTER IMPLEMENTING UNEVEN-AGED SILVICULTURE IN PINE-HARDWOOD STANDS OF THE SILTY UPLANDS OF MISSISSIPPI [1]

Michael G. Shelton and Paul A. Murphy [2]

Abstract. Eighteen 0.5-acre permanent plots were established in an irregularly-aged, pine-hardwood stand. Plots were harvested to leave two levels of pine basal area (45 and 60 ft^2/acre) and three hardwood levels (0, 15, and 30 ft^2/acre) using the single tree selection method. The development of pine regeneration and understory vegetation was monitored at 10 permanent locations within each net plot. Pine regeneration averaged 32,000 seedlings/acre 1 growing season after a bumper seed crop; seed production showed a weak positive correlation with pine basal area [fit index (FI) = 0.16]. The number of pine seedlings did not vary significantly with overstory basal area, but seedling size and percentage stocking were negatively related to overstory basal areas (FI = 0.26 to 0.52). The coverage of herbs, vines, hardwoods, and total understory vegetation was negatively related to overstory basal areas (FI = 0.20 to 0.41), whereas grass and shrub coverage did not vary significantly. Results of the study stress the importance of overstory-understory relationships in uneven-aged silviculture.

Introduction

Most of our experience in the uneven-aged silviculture of loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.) pines was developed over a 50-year period at the Crossett Experimental Forest in southern Arkansas (Reynolds 1959, 1969; Reynolds and others 1984). Uneven-aged silviculture was used to rehabilitate understocked, cutover stands that already had somewhat of a reverse-J size-class distribution. Crossett guidelines call for aggressive competition control and periodic harvests, which create a favorable environment for pine regeneration and provide acceptable rates of growth and yield. However, little is known about applying uneven-aged silviculture to mature pine stands, which typically have a significant hardwood component and lack a reverse-J structure. Such stands pose a unique set of problems: (1) some level of hardwood control must be imposed to create a favorable environment for pine regeneration, (2) a reverse-J structure must be developed, which will likely take several decades, and (3) the response of suppressed pines of the original stand to release is questionable and may have long lasting effects on growth and yield and the sustainability of future harvests (Shelton and Murphy 1991).

Because mature pine-hardwood stands are common on public lands and knowledge is needed concerning alternative silvicultural systems, the USDA Forest Service National Forests in Mississippi and Southern Forest Experiment Station initiated this research in 1990. Some of the problems associated with applying uneven-aged silviculture to mature pine stands with a significant hardwood component are being addressed in this research effort. The first-year response of regeneration and understory vegetation is reported here.

Methods

Study Area

The study was installed in the Homochitto National Forest in a mature, second growth pine-hardwood stand located in Franklin County, Mississippi. Soils in the study area are mapped as the Lorman series (Vertic Hapludalfs), which has a silty loam surface horizon and a clayey subsurface. The area is located in the Southern Mississippi Valley Silty Uplands, and soils were formed in a mantle of loess. Elevations range from 200 to 260 feet above sea level. Plots were located on the side slopes in an area of undulating topography; slopes ranged from 8 to 15 percent. Aspects of individual plots occurred in every quarter. Site indexes at 50 years averaged 93 feet for loblolly pine and 84 feet for shortleaf pine.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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The study area has a subtropical, humid climate with a mean annual precipitation of 55 inches. Winter is the wettest season and autumn is the driest. Water deficits typically develop during the summer. Temperatures average 52 °F during the winter and 81 °F during the summer.

Overstory pine basal areas averaged 81 ft^2/acre before harvest, with two-thirds consisting of shortleaf pine and one-third loblolly pine. Shortleaf's dominance may reflect the past influence of fire, mostly due to its sprouting ability when young. Overstory hardwood basal areas averaged 32 ft^2/acre; 60 percent was in mixed oaks [chiefly southern red oak (*Quercus falcata* Michx.) and white oak (*Q. alba* L.)], and 23 percent was in sweetgum (*Liquidambar styraciflua* L.) and blackgum (*Nyssa sylvatica* Marsh.).

Study Design and Treatment Implementation

Eighteen square, 1.6-acre gross plots were installed, each having an interior, square, 0.5-acre net plot. Treatments called for the reduction of overstory basal area to two levels for pine (45 and 60 ft^2/acre in trees ≥3.6 inches in d.b.h.) and three levels for hardwoods (0, 15, and 30 ft^2/acre). Treatments were assigned in a completely random design with three replications for each pine-hardwood combination for a total of 18 plots.

The pine harvest was implemented using the basal area-maximum diameter-quotient technique of single-tree selection (Farrar 1984). Guidelines were 45 or 60 ft^2/acre for basal area, 24 inches for maximum diameter, and a quotient of 1.2 for 1-inch diameter classes. Guidelines for maximum diameter and quotient were followed as closely as feasible because the stand lacked a balanced reverse-J structure. Hardwood retention favored the higher quality red and white oaks; these were typically the larger hardwoods.

Plots were harvested during dry weather in September and early October of 1990. Logs were skidded tree-length, and no special restrictions were placed on loggers. Silvicultural treatments that were uniformly applied to all plots include the following: (1) a controlled burn during the winter of 1988/89, (2) control of all submerchantable hardwoods ≥1 inch in d.b.h. with stem-injected herbicide (Garlon® 3A) during early June 1991, and (3) control of nonoak hardwood sprouts with foliar-applied herbicide (Garlon® 4) during early July 1991. Herbicide treatments were applied by contract crews following label directions; research crews did some touchup injection work.

Measurements

Before harvest, tree seedlings and shrubs were inventoried by size classes (≤0.5, 0.6 to 2.5, 2.6 to 4.5, and ≥4.6 feet tall and ≤0.5 inches in d.b.h.) and species or species group on a total of 36 temporary milacre plots over the study area, after full leaf-out in late April 1990. Tree saplings and shrubs (0.6 to 3.5 inches in d.b.h.) were inventoried by 1-inch d.b.h. classes and species or species group on a 0.01-acre plot centered around each milacre plot. Coverage of understory vegetation (≤6 feet tall) was ocularily estimated on 90 temporary milacre plots in the following groups: grasses, herbs, vines, shrubs, hardwoods, pines, and total coverage.

After harvest, 10 permanent points were systematically located within each net 0.5-acre plot. Points were located such that none was closer than 30 feet from the net plot boundary and 88 feet from the gross plot boundary. During the dormant season following harvest, all retained pines and hardwoods (≥3.6 inches in d.b.h.) on the net plots were measured for d.b.h.; about one-fifth of the trees were measured for height, crown dimensions, and age.

A year after the harvest (late September 1991), all woody plants ≤0.5 inches in d.b.h. were counted on a small circular plot centered around each of the 10 permanent points within the net plot. Because of the large number of seedlings present on some plots, a variable plot size was employed. Plot area (either 0.25, 0.5, or 1 milacre) was selected to yield a maximum tally of about 50 pine seedlings. However, 88 percent of the plots were 1 milacre in size. Counts were made using the same procedures as before harvest. Counts were generally made by species, but no distinctions were made between shortleaf and loblolly pines because of difficulties in making field identification at the early stage of seedling development. Multiple-stemmed hardwoods were tallied as one individual, evaluating size for the tallest stem. On each regeneration subplot, the two largest pine seedlings (if any) were selected as the dominant pine seedlings and were measured for groundline diameter, height, and crown width. These seedlings were also classified as being free-to-grow or overtopped by understory vegetation and/or overstory trees; the species group of the overtopping vegetation was recorded. Saplings were evaluated on a 0.01-acre plot using the same procedure as before harvest.

Horizontal coverage of competing vegetation was ocularily estimated on each milacre plot as before harvest.

Seed production was monitored from October 1990 through February 1991 in three 0.9-ft^2 seed traps per plot; they were located about 30 feet from the plot center in a triangular pattern and were about 100 feet from the outer plot boundary. Seed viability was determined by splitting seeds and inspecting the contents (Bonner 1974). Seeds with full, firm, undamaged, and healthy tissue were judged to be potentially viable. Shortleaf pine seeds were distinguished from those of loblolly pine by size (shortleaf pine seeds are smaller than loblolly pine seeds) and the amount of force required to split the seeds (shortleaf pine seeds require less force than loblolly pine seeds).

Data Analysis and Modeling

Mean values were calculated from the 10 regeneration subplots for each net plot. Milacre plots were considered stocked by pine and hardwood regeneration if at least one seedling was present for the species or species group. Mean seedling height was calculated from the number of seedlings in each height class and the class midpoint. Overstory basal areas were determined from the inventory conducted on each net plot after harvest.

After evaluating several candidate functions, the following form was selected for analysis of regeneration and understory vegetation:

$$Y = \exp(b_0 + b_1PBA + b_2HBA) \quad (1)$$

where Y is the response variable; PBA is the pine basal area after harvesting in ft^2/acre; HBA is the hardwood basal area after harvesting in ft^2/acre; and the b_i's are coefficients to be determined. Response variables were size, number, and stocking of pine and hardwood seedlings and the coverage of understory vegetation. Equations were fitted by nonlinear least squares regression using the SAS procedure MODEL (SAS Institute 1988). Variables were eliminated from the full model if their coefficient did not significantly differ from zero at a probability level of ≤ 0.10.

Results

Pine Seed Production

A bumper seed crop was produced in 1990. Seed production was weakly related to pine basal area as indicated in the following equation, presented with fit index (FI), root mean square error (RMSE), mean seed production ($\bar{Y}$), and degrees of freedom (DF):

$$Y = \exp(-0.130 + 0.0113PBA) \quad (2)$$

where FI = 0.16, RMSE = 0.348, $\bar{Y}$ = 1.46, and DF = 16.

In this equation, seed production (Y) is in millions of sound seeds per acre, and pine basal area (PBA) is restricted to the trees of seed producing sizes (ft^2/acre in trees $\geq$12 inches in d.b.h.). Predicted values range from 1.25 to 1.75 million seeds per acre. Grano (1970) found that loblolly pine stands with a long history of uneven-aged silviculture maximized seed production at basal areas of 60 to 70 ft^2/acre. Hardwood basal area had no significant effect on pine seed production in this first year of the study. Others have reported that release and hardwood control substantially improves pine seed production (Phares and Rogers 1962, Wahlenberg 1960, Yocum 1971). Undoubtedly, it is too soon to expect a response to the treatments imposed in this study, because the pine reproductive cycle requires 2 years for completion.

The mixed shortleaf-loblolly pine composition of the study area allows an interesting comparison of the two species' seed production capabilities. For this comparison, we expressed relative seed production of the two species in terms of their respective basal areas in trees of seed producing sizes. Shortleaf pine produced 40,000 sound seeds per unit of basal area compared to 16,000 for loblolly pine--a significant difference (P = 0.001). Of course, this observation period is too short to draw any broad conclusions, but it does demonstrate that shortleaf pine can at times be a prodigious seed producer. Most of the data collected on shortleaf pine seed production has been restricted to poorer sites (Wittwer and Shelton 1992), and it has not been adequately studied on the better sites. We will continue monitoring seed production in this study to determine if this pattern continues.

Regeneration Density

Only 42 pine seedlings and saplings per acre occurred in the study area before harvest (table 1). This lack of advanced pine regeneration reflects the high overstory basal areas and the controlled burn conducted before harvest. By contrast, a total of 13,000 hardwood root stocks was present before harvest. Shrubs and other small trees (OST), which were the most tolerant members of the understory, made up the bulk of this total (84 percent). The number of hardwood seedlings and saplings showed

Table 1. *Mean number of seedlings and saplings before harvest (1990) and the seedlings 1 year after harvest (1991).*

Species group	1990			1991
	Seedlings	Saplings	Total	Seedlings [1]
	(number/acre)			
Pines	28	14	42	32,000*
Oaks [2]	800	100	900	800
OLT [3]	890	240	1,130	970
OST [4]	5,400	240	5,640	2,100*
Shrubs [5]	5,200	110	5,310	4,900
Nonpine total	12,290	690	12,980	8,770*
Overall total	12,318	704	13,022	40,770*

[1] Only one sapling (a pine) was tallied on 180 regeneration subplots; it is not shown. An asterisk indicates that the analysis of variance testing between the totals in 1990 and 1991 was significant at a probability level of 0.05.

[2] Principally water oak (*Quercus nigra* L.), white oak (*Q. alba* L.), and southern red oak (*Q. falcata* Michx.)

[3] Other large trees--principally blackgum (*Nyssa sylvatica* Marsh.), sweetgum (*Liquidambar styraciflua* L.), black cherry (*Prunus serotina* Ehrh.), and hickory (*Carya* spp.).

[4] Other small trees--principally dogwood (*Cornus florida* L.), red maple (*Acer rubrum* L.), and winged elm (*Ulmus alata* Michx.).

[5] Principally American beauty-berry (*Callicarpa americana* L.), huckleberries (*Vaccinium* spp.), hawthorns (*Crataegus* spp.), and viburnums (*Viburnum* spp.).

no significant relationship with the overstory basal areas in the unharvested stand.

One year after harvesting, the number of pine seedlings averaged 32,000/acre (table 1). Nearly all of these seedlings came from the 1990 seed crop. The large number of pine seedlings reflected the bumper seed crop, the favorable seedbed conditions resulting from harvest, and the reduced competition levels from the harvest and vegetation management. Although this seedling density appears high, overstocking is not anticipated to be a future problem because of logging damage during subsequent cycle cuts, self-thinning, and suppression by the overstory.

The number of hardwoods present 1 year after harvest reflects the net effects of several stand disturbances, and changes are thus more difficult to interpret. Multiple sources of hardwood seedlings include: (1) seeds from the 1990 seed crop (where a hardwood overstory was retained) and dormant older seeds of some species, (2) advanced regeneration that was below the minimum size limit for herbicide treatment, and (3) sprouting of harvested stems and submerchantable stems that were top-killed during logging and/or the herbicide application. Thus, the means in table 1 reflect the net change of these gains and losses. The OST group was the only species group that showed a significant decrease in seedling numbers, which declined by over one-half. The total for the nonpine groups was reduced by about one-third--a significant difference. However, a considerable hardwood component still exists within the stand despite the high level of disturbance. The major effect of this disturbance was a drastic reduction in hardwood size, with the virtual elimination of all unwanted merchantable trees and saplings, and a slight reduction in the number of seedlings. However, the silvicultural goal of these treatments appears to be accomplished: the reduction of hardwoods to a level that allows an acceptable pine component to capture the understory niches rather than to totally eliminate all competition.

One year after harvesting, the number of seedlings in the other large trees (OLT) group and the percentage stocking of pine and OLT seedlings were significantly affected by the overstory basal areas (table 2, equations 3, 4, and 5). These effects probably reflect the shade intolerance of the pines and OLT, which were the most intolerant of the represented species groups. Overstory basal areas explained 25 to 47 percent of the variation in these

Table 2. *Equations and associated statistics for regeneration and the coverage of understory vegetation 1 year after harvest.*

Equation [1]	Fit index [2]	Root mean square error	Mean value of Y	Equation number
Number per acre:				
OLT = exp(7.26 - 0.0261HBA)	0.38	451	972	(3)
Seedling stocking (percent):				
Pine = 100 - exp(-1.29 + 0.0458PBA + 0.0594HBA)	0.50	11.9	85.6	(4)
OLT = 100 - exp(3.86 + 0.0101HBA)	0.25	14.3	42.8	(5)
Mean seedling height (feet):				
Pine = exp(0.301 - 0.0162PBA - 0.0142HBA)	0.40	0.127	0.429	(6)
OLT = exp(2.54 - 0.0340PBA - 0.0196HBA)	0.45	0.542	1.40	(7)
OST = exp(0.0706 - 0.0119HBA)	0.19	0.313	0.886	(8)
Dominant pine size [3]:				
GLD = exp(-1.81 - 0.0134PBA - 0.0130HBA)	0.56	0.0120	0.0619	(9)
HGT = exp(0.296 - 0.0133PBA - 0.0126HBA)	0.57	0.0932	0.514	(10)
CRW = exp(-0.994 - 0.0131PBA - 0.00872HBA)	0.35	0.0345	0.152	(11)
Understory vegetation (percent coverage):				
Herbs = exp(1.89 - 0.0275HBA)	0.41	2.12	4.39	(12)
Vines = exp(3.83 - 0.0326PBA - 0.0170HBA)	0.29	2.95	5.65	(13)
Hardwoods = exp(2.06 - 0.0137HBA)	0.20	2.55	6.31	(14)
Total = exp(4.13 - 0.00806HBA)	0.21	12.1	54.4	(15)

[1] There are 15 degrees of freedom for equations with 2 independent variables and 16 for those with 1 independent variable.

[2] $$\textit{Fit Index} = 1 - \sum (Y_i - \hat{Y}_i)^2 / \sum (Y_i - \bar{Y})^2$$

[3] GLD = groundline diameter (inches); HGT = height (feet); CRW = crown width (feet).

response variables. The effects of basal area were consistently negative. Hardwood basal area was the most important variable, and pine basal area was significant only for pine stocking. The stocking of pine seedlings was 96 to 98 percent for the pure pine overstories; comparable values were 74 to 87 percent when a hardwood basal area of 30 ft^2/acre was retained (fig. 1). However, all these stocking levels for pine seedlings exceed the minimum acceptable limit for uneven-aged pine stands of 200 submerchantable stems per acre and 50 percent milacre stocking (Cain and others 1987).

The lack of a negative influence of basal area on the number of pine seedlings may in part be due to the fair degree of shade tolerance displayed by young pines (Becton 1936, Bormann 1956, Wahlenberg 1960). Seedlings can become established and subsist in low light intensities for a number of years before dying. This early shade tolerance of loblolly and shortleaf pines is one of their most favorable attributes

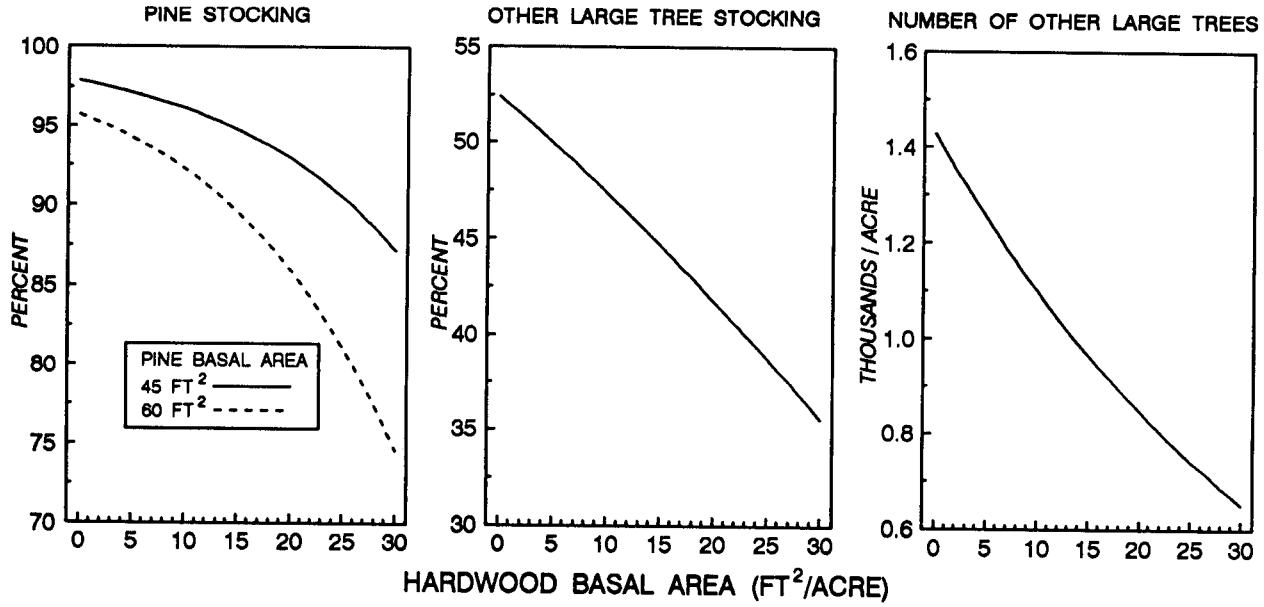

Figure 1. *Effects of overstory basal areas on pine and OLT seedlings 1 year after harvest.*

for the successful application of uneven-aged silviculture.

Regeneration Size

The pine species group had the shortest seedlings both before and 1 year after harvest (table 3). The tallest seedlings were the oaks and members of the OLT group, both before and after harvest. All groups except the shrubs increased in mean height 1 year after harvest; the increase was greatest for the OLT group.

Table 3. *Mean seedling height for species groups before harvest in (1990) and 1 year after harvest (1991).*

Species group	Year [1]	
	1990	1991
	(feet)	
Pines	0.2b	0.4d
Oaks	1.0ab	1.2ab
OLT	1.0ab	1.4a
OST	0.6ab	0.9bc
Shrubs	0.8ab	0.8c

[1] Means of a column with the same letter are not significantly different by Duncan's multiple range test (P = 0.05).

Mean seedling heights of pines and members of the OLT and OST groups were significantly affected by overstory basal areas, which explained 19 to 45 percent of the variation (table 2; equations 6, 7, and 8). Basal area effects were consistently negative. For these species groups, mean seedling heights for the lowest pine basal area with no hardwoods were roughly twice as tall as that for the greatest pine-hardwood basal area (fig. 2). The effects of varying levels of overstory basal area are exerted through higher levels of competition for limited resources--namely light and water.

Groundline diameter, height, and crown width of the dominant pine seedlings (the two largest per subplot, if present) were also negatively affected by both the pine and hardwood overstory basal areas, with fit indices ranging from 0.35 to 0.56 (table 2; equations 9, 10, and 11). The dominant seedlings in the plots with the lowest pine basal area and no hardwoods were consistently about twice as large as those in the plots with the greatest pine-hardwood basal area.

Overtopped Status

The dominant pine seedlings were classified as being free-to-grow or overtopped by understory vegetation and/or overstory trees. Fifty-six percent of these seedlings were classified as being free-to-grow from understory vegetation. The percentage of dominant seedlings overtopped by understory vegetation was as follows: 36 percent by grasses, 4 percent by herbs, 2 percent by vines, 1 percent by shrubs, and 1 percent by hardwoods. Grasses have been shown to substantially reduce the growth of pine seedlings, and in some understory conditions, pines respond more to herbaceous competition control than to hardwood control (Cain 1988). However, pines will typically grow above such herbaceous competition.

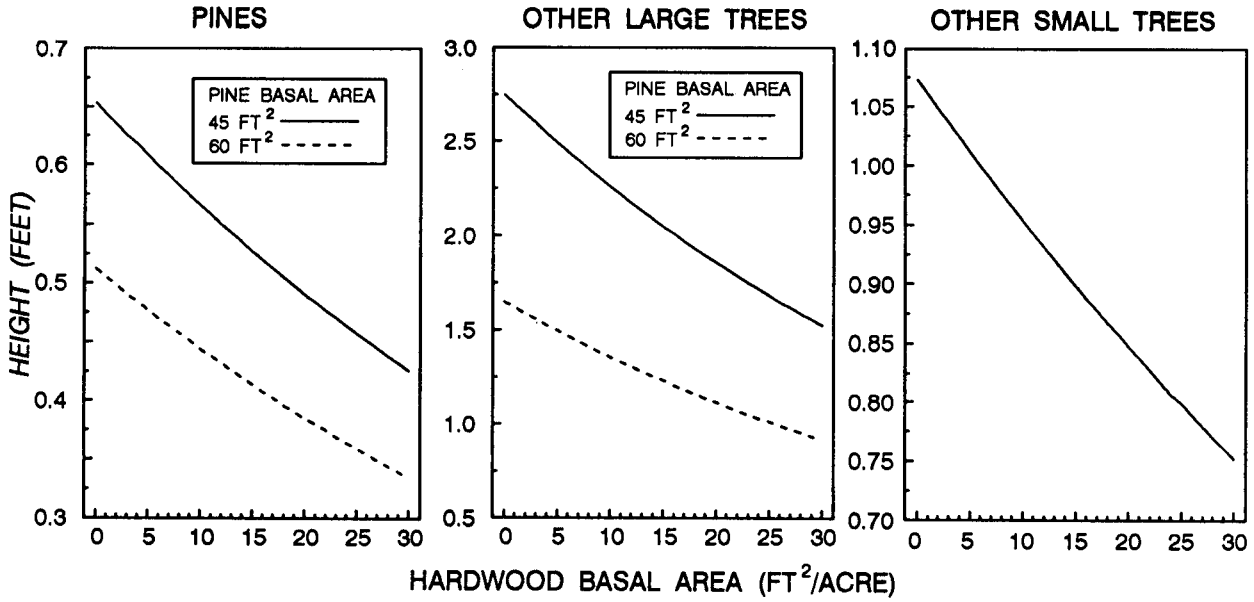

Figure 2. *Mean seedling height 1 year after harvest.*

As would be expected, the overtopping by overstory trees strongly reflected the overstory basal areas, and the percentage of overtopped seedlings ranged from 48 percent, for the lowest pine basal area with no hardwoods, to 93 percent, for the highest pine-hardwood basal area (fig. 3). Overtopping of seedlings by an overstory tree is a common occurrence in uneven-aged stands. Although the development of these seedlings is undoubtedly suppressed, harvesting during subsequent cycle cuts may provide release. An irregular canopy and multiple occupancy are characteristic of uneven-aged stands and are responsible for their complex stand dynamics.

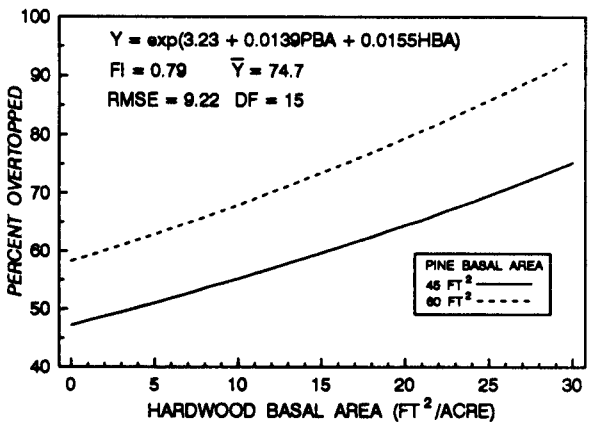

Figure 3. *Percentage of dominant pine seedlings overtopped by overstory trees 1 year after harvest.*

Understory Coverage

Response of the understory to harvesting and hardwood control varied among its components--grasses, herbs, and pines increased in coverage; vines decreased; whereas hardwoods remained the same (table 4). These differences reflect each group's response to the resource rich environment created by stand disturbance. Groups with an opportunistic reproduction strategy, such as pines and grasses, displayed large increases in coverage. A similar response of the understory community has been described for a wide variety of reproduction cutting methods and overstory conditions (Blair and Brunett 1976, Ehrenreich and Crosby 1960, Joyce and Baker 1987, Nixon and others 1981, Schuster 1967, Stransky and others 1986).

Overstory basal areas significantly affected the coverage of herbs, vines, hardwoods, and the total coverage (fig. 4; table 2, equations 12, 13, 14, and 15). Overstory basal areas were consistently negative in their effects and explained 20 to 41 percent of the variation in coverage. Hardwood basal area was the more important variable, and pine basal area was only significant for the vine group. Herbs and vines were the most responsive groups to overstory basal area, and coverage in the lowest pine basal area with no hardwoods was two to three times that in the highest pine-hardwood basal area. A similar response for hardwoods and the total coverage was 1.5 and 1.3 times, respectively.

Table 4. *Mean coverage of understory vegetation before harvest (1990) and 1 year after harvest (1991).*

Species group	Year [1]	
	1990	1991
	(percent)	
Grasses	7	29*
Herbs	1	4*
Vines	9	6*
Shrubs	3	5*
Hardwoods	6	6
Pines	0	7*
Total	26	54*

[1] An asterisk indicates that the analysis of variance testing between years was significant at a probability level of 0.05.

Management Implications and Conclusions

Because of pine's shade intolerance, seedling development will, to some extent, be suppressed in any regeneration cutting method retaining an overstory. Thus, uneven-aged silviculture involves a compromise between the retention of adequate overstory for acceptable merchantable growth and reduction of the overstory to provide the environmental conditions required for regeneration. Pine growth rates in both the overstory and the understory will be below their short-term potential, but this compromise provides a system that is sustainable throughout time. Hardwoods appear to suppress the development of pine seedlings to a greater degree than an equivalent amount of pines, which reflects differences in crown size and foliage geometry. Thus, the threshold levels for retained hardwoods within an uneven-aged pine stand will likely be low, even if the pine basal area is reduced accordingly. However, this study evaluates the effects of hardwoods that are uniformly distributed throughout the stand. Other spatial distributions may be more feasible, such as favoring hardwoods along drainages or in clumps. Such distributions have a number of advantages: (1) optimal species-site relationships, (2) protection of sensitive areas, (3) protection of hardwoods during vegetation management, (4) simplified stand regulation and marking, and (5) providing varied wildlife habitats.

The results presented here are too preliminary to make specific recommendations concerning the threshold levels for hardwood retention within uneven-aged pine stands. Several 5-year cutting cycles may be required before long-term patterns of understory stand dynamics become apparent.

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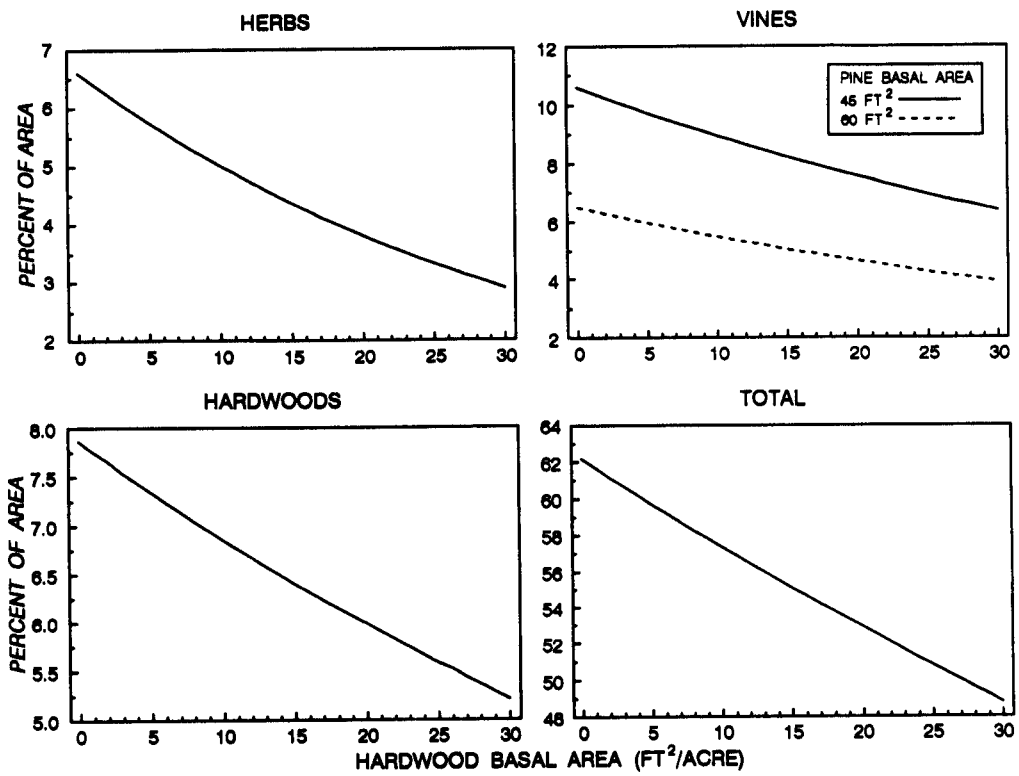

Figure 4. *Coverage of understory vegetation 1 year after harvest.*

NITROGEN AND PHOSPHORUS NUTRITION AFFECTS THE GROWTH PARAMETERS AND MYCORRHIZAL SYMBIOSIS OF NORTHERN RED OAK SEEDLINGS [1]

R.T. Reber and P.E. Pope [2]

Abstract. Stratified *Quercus rubra* L. seeds were sown in 1.9 liter containers with a Plainfield fine sand previously inoculated with one of three species of ectomycorrhizal forming fungi, *Pisolithus tinctorius*, *Hebeloma crustuliniforme* and *Laccaria laccata*. A modified Hoagland's solution was added weekly after shoot emergence to provide nitrogen levels of 0, 100 and 200 ppm, and phosphorus levels of 0, 50 and 100 ppm. Both *P. tinctorius* and *H. crustuliniforme* successfully colonized the root tips of *Q. rubra*. Seedlings that were inoculated with *P. tinctorius* were taller and had greater root, stem and foliage biomass than the other inoculation treatments or the control in most of the fertility regimes. Although *H. crustuliniforme* colonized *Q. rubra*, the physical attributes of the seedlings at most levels of fertility were not increased. High levels of N and P in the soil media promoted seedling growth, but mycorrhizal colonization was significantly decreased at these high levels of fertility.

Introduction

The effects of nitrogen and phosphorus fertilization on seedling growth and ectomycorrhizal development are important to nursery production. The success of outplantings is affected by the quality of nursery stock (Johnson, 1979). Generally, high soil fertility induced by fertilization will decrease mycorrhizal colonization (Marx et al., 1977; Ruehle, 1980; Pope and Chaney, 1984; Ruehle and Wells, 1984). Different ectomycorrhizal fungal species that colonize oak respond differently in colonization efficacy and influence in nutrient uptake.

This study was conducted to determine the effects of N-P fertilization rates on the ectomycorrhizal colonization of northern red oak (*Quercus rubra* L.). Growth of red oak seedlings inoculated with different fungal species was measured. Nutrient uptake, as measured by foliar content, was used to determine the influence of N-P fertilization and ectomycorrhizal colonization on seedling nutrition.

Materials and Methods

Soil Collection and Preparation

Soil was collected from the upper 30-40 cm at the Jasper-Pulaski State Tree Nursery in Pulaski County, Indiana. The soil was a Plainfield fine sand (Typic Udipsamment-mixed mesic). The pH of the soil was 5.2-5.3 and the cation exchange capacity was an extremely low 5-6 cmole (+) Kg^{-1}. Organic matter content was 0.3%-0.5%. Total nitrogen was extremely low (0.02%-0.03%).

The soil was prepared by removing litter and plant roots, and then fumigating with Bromo-A-Bed (98% methyl bromide and 2% chloropicrin; Great Lakes Chemical Corp., West Lafayette, Indiana) at the rate of 0.3 Kg/m^2 soil. After fumigation, the soil was spread out on a plastic sheet to allow for volatization of the methyl bromide before seeds were planted.

Seed Preparation and Inoculation

Northern red oak (*Quercus rubra* L.) seeds were obtained from the Jasper-Pulaski State Tree Nursery. The seeds were collected from three parent trees of exceptional form and uniformity near La Porte in La Porte County, Indiana. The seeds were screened for potential viability by the seed flotation method (Bonner and Vozzo, 1987). The seeds were stratified in polyethylene bags at 5°C for six months (Bonner and Vozzo, 1987). Before planting, the seeds were surface sterilized in a mild detergent solution (Alconox) and rinsed in distilled water.

Three species of ectomycorrhizal fungi were obtained from Mycorr Tech Inc., Pittsburgh, Pennsylvania. The species used were *Pisolithus tinctorius* (inoculum 306), *Hebeloma crustuliniforme* (inoculum HcS166) and *Laccaria laccata* (inoculum

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Graduate Research Assistant and Professor, respectively, Purdue University, West Lafayette, IN. Purdue Agricultural Experiment Station Journal Paper No. 13676.

L1S238). These fungal species were cultured/grown on a vermiculite media supplemented with a nutrient solution. These nutrients were washed out of the vermiculite prior to shipping. The vermiculite media was mixed 1:10 by volume with the Plainfield fine sand in 1.9 L milk cartons with an open bottom to allow unrestricted water flow. A weed barrier mat, between the steel mesh table and the cartons, was used to keep soil in place.

Fertilization and Seedling Care

The seeds were sown in the inoculated soil. For the first four weeks the soil was watered every other day to field capacity. Fertilization treatments were applied after emergence of all shoots, and begining at the end of the fourth week. Each week following 500 ml of a modified Hoagland's solution was added to each container (Hoagland and Arnon, 1950). Both ammonium and nitrate forms of nitrogen were added (1:1 ratio of NH_4 to NO_3). Nitrogen was added at a rate of 0, 100 and 200 ppm. Phosphorus was added at a rate of 0, 50 and 100 ppm. Three days after each application, the seedlings were watered to field capacity with deionized water to reduce the buildup of possible toxic micronutrients and to keep the concentrations of the macronutrients at the same level. Seedlings were grown in a greenhouse for 20 weeks at a photoperiod of 15 h and maximum and minimum temperatures of 35 and 15° C, respectively.

Experimental Design and Seedling Measurements

The study was arranged as a whole plot randomized complete block design (Steele and Torrie, 1980). A random sample of 144 seedlings was analyzed. A total of nine fertility regimes were used, each representing a whole plot. These fertility regimes were comprised of three concentrations of N and P arranged in a factorial design. Fertility regimes were arranged randomly. Each block received a different nutrient treatment and was replicated four times throughout the experiment. Different fungal treatments were used--a control and three fungal species. The data were analyzed by analysis of variance (ANOVA) and means were separated by Duncan's new multiple range test.

At the end of the study (20 weeks), seedlings were harvested. Total leaf area, total leaf dry weight, percent foliar N, percent foliar P, stem height, total seedling dry weight, total lateral root dry weight and percent mycorrhizal colonization was determined for each seedling. Leaf area for each seedling was measured on a Delta-T leaf meter. Two lateral roots were chosen at random from each seedling, stained (Daughtridge et al., 1986), and examined under 50x magnification to assess mycorrhizal development. Foliar tissue was dried at 60°C to a constant weight. Digestions were performed following the methods of Adler and Wilcox (1985). Ammonium nitrogen was determined by steam distillation (Keeney and Nelson, 1982). Phosphorus was determined by a variation of the 1,2,4-amino naphthol sulfonic acid reduced molybdophosphoric blue color method described by Jackson (1958).

Results

To ease the statistical explanation, the physical characteristics of the seedlings associated with the balanced nitrogen and phosphorus nutrient treatments will be compared (N-0 ppm,P-0 ppm; N-100 ppm,P-50 ppm; N-200 ppm,P-100 ppm) when comparisons are made between fungal treatments. Total leaf area was significantly increased by increasing phosphorus levels only in fertility regimes at 100 ppm N. N levels of 100 and 200 ppm produced significantly greater leaf dry weights than 0 ppm N. Total leaf dry weight showed similar results (Table 1). *P. tinctorius* inoculated seedlings produced significantly greater total leaf areas and total leaf dry weights at 100 ppm N and 50 ppm P than the control seedlings. High levels of fertility suppressed differences between leaf area of the control seedlings and *P. tinctorius* inoculated seedlings. *H. crustuliniforme* and *L. laccata* inoculated seedlings did not produce significantly greater leaf areas or total leaf dry weights than the control within a fertility treatment (Table 2).

Averaged over all the fungal treatments (Table 3), leaf tissue %P was significantly greater at high P levels in the fertility treatments. High levels of nitrogen fertilization significantly increased foliar %N at each P fertility treatment. At 100 ppm N and 50 ppm P, seedlings inoculated with *H. crustuliniforme* had significantly greater leaf tissue %P than the control seedlings inoculated with the other fungal species. At higher levels of fertility, the advantage of *H. crustuliniforme* to provide phosphorus for translocation to the foliar tissue was not evident (Table 4). At 0 ppm N and 0 ppm P, seedlings inoculated with *P. tinctorius* had significantly greater leaf tissue %N than the control seedlings and seedlings inoculated with *L. laccata*, but seedlings inoculated with *P. tinctorius* did not have significantly greater

Table 1. Influence of nitrogen and phosphorus fertilization on total leaf area and total leaf dry weight after 20 weeks. Numbers represent the mean for the 3 fungal treatments[1] at a specific nutrient regime.

Total Leaf Area (cm^2)

Nitrogen Fertilization (ppm)	Phosphorus Fertilization (ppm) P-0	P-50	P-100
N-0	192.8a[2]	185.7a	171.3a
N-100	302.2b	428.7c	549.4d
N-200	371.6bc	498.4c	416.0bc

Leaf Dry Weight (g)

Nitrogen Fertilization (ppm)	Phosphorus Fertilization (ppm) P-0	P-50	P-100
N-0	1.2a[2]	1.0a	1.0a
N-100	2.0b	2.6b	3.2bc
N-200	2.4b	3.3c	2.6b

[1] *Pisolithus tinctorius, Hebeolma crustuliniforme* and *Laccaria laccata* mycelium inoculum applied at a rate of 1:10 by volume with the A horizon of a Plainfield fine sand.
[2] Means followed by the same letter are not significantly different by Duncan's new multiple range test ($p=0.05$).

Table 2. *Influence of nitrogen and phosphorus fertilization and mycorrhizal fungal inoculation on total leaf area and total leaf dry weight after 20 weeks.*

Total Leaf Area (cm^2)

N and P Fertilization (ppm)	Control	Pt.[1]	Hebeloma	Laccaria
N-0, P-0	123.3a[2]	201.5a	187.8a	189.0a
N-100, P-50	295.8b	619.5c	364.0bc	302.0b
N-200, P-100	477.8bc	476.0bc	490.3bc	282.8b

Total Leaf Dry Weight (g)

N and P Fertilization (ppm)	Control	Pt.[1]	Hebeloma	Laccaria
N-0, P-0	0.7a[2]	1.3a	1.3a	1.1a
N-100, P-50	1.9b	3.7c	2.3bc	1.9b
N-200, P-100	2.9bc	3.1bc	3.0bc	1.6ab

[1] *Pisolithus tinctorius, Hebeolma crustuliniforme* and *Laccaria laccata* mycelium inoculum applied at a rate of 1:10 by volume with the A horizon of a Plainfield fine sand.
[2] Means followed by the same letter are not significantly different by Duncan's new multiple range test ($p=0.05$).

Table 3. *Influence of nitrogen and phosphorus fertilization on percent foliar phosphorus and nitrogen after 20 weeks. Numbers represent the mean for the 3 fungal treatments[1] at a specific nutrient regime.*

Foliar Phosphorus (%)

Nitrogen Fertilization (ppm)	Phosphorus Fertilization (ppm) P-0	P-50	P-100
N-0	0.11a[2]	0.44b	0.58b
N-100	0.13a	0.25ab	0.39b
N-200	0.11a	0.30ab	0.37b

Foliar Nitrogen (%)

Nitrogen Fertilization (ppm)	Phosphorus Fertilization (ppm) P-0	P-50	P-100
N-0	0.58a[2]	0.56a	0.49a
N-100	1.07b	0.86ab	1.32b
N-200	0.94b	1.44c	1.37bc

[1] *Pisolithus tinctorius, Hebeolma crustuliniforme* and *Laccaria laccata* mycelium inoculum applied at a rate of 1:10 by volume with the A horizon of a Plainfield fine sand.
[2] Means followed by the same letter are not significantly different by Duncan's new multiple range test (p=0.05).

Table 4. *Influence of nitrogen and phosphorus fertilization and mycorrhizal fungal inoculation on percent foliar phosphorus and nitrogen after 20 weeks.*

Foliar Phosphorus (%)

N and P Fertilization (ppm)	Control	Pt.[1]	Hebeloma	Laccaria
N-0, P-0	0.14a[2]	0.11a	0.15a	0.07a
N-100, P-50	0.23a	0.19a	0.36b	0.22a
N-200, P-100	0.27ab	0.39b	0.38b	0.33b

Foliar Nitrogen (%)

N and P Fertilization (ppm)	Control	Pt.[1]	Hebeloma	Laccaria
N-0, P-0	0.37a[2]	0.74b	0.59ab	0.43a
N-100, P-50	0.63ab	0.62ab	1.00b	0.95b
N-200, P-100	1.92c	1.39c	1.42c	1.29bc

[1] *Pisolithus tinctorius, Hebeolma crustuliniforme* and *Laccaria laccata* mycelium inoculum applied at a rate of 1:10 by volume with the A horizon of a Plainfield fine sand.
[2] Means followed by the same letter are not significantly different by Duncan's new multiple range test (p=0.05).

leaf tissue %N than seedlings inoculated with *H. crustuliniforme* (Table 4).

Stem height was significantly affected by N fertility. N levels of 100 and 200 ppm produced seedlings significantly taller than 0 ppm N. Phosphorus increase in the fertility regime did not significantly increase the stem height (Table 5). Total seedling dry weight followed the same trend as stem height. At very low fertility regimes (0 ppm N, 0 ppm P), no fungal treatments increased stem height over the controls. Seedlings inoculated with *P. tinctorius* produced significantly greater stem heights than seedlings inoculated with *L. laccata* and the control seedlings at medium levels of fertility, but not significantly greater stem heights than seedlings inoculated with *H. crustuliniforme* (Table 6). At medium levels of fertility, seedlings inoculated with P. tinctorius significantly increased total seedling dry weight over the control seedlings, but this advantage was not seen at the highest levels of fertility (Table 6).

Lateral root dry weight was significantly affected by the fertility regime. Regardless of the P fertility regime, seedlings receiving 200 ppm N produced significantly greater lateral root mass than seedlings receiving 0 ppm N. The greatest total lateral root dry weight was achieved at 100 ppm N and 100 ppm P (Table 7). At lower levels of fertility there was a trend for seedlings inoculated with *P. tinctorius* and *H. crustuliniforme* to produce greater lateral root dry weights than the control seedlings, but it could not be verified statistically.

At low and moderate nutrient regimes, *P. tinctorius* and *H. crustuliniforme* inoculated seedlings had a higher percentage infection than seedlings inoculated with *L. laccata* or the control seedlings (Table 8). At the highest fertility regime (200 ppm N, 100 ppm P), *P. tinctorius* inoculated seedlings had a higher percentage of root tips colonized than *L. laccata* inoculated seedlings or the control seedlings. Seedlings inoculated with *P. tinctorius* produced significantly more colonization over the control seedlings in all of the fertility regimes. Seedlings inoculated with *L. laccata* did not produce significant colonization in any of the fertility regimes (Table 8).

Discussion

The results of this study indicate that red oak seedlings inoculated with *P. tinctorius* produced greater physical parameters than the control seedlings. This supports previous findings of Pope (1988) and Dixon et al. (1984) who found greater physical parameters in oak seedlings inoculated with *P. tinctorius*. High levels of N in the soil media will produce large seedlings, but mycorrhizal colonization is sacrificed at high levels of soil fertility. Both *P. tinctorius* and *H. crustuliniforme* colonized red oak. *H. crustuliniforme* did not effectively increase many physical attributes of the seedlings, but it was the only fungal species to show an increase in foliar P concentration. *P. tinctorius* inoculated seedlings did not show an increase in foliar P. Mitchell et al. (1984) showed that even though *P. tinctorius* was an effective colonizer of *Quercus alba*, *Quercus velutina* and *Quercus robur*, these seedlings did not show a significant increase in foliar P concentration. Although *L. laccata* colonizes many species in the family Pinaceae (Molina and Chamard, 1983), it did not colonize red oak. This experiment was the first test conducted to determine if *L. laccata* would effectively colonize red oak.

Using red oak as an indicator species of fungal efficacy, mycorrhizal colonization by *P. tinctorius* and *H. crustuliniforme* would be greater on nutrient-rich sites than on poor sites. *P. tinctorius* would be an excellent choice for inoculating nursery beds to produce large seedings for use in outplantings. *P. tinctorius* has been shown to be an effective colonizer and growth promoter on oak seedlings in nursery beds (Pope, 1988; Dixon et al., 1981). This would produce a seedling with ample shoot growth. Large red oak seedlings have shown greater success in outplantings (Johnson et al., 1986). This greater shoot growth suggests that future studies should be conducted to determine the influence of seedling balance on outplanting survivability and growth.

Conclusions

Seedlings that were inoculated with *P. tinctorius* produced the most significant gains in physical parameters. Although seedlings inoculated with *H. crustuliniforme* exhibited a significant amount of the symbiont, physical parameters were not significantly increased in most cases. *L. laccata* did not prove to be a successful colonizer of red oak. *P. tinctorius* would be the best fungal species to be used in nursery beds planted with red oak.

Table 5. *Influence of nitrogen and phosphorus fertilization on stem height and total seedling dry weight after 20 weeks. Numbers represent the mean for the 3 fungal treatments[1] at a specific nutrient regime.*

Stem Height (cm)

Nitrogen Fertilization (ppm)	Phosphorus Fertilization (ppm) P-0	P-50	P-100
N-0	11.8a[2]	11.4a	12.0a
N-100	18.6ab	24.6b	28.6b
N-200	21.6b	28.3b	29.0b

Total Seedling Dry Weight (g)

Nitrogen Fertilization (ppm)	Phosphorus Fertilization (ppm) P-0	P-50	P-100
N-0	4.9a[2]	4.6a	4.4a
N-100	8.7b	9.8b	12.1b
N-200	9.4b	11.4b	9.3b

[1] *Pisolithus tinctorius, Hebeolma crustuliniforme* and *Laccaria laccata* mycelium inoculum applied at a rate of 1:10 by volume with the A horizon of a Plainfield fine sand.
[2] Means followed by the same letter are not significantly different by Duncan's new multiple range test (p=0.05).

Table 6. *Influence of nitrogen and phosphorus fertilization and mycorrhizal fungal inoculation on stem height and total seedling dry weight after 20 weeks.*

Stem Height (cm)

N and P Fertilization (ppm)	Control	Pt.[1]	Hebeloma	Laccaria
N-0, P-0	11.1a[2]	12.1a	10.8a	12.7a
N-100, P-50	14.4a	35.9b	22.0ab	15.9a
N-200, P-100	30.4b	29.8b	31.4b	25.8b

Total Seedling Dry Weight (g)

N and P Fertilization (ppm)	Control	Pt.[1]	Hebeloma	Laccaria
N-0, P-0	4.1a[2]	5.4a	4.7a	4.7a
N-100, P-50	7.1ab	12.2c	8.9bc	8.5b
N-200, P-100	9.7bc	11.5c	9.7bc	6.7ab

[1] *Pisolithus tinctorius, Hebeolma crustuliniforme* and *Laccaria laccata* mycelium inoculum applied at a rate of 1:10 by volume with the A horizon of a Plainfield fine sand.
[2] Means followed by the same letter are not significantly different by Duncan's new multiple range test (p=0.05).

Table 7. *Influence of nitrogen and phosphorus fertilization on lateral root dry weight after 20 weeks. Numbers represent the mean for the 3 fungal treatments[1] at a specific nutrient regime.*

Nitrogen Fertilization (ppm)	Total Lateral Root Dry Weight (g) Phosphorus Fertilization (ppm) P-0	P-50	P-100
N-0	0.72a[2]	0.75a	0.61a
N-100	0.91ab	1.10ab	1.71b
N-200	1.36b	1.40b	1.41b

[1] *Pisolithus tinctorius, Hebeolma crustuliniforme* and *Laccaria laccata* mycelium inoculum applied at a rate of 1:10 by volume with the A horizon of a Plainfield fine sand.
[2]Means followed by the same letter are not significantly different by Duncan's new multiple range test (p=0.05).

Table 8. *Influence of nitrogen and phosphorus fertilization and mycorrhizal fungal inoculation on lateral root dry weight and percent mycorrhizal colonization after 20 weeks.*

N and P Fertilization (ppm)	Total Lateral Roots Dry Weight (g) Control	Pt.[1]	Hebeloma	Laccaria
N-0, P-0	0.59a[2]	0.78ab	0.75ab	0.64a
N-100, P-50	0.70ab	1.28b	1.18b	0.87ab
N-200, P-100	1.10b	1.47b	1.00b	1.70b

N and P Fertilization (ppm)	Mycorrhizal Colonization (%) Control	Pt.[1]	Hebeloma	Laccaria
N-0, P-0	7.4b[2]	66.4d	42.3c	9.7b
N-100, P-50	1.9a	43.2c	11.4b	4.4a
N-200, P-100	1.2a	13.2b	7.0ab	2.7a

[1] *Pisolithus tinctorius, Hebeolma crustuliniforme* and *Laccaria laccata* mycelium inoculum applied at a rate of 1:10 by volume with the A horizon of a Plainfield fine sand.
[2] Means followed by the same letter are not significantly different by Duncan's new multiple range test (p=0.05).

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COVARIATE ANALYSIS OF NORTHERN RED OAK SEEDLING GROWTH [1]

Donald J. Kaczmarek and Phillip E. Pope [2]

Abstract. Generally, northern red oak plantings exhibit acceptable survival rates, but growth rates are often unacceptable and tend to be highly variable. Research was undertaken with 1-0 northern red oak seedlings to determine if seedling growth following outplanting was related to the initial number of first-order lateral roots. Plantations were established in west central, south central, and southwest Indiana. Seedlings were placed in one of four seedling classes based on the number of first-order lateral roots (FOLR) and were planted with or without root-pruning treatments. Two year net height growth was not influenced by the number of FOLR.

Number of FOLR was positively correlated with seedling size. Analysis of covariance was used with either initial seedling height or initial seedling stem volume as the covariate. In some cases, this technique improved the sensitivity of the analysis. If seedling size is considered, seedlings with a greater number of FOLR did perform slightly better than seedlings with fewer FOLR. This suggests that a combination of seedling morphological characteristics must be considered rather than a single morphological characteristic.

Introduction

Artificial regeneration of oak species is becoming increasingly more common across the eastern United States. Oak plantings have increased as marginal quality farmlands are converted to forest plantations. Increased emphasis has also been placed on securing oak regeneration on high quality sites. On these sites, oaks are often the dominant species in the overstory, but reproduction is sparse or lacking. Planting oak seedlings is an alternative to augment the sparse natural oak regeneration.

These plantings, whether located on former agricultural lands or in forest situations often share two characteristics. Initial seedling survival is usually high, but growth rates are often slow (Hilt, 1977, Loftis, 1979, Loftis and McGee, 1986). While the mean growth rate of planted trees is often disappointing, there are individuals which exhibit growth rates that surpass the mean (Russell, 1973, Johnson et al., 1984). Research to identify the morphological characteristics associated with rapid seedling growth is ongoing and various classification systems have been developed. Northern red oak (Quercus rubra L.) seedlings have been classified based on initial height at the time of planting (Johnson et al., 1984) or by root-collar diameter (Loftis, 1979), but neither method has been consistently reliable for separating seedlings into classes with differing growth potential. Kormanik (1986) demonstrated an effective seedling grading system for sweetgum (Liquidambar styraciflua L.) based on the number of first-order lateral roots (FOLR). He hypothesized that the number of FOLR is the overriding morphological trait determining seedling survival and growth rates after seedlings are planted. Ruehle and Kormanik (1986) proposed that a morphological grading system based on the number of FOLR should be developed and tested for northern red oak.

The objectives of this study were to determine if the number of FOLR are useful indicators of northern red oak seedling quality. Seedlings were placed into one of four classes based on the number of FOLR. Covariate analysis was performed to determine if the initial seedling height or seedling stem volume are important covariates influencing the growth of seedlings in these classes.

Methods

Three planting sites were selected, one located in west-central, one in south-central, and one in south-west Indiana. All sites were former agricultural lands in the early stages of old-field succession. Each planting was enclosed within an electrical fence to reduce deer damage to the seedlings. At all locations, the herbicide OUST (sulfometuron methyl-Dupont)

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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was applied via a high pressure directed spray nozzle at the rate of 2.5 oz/acre.

The planting in west-central Indiana is located in Tippecanoe County. This area is in the Entrenched Valley Section of the Central Till Plain Natural Region (Homoya et al., 1985). The soil at this location is a Fincastle-Starks silt-loam (fine silty, mixed aeric ochraqualfs). The site index for northern red oak was 75 (Soil Conservation Service, unpublished data).

The planting in south-central Indiana is located in Morgan County. This area is classified as the Brown County Hills Section of the Highland Rim Natural Region (Homoya et al., 1985). The soil is an Alford silt-loam (fine-silty, mixed mesic typic hapludalf) with a site index for white oak of 90 (Soil Conservation Service, 1981).

The final planting site is located in DuBois County. This site is located in the Crawford Upland Section of the Shawnee Hills Natural Region. The soil is a Zanesville silt-loam (fine-silty, mixed mesic typic fragiudalf) with a site index for northern red oak of 68 (Soil Conservation Service, 1980).

All seedlings used for this study were obtained from Indiana's Jasper-Pulaski State Nursery at Medaryville, Indiana and were undercut 1-0 northern red oak planting stock at least 30 cm in height with a root-collar diameter of at least 5 mm. Seedlings were placed into one of four classes based on the number of FOLR with a diameter of 1 mm or greater.

Class 1: 13 or more FOLR.
Class 2: 9-12 FOLR.
Class 3: 5-8 FOLR.
Class 4: 4 or less FOLR.

Additional seedling measurements that were made on all seedlings prior to planting included the following:

1. The height from the root-collar to the terminal bud (cm).
2. The root-collar diameter (nearest 0.02 mm).
3. The number of growth flushes.
4. The number of FOLR greater than or equal to 1 mm in diameter.
5. Seedling stem volume (cm^3) was calculated as 1/3 (π r^2 H) where r=radius of the root-collar and H=seedling height.

Two plantings were made at each site. Each planting was arranged in a randomized complete block design. In the first planting, 80 seedlings, 20 of each of the four classes, were planted without any root pruning in holes 20 cm in diameter and 30 cm in depth. In the second planting, 80 seedlings, 20 from each of the three seedling classes, were root-pruned and were planted in slits formed by a KBC planting bar. The taproot was pruned to approximately 20 cm in length and the lateral roots were pruned to a corresponding degree. At each site, comparisons of seedling growth were made between seedling classes in each planting treatment. Comparisons were not made between planting sites or planting treatment within each site. Planting dates were April 9, 16, and 23, 1990 for the DuBois, Morgan, and Tippecanoe County sites respectively.

Duncan's Multiple Range Test was used to separate initial morphological characteristics among seedling classes. Analysis of variance tests were conducted to determine if net height growth through two growing seasons differed among seedling classes at each planting site. Duncan's Multiple Range Test was used to separate mean net height growth by seedling class (SAS Institute, 1985).

A Proc Corr Pearson Procedure (SAS Institute, 1985) was used to calculate Pearson Correlation Coefficients for the relationship between initial morphological characteristics. Covariate analysis was also performed. The covariates chosen for the analysis were initial seedling height and seedling stem volume. Therefore, the analysis will be conducted with four seedling classes based on the number of FOLR and either the initial seedling height or stem volume as the covariate. If either of the covariates was significant, a least-squares mean procedure was used to calculate adjusted mean height growth for seedling classes (SAS Institute, 1985).

Results

Initial morphological characteristics for all non root-pruned and root-pruned seedlings are listed in Table 1. Significant correlations existed between the number of FOLR and seedling height, root-collar diameter, and stem volume (Table 2). Therefore, seedlings in classes with greater numbers of FOLR (higher grade seedling classes) were generally taller, had greater root-collar diameters, and stem volumes.

At each planting site, two-year net height did not differ significantly among seedling classes for non root-pruned seedlings (Table 3). For root-pruned seedlings at the DuBois County site, class 2 seedlings experienced significantly less dieback than class 1 seedlings. There were no significant differences in two-year growth for root-pruned seedlings at the

Table 1. *Initial morphological characteristics of non root-pruned and root-pruned seedlings planted at the DuBois, Morgan, and Tippecanoe County sites.*

Morphological Characteristic	Seedling Class 1	2	3	4	Overall Mean
Non Root-Pruned					
Height (cm)	65.8a (17.5)*	58.6b** (17.0)	53.2b (13.3)	44.9c (12.9)	55.6 (17.0)
Root collar diameter (mm)	9.41a (1.05)	8.49b (1.18)	7.43c (1.16)	6.69d (1.12)	8.01 (1.53)
Number of flushes	3.65a (0.55)	3.52ab (0.60)	3.55ab (0.53)	3.40b (0.49)	3.53 (0.55)
Number of FOLR***	15.7a (3.0)	10.1b (1.1)	6.7c (1.0)	3.0d (1.2)	8.86 (5.0)
Stem volume (cm^3)	15.86a (6.73)	11.61b (5.40)	8.06c (3.64)	5.65d (3.29)	10.29 (6.26)
Root-Pruned					
Height (cm)	64.4a (16.5)	48.2b (10.0)	51.4b (16.6)	46.5b (12.6)	52.6 (15.8)
Root collar diameter (mm)	9.24a (1.34)	7.81b (0.96)	7.35c (0.93)	6.64d (0.92)	7.76 (1.42)
Number of flushes	3.62a (0.52)	3.37b (0.49)	3.47ab (0.54)	3.42ab (0.53)	3.47 (0.52)
Number of FOLR***	16.3a (3.9)	10.3b (1.1)	6.7c (1.1)	3.3d (1.0)	9.2 (5.3)
Stem volume (cm^3)	15.18a (6.98)	7.93b (2.96)	7.62b (3.99)	5.61c (2.53)	9.08 (5.74)

* Numbers in parenthesis indicate the standard deviation.
** Means in the same row followed by the same letter are not significantly different at P = .05 using Duncan's Multiple Range Test.
*** FOLR = First-order lateral root.

Morgan County planting site, while at the Tippecanoe County site class 4 seedlings had significantly less stem dieback than did class 1 seedlings (Table 3).

The fact that increasing numbers of lateral roots were correlated with increasing seedling size indicated that a covariate data analysis could be useful in explaining growth responses of seedlings. By utilizing a covariate analysis, initial size differences among seedling classes are factored into the analysis. When the covariate analysis is conducted, the sensitivity of the test to detect growth trends is significantly improved for non root- pruned seedlings at the DuBois and Tippecanoe County sites. Initial seedling height was a signifigant covariate at both sites and seedling stem volume was a signifiant covariate at at the DuBois County site. Both seedling height and stem volume were significant covariates for root-pruned seedlings at the DuBois and Morgan County sites. The sites and planting treatments for sites where a covariate analysis is appropriate are listed in Table 4. Significant F-values for the covariate indicate that an analysis of covariance is appropriate. The least-squares means are computed for combinations where the covariate analysis is appropriate and are listed in

Table 5. The least-squares means adjusts the mean growth of seedling classes based on the differences in the chosen covariate among the seedling classes.

Table 2. *Correlations between the number of FOLR and initial seedling height, root collar diameter, and stem volume for root-pruned and non root pruned seedlings.*

Characteristic	Prob > F	R^2	r
Non Root-Pruned			
Seedling Height	0.0001	0.2193	0.4683
Root Collar Diameter	0.0001	0.4857	0.6969
Stem Volume	0.0001	0.4136	0.6431
Root-Pruned Seedlings			
Seedling Height	0.0001	0.1347	0.3670
Root Collar Diameter	0.0001	0.5013	0.7080
Stem Volume	0.0001	0.3921	0.6262

Table 3. *Two year net height growth (cm) for non root-pruned and root-pruned seedlings planted at the DuBois, Morgan, and Tippecanoe County sites.*

	Site		
	DuBois County	Morgan County	Tippecanoe County
Seedling Class	Year 2	Year 2	Year 2
Non root-pruned			
1	10.4a	−11.4a	−17.2a
2	3.5a	−5.8a	−22.7a
3	2.4a	−3.5a	−25.9a
4	2.0a	−3.2a	−26.0a
Root-pruned			
1	−14.2a	−10.8a	−41.9a
2	−1.1b	−8.4a	−31.0ab
3	−3.2ab	−11.0a	−34.4ab
4	−4.5ab	−10.0a	−27.7b

Mean net height growth values in the same planting treatment in the same column with the same letter do not differ significantly from each other at P = .05.

The covariate analysis leads to the following conclusions in comparison to the standard one-way ANOVA. From an evaluation of growth of non root-pruned seedlings at the DuBois County site with a standard ANOVA, we conclude that there are no significant differences in two year net height growth among seedling classes. Based on the covariate analysis, initial height and stem volume do influence growth. The adjusted means for height and stem volume reveal that class 1 seedlings exhibit significantly greater growth than seedlings in classes 2, 3, or 4. At the Tippecanoe County planting site class 1 seedlings exhibited significantly less dieback than seedlings in classes 3 or 4. Initial height and stem volume were significant covariates for root-pruned seedlings at the DuBois and Morgan County sites. A standard ANOVA reveals that at the DuBois County site, class 2 seedlings suffered significantly less dieback than class 1 seedlings, while the analysis of covariance with stem volume as the covariate reveals that class 3 seedlings suffered more dieback than seedlings in the other classes. Covariate analysis reveals that height and stem volume were significant covariates for root-pruned seedlings at the Morgan County site but adjusted means did not differ at the 5% level.

Discussion

Based on this study, the number of FOLR, as a single variable, is not a reliable indicator of northern red oak seedling growth potential. Seedling classification based strictly on this variable does not consistently differentiate northern red oak seedlings into groups with different growth potential. This contrasts to earlier work with sweetgum (Kormanik, 1986), which indicated that seedling growth potential could be related to the number of FOLR. In our study, initial seedling height, root-collar diameter, and stem volume were significantly correlated with the number of FOLR when the seedlings were lifted from the nursery. This agrees with earlier work by Schultz and Thompson (1990) which also demonstrated that initial height and root-collar diameter of northern red oak seedlings were related to the number of FOLR. In our study however, the assumed growth advantages of seedlings with large numbers of FOLR at lifting did not carry-over when the seedlings were outplanted under old field conditions. Neither root-pruned nor non root-pruned seedlings in higher grade seedling classes demonstrated significant growth advantages through two growing seasons. The fact that seedlings with greater numbers of FOLR also had greater shoot biomass to support may have offset the potential advantage of increased FOLR development. In a case like this, covariate analysis can often improve the sensitivity of the analysis.

The use of initial seedling height does, under some conditions, improve the analysis and possible interpretations of our experiment. Interpretation of the results of the covariate analysis are that growth did not vary among initial seedling classes, but that

growth was significantly influenced by initial seedling height. The use of the LSMEANS (SAS Institute, 1985) with seedling growth adjusted for initial seedling height reveals that higher grade non root-pruned seedlings do possess a potential growth advantage over lower grade seedlings at the DuBois and Tippecanoe County sites and that the adjusted means were not significant at the 5% level for root-pruned seedlings at the DuBois and Morgan County sites (Table 5). It should be cautioned that there was no actual growth advantage for higher grade seedlings, but rather a potential advantage when the mean growth was adjusted for differences in initial seedling size. Covariate analysis indicates that for a given seedling size, increasing numbers of FOLR are generally advantageous, but that differences in seedling size are more significant than increasing numbers of FOLR. The importance of initial seedling size and balance of seedling morphological traits was demonstrated by Johnson et al. (1984). In this study, large seedlings that were planted without top-pruning treatments were subject to increased stem dieback following outplanting. When these seedlings were top-pruned however, they possessed a growth advantage compared to smaller seedlings. While the number of FOLR a seedling possesses when outplanted may be important when viewed in combination with other morphological characteristics, it does not appear that it should be the sole criteria in assessing northern red oak seedling quality. Ruehle and Kormanik's suggestion that northern red oak seedling quality could be defined on the basis of the number of FOLR has not been conclusively demonstrated. Rather, it appears that northern red oak seedling quality is determined by a combination of morphological traits and that FOLR development should be one of a series of traits examined.

The results of our study indicate that an experiment designed with initial height as a bases for seedling classes would be a better indicator of seedling growth following outplanting than FOLR. If appropriate, the number of FOLR could be used as a covariate.

Table 4. *ANOVA tables for sites and planting treatments or seedling stem where a covariate analysis is appropriate when FOLR volume is used as a covariate.*

		Height as Covariate		Stem Volume as Covariate	
Site	Source	F-value	P>F	F-value	P>F
		Non root-pruned seedlings			
DuBois Co.	Block	0.91	0.5626	1.03	0.4465
	Seedling Class	2.62	0.0649	3.89	0.0164
	Covariate	15.25	0.0004	7.86	0.0080
	Cov*Class	2.52	0.0726	3.89	0.0164
Tipp. Co.	Block	1.10	0.3964	0.72	0.7326
	Seedling Class	1.22	0.3205	0.86	0.4704
	Covariate	7.35	0.0110	2.40	0.1316
	Cov*Class	1.28	0.3003	0.44	0.7282
		Root-Pruned Seedlings			
DuBois Co.	Block	1.27	0.2651	1.36	0.2111
	Seedling Class	2.17	0.1071	2.93	0.0454
	Covariate	7.16	0.0108	5.53	0.0239
	Cov*Class	2.17	0.1074	3.45	0.0256
Morgan Co.	Block	0.94	0.5421	0.73	0.7267
	Seedling Class	0.50	0.6864	0.96	0.4357
	Covariate	8.54	0.0100	4.26	0.0557
	Cov*Class	0.83	0.4954	1.62	0.2240

Table 5. *Mean two year height growth unadjusted and adjusted for initial seedling height and stem volume for non root-pruned and root-pruned seedlings where a covariate analysis is appropriate.*

	Site					
	DuBois County			Tippecanoe County		
		Covariate			Covariate	
Seedling Class	Unadjusted	Height	Stem Vol	Unadjusted	Height	Stem vol
Non root-pruned						
1	10.4 a	12.3 a	14.3 a	−17.2 a	-5.1 a	−1.4 a
2	3.5 a	2.2 b	1.1 b	−22.7 a	-22.4 a	−22.4 a
3	2.4 a	2.0 b	−1.6 b	−25.9 a	-27.6 a	−26.3 a
4	2.0 a	−1.0 b	−0.7 b	−26.0 a	-46.9 b	−41.6 b
	DuBois County			Morgan County		
		Covariate			Covariate	
Seedling Class	Unadjusted	Height	Stem Vol	Unadjusted	Height	Stem vol
Root-pruned						
1	−14.2 a	−11.9 a	−12.7 a	−10.8 a	−1.3 a	0.9 a
2	−1.1 b	−1.5 a	−0.9 a	−8.4 a	−1.9 a	1.5 a
3	−3.2 ab	−7.6 a	−20.3 b	−11.0 a	−8.1 a	−15.5 a
4	−4.5 ab	−2.8 a	−8.8 a	−10.0 a	−14.7 a	−22.2 a

Mean net height growth values in the same planting treatment in the same column with the same letter do not differ significantly from each other at P = 0.05.

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EFFECTS OF WEED CONTROL AND FERTILIZATION ON PLANTATION ESTABLISHMENT AND GROWTH OF GREEN ASH, SWEET GUM, AND LOBLOLLY PINE: FOUR YEAR RESULTS [1]

George M. Hopper, Edward R. Buckner, John A. Mullins [2]

Abstract. The effectiveness of weed control and fertilization for enhancing growth and survival of green ash (*Fraxinus pennsylvanica* Marsh.), sweet gum (*Liquidambar styraciflua* L.), and loblolly pine (*Pinus taeda* L.) planted on wet and dry sites in West Tennessee was evaluated. Bareroot seedlings were planted in spring, 1989. Four treatments were evaluated on each species, 1) fertilized with starter tablets (22-8-2) at time of planting, 2) shield sprayed with herbicide to control weeds, 3) given a combination of fertilization and weed control, and 4) a control receiving no treatment. All species performed better on the wet site than on the dry site. Significantly better growth and survival occurred in the weed control plots compared to all other treatments. After four growing seasons there were no significant differences in height growth among the species tested. Green ash survival was better than that of sweet gum and loblolly pine.

Introduction

Approximately half of Tennessee's land area is forested, of which 85 percent is classified as hardwoods. Most (91 percent) of this forest land is privately owned. Timber management is not widely practiced on privately owned lands in Tennessee. According to recent forest surveys Tennessee's forests are producing at about one-half of their potential.

The options available to landowners for improving forest productivity are somewhat limited. Where there is adequate stocking of desirable species on good sites, timber stand improvement activities in hardwood stands should assure a productive forest. However, high grading, woods grazing and forest fires have left much of Tennessee's hardwood forest in such poor condition that starting over with a "new forest" is the only viable option. As the composition of many existing stands is not of desirable species, planting trees is the only way of establishing a productive stand. Planting also enables capturing the significant gains that tree improvement programs have provided.

There are many public programs now available for private non-industrial landowners to use cost sharing and technical assistance in forest resource management. Many of these landowners are interested in growing trees especially hardwood trees and there is wide variation in the quality of land available for tree crop production.

This study was designed to provide recommendations for landowners interested in planting trees on marginal lands, and to test the practicality of weed control and fertilization for enhancing survival and growth of green ash, sweet gum, and loblolly pine. These are feasible silvicultural practices for the non-industrial, private forest landowner on three tree species that are readily available to landowners in Tennessee.

Methods

Trees were planted in March, 1989 on the West Tennessee Agricultural Experiment Station in Jackson, Tennessee. The Experiment Station is located in the Upper Coastal Plain. The study location was formerly an old pasture.

Two sites were used on the 3-acre study location: a low, flat first bottom (wet site) and 2) a sloping terrace face underlain with a deep sand (dry site). The wet site was poorly drained. Soils on the wet site were Bibb series--a fine, sandy loam. The dry site was highly variable, well drained, and tended to be droughty. Soils on the dry site were Eustis series--a severely eroded loamy, sand.

Prior to planting, the entire study area was sprayed with Gromoxone in an attempt to control a

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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heavy fescue and bermuda grass sod. Heavy weed competition included bermuda grass, fescue, common ragweed, dock, morning glory, giant ragweed, Johnson grass, goldenrod and miscellaneous annuals.

A randomized complete block split-plot design with four blocks was situated on both the dry site and the wet site. Three species--(green ash, sweet gum, and loblolly pine) were randomly assigned to whole-plots within each block. Each whole-plot was split into four sub-plots in each of which four cultural treatments-(control, Fertilization, spot herbicide application and a combined fertilization and herbicide application) were randomly assigned. Each whole plot consisted of four sub-plots (25 trees) planted in five rows of five trees each on a 7' x 7' spacing. Bare-rooted seedlings were provided by Westvaco Corporation and hand planted. Sweet gum seedlings were root pruned to prevent "J" rooting when planting.

Fertilization consisted of placing a slow-release starter tablet (22-2-8) in the closing hole at planting time. In April prior to the fourth growing season, one cup of ammonium nitrate was applied near the base of the fertilized trees. Field fertility levels prior to planting were low for nitrogen, and low to medium for phosphorous and potassium and averaged a pH of 5.3.

Weed control was accomplished by shielding seedlings and spraying with Round-up during each of the four growing seasons, as follows: May 1989, July 1989, June 1990, June 1991, May 1992 and July 1992.

Survival and total tree height was recorded for each tree in the fall of 1989, 1990, 1991 and 1992. The data were analyzed using Type III General Linear Models program and options of Statistical Analysis System (SAS 1985). Mean separations were accomplished with Duncan's Multiple Range option (SAS 1985).

Results and Discussions

After four years trees survived significantly better on the wet site (89%) than the dry site (48%) over all treatments (Table 1). That this was the case despite much greater weed competition on the wet site indicates that adequate moisture compensates for the stresses induced by the intense weed competition. Mortality continued over the four-year measurement period on the dry site while on the wet site most of the mortality was during the first year following establishment (Table 1).

Green ash survival (86%) was significantly higher than loblolly pine (62%) and sweet gum (56%) (Table 1). Mortality for loblolly pine and sweet gum, was most noticeable on the dry site. After four years, percent survival for sweet gum and loblolly pine on the dry site was 28.2 percent and 44.5 percent, respectively. Green ash survival on the dry site was 73.0 percent after four years.

Controlling competition increased the survival percent significantly (Table 1). After four years, trees with weed control averaged 77 survival, whereas plots without weed control, yet fertilized averaged 62 percent survival, and control plots averaged 61 percent survival. Fertilization did not appear to improve survival. This may indicate that the fertilizer starter tablets were of limited or no benefit to early tree establishment. Perhaps the fertilizer was utilized by the weeds rather than the trees.

Site was a factor in total height growth. Trees were significantly taller on the wet site than the dry site (Table 2). After one year, the wet site trees were about six inches taller than the dry site trees, and after four years, wet site trees were approximately one foot taller than dry site trees. There was no significant difference in tree heights by site or treatment at initial planting. Increased tree height on the wet site indicates a better site for tree growth, probably a result of improved moisture availability, in spite of the severe weed competition on the wet site.

Weed control increased height growth. Trees with weed control, both with and without fertilization, were significantly taller than trees without weed control (Table 2). Trees with weed control averaged 9.94 feet in height after four years and only 8.88 feet and 8.69 feet for the fertilizer and check plots, respectively. This increased height growth for the weed control treatment over other treatments was consistent from year one through year four (Table 2).

There were differences in the response of species to the wet or dry site (Table 3). Green ash grew significantly more each year on the wet site than the dry site. Loblolly pine also performed better on the wet site however, the annual growth between the sites was significantly greater only during the first and fourth growing seasons. Sweet gum annual growth was significantly better on the wet site only during the first growing season. The better growth of the sweet gum on the dry site during the fourth growing season, 4.3 feet on the dry site versus 4.1 feet growth for the wet site, may reflect the natural selection process of superior trees on the dry site since only 28 percent survival was present for sweet gum by the fourth year

on the dry site. The variation in yearly performance likely reflects species/site/treatment interactions that could not be deciphered on these particular contrasting sites.

Table 1. *Four year survival percent of green ash, sweet gum and loblolly pine as effected by site, species, and treatment.*

Source	Year 1989	1990	1991	1992
	%Survival			
Site				
Wet	91 a	90 a	89 a	89 a
Dry	59 a	57 b	49 b	48 b
Species				
Green ash	90 a	88 a	86 a	86 a
Sweet gum	64 c	64 b	57 c	56 b
Loblolly pine	73 b	70 b	65 b	62 b
Treatment				
Check	67 b	66 b	62 b	61 b
Fertilized	69 b	66 b	63 b	62 b
Weed Control	83 a	82 a	78 a	77 a
Combined	83 a	82 a	76 a	76 a

*Means not followed by the same letter within a source effect are significantly different at $P<.05$.

Table 2. *Four year heights of trees for sites, and treatments.*

Source	Year 1989	1990	1991	1992
	height (ft)			
Site				
Wet	2.41 a	3.84 a	5.80 a	9.74 a
Dry	1.97 b	3.14 b	5.04 b	8.77 b
Treatments				
Check	2.05 b	3.08 b	5.02 b	8.69 b
Fertilized	2.03 b	3.13 b	5.07 b	8.88 b
Weed control	2.37 a	3.96 a	5.94 a	9.94 a
Combined	2.29 a	3.79 a	5.65 a	9.54 a

*Means not followed by the same letter within a source effect are significantly different at $P<.05$.

Annual height growth also varied among cultural treatments (Table 4). On both sites, green ash and loblolly pine grew better when the weed control treatment was applied (Table 4). The annual height growth gains were in the first and second years. For green ash and loblolly pine this would indicate that weed control during the first and second year of establishment would be recommended.

The growth of sweet gum was better in the weed control treatment only in the second year on the dry site and in the first year on the wet site (Table 4). In general sweet gum appeared less responsive to the weed control treatment than did the other two species. Sweet gum was the only species that grew better in the fertilized plots. This was especially true in year four on the wet site. Though several reports indicate fertilization as a desirable cultural treatment (Vann, 1984) the fertilization in this study with starter tablets did not significantly increase any of the trees growth or survival.

Overall, weed control was the only cultural treatment that appeared to produce significant gains in height growth (Table 4). On the wet site, weed control increased height growth for years one and two and on the dry site weed control increased growth during year two. These increases did not persist beyond year two. Increased height growth due to weed control was probably due to increased available soil moisture. Other studies have suggested similar responses to weed control in seedling survival and growth (Van Sambeek and McBride, 1991; Todhunter and Beineke, 1979; Haywood 1988). Some reports have attributed reduced tree growth in fescue sod to the production of fescue phytotoxins (Rink and Van Sambeek 1985). Since fescue was one of the strong competitors in this study, phytotoxins may be involved in the weed control effects.

Conclusions

Survival, total height and height growth for all species was higher on the wet site than on the dry site. Although competition of grass and weeds was also much more intense on the wet site, the improved moisture conditions probably contributed to the increased establishment and growth. Survival after four years was 89 percent on the wet site versus only 49 percent on the dry site.

Across all species and over both sites, trees with weed control, or combined weed control and fertilizer, performed the best in terms of survival, total height and annual height growth.

The slow release starter tablets did not seem to enhance establishment or tree growth in this study. Perhaps the fertilizer increased weed competition and, in the absence of weed control, was actually a deterrent to seedling performance. However, even on the plots where both fertilizer and weed control treatments were used, trees did not survive or grow significantly better than weed control alone.

There seemed to be some differences among the species tested in regard to site suitability. While sweet gum appeared to out perform other species after establishment on the dry site, its survival was very low (28%). Green ash was the best performer on the

Table 3. *Annual height growth of green ash, sweet gum, and loblolly pine for four years as effected by site.*

	Green Ash				Sweet Gum				Loblolly Pine			
	1989	1990	1991	1992	1989	1990	1991	1992	1989	1990	1991	1992
	annual height growth (feet)											
Site												
Dry	0.48b	1.01b	1.07b	3.87b	0.25b	1.22a	1.70a	4.30a	0.67b	1.41a	1.85a	2.89b
Wet	0.84a	1.88a	2.39a	4.59a	0.66a	1.27a	1.78a	4.15a	1.01a	1.21a	1.73a	3.13a

*Means in columns not followed by the same letter are significantly different at $P < .05$.

Table 4. *Annual height growth for green ash, sweet gum, and loblolly pine for four years as effected by site and treatment.*

Site and Treatment	Green Ash				Sweet Gum				Loblolly Pine			
	1989	1990	1991	1992	1989	1990	1991	1992	1989	1990	1991	1992
	annual height growth (feet)											
Dry												
Check	0.36b	0.72b	1.77a	3.88a	0.27a	1.13b	1.23a	4.57a	0.59b	1.27a	1.98a	2.77a
Fertilize	0.26b	0.58b	1.45a	3.64a	0.34a	1.09b	2.07a	4.54a	0.51b	1.31a	1.80a	2.73a
Weed Control	0.69a	1.58a	1.94a	4.29a	0.36a	1.35a	1.92a	4.24a	0.76a	1.54a	1.79a	3.04a
Combine	0.61a	1.15a	1.63a	3.68a	0.06a	1.31a	1.62a	3.91a	0.83a	1.53a	1.83a	3.02a
Wet												
Check	0.51b	1.66a	2.60a	4.39a	0.62b	1.04a	1.71a	3.46b	0.78b	0.96b	1.59a	2.93b
Fertilize	0.53b	1.69a	2.52a	4.47a	0.59b	0.84a	2.01a	4.62a	0.70b	0.97b	1.66a	2.85b
Weed Control	1.11a	1.70a	2.19a	4.44a	0.76a	1.66a	1.86a	4.10ab	1.29a	1.36a	1.74a	3.48a
Combine	1.22a	2.26a	2.25a	5.04a	0.67b	1.53a	1.55a	4.42a	1.26b	1.22a	1.92a	3.27ab

*Means in columns not followed by the same letter are significantly different at $P = .05$.

wet site during the first four years. The comparative performance of loblolly pine was not affected by site.

Acknowledgements

This research was supported by McIntire-Stennis funds and the West Tennessee Agricultural Experiment Station. The authors wish to thank Dr. James Brown and the staff at the West Tennessee Station for their able assistance in this research. The authors also thank Larry Tankersley and Bill Moschler for their professional reviews of the manuscript.

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EFFECTS OF RESIDUALS ON SUCCEEDING STAND DEVELOPMENT FOLLOWING CLEARCUTTING [1]

Michael J. Young, Robert C. Kellison and Donald J. Kass [2]

Abstract. An upland slope and ridge stand of mixed hardwoods, composed of upland oaks (*Quercus spp.*), blackgum (*Nyssa sylvatica* Marsh.), and red maple (*Acer rubrum* L.), was harvested in 1986. Four harvest treatments were imposed, in which residual basal overstories of 0, 7, 19 and 36 ft^2 per acre were left. Following harvest, the residual stand was dominated by red maple, blackgum, and mixed oaks. Mortality was highest in residuals during the first two years and decreased with increasing residual overstory. Periodic annual increments of residuals over five years decreased from 0.16 inches in the 10 ft^2 plots to 0.08 inches in the 40 ft^2 plots, with very little height growth occurring. Crown length, an indication of epicormic branching, increased by as much as 75% over the 5 year period in the 10 ft^2 treatments. Composition of the regeneration was unaffected by overstory treatments, however, height of the regeneration decreased with higher residual levels. Stem densities of regeneration were greatest under the 40 ft^2 treatments, and seedling-origin stems increased from 5,125 per acre in the 10 ft^2 treatments to over 13,000 per acre in the 40 ft^2.

Introduction

The typical southern Appalachian hardwood stand is dominated by low quality trees resulting from repeated single-tree selection and diameter-limit cuts. Clearcutting is a successful and widely accepted method for refurbishing and regenerating these high-graded stands (Beck 1980, Kellison et al. 1981, Heiligmann et al. 1985).

Following a commercial clearcut, there are often numerous desirable species below merchantable size, cull trees, and/or undesirable species which remain standing. Most silvicultural guides to clearcutting recommend removal or control of residual trees down to about 2 inches in diameter, as it is believed if left standing they will deteriorate in quality and interfere with the development of the new regeneration (Roach and Gingrich 1968, Beck and Della-Bianca 1981). If overstory competition is high enough, it is thought that fast-growing, shade intolerant species may be precluded from developing. In any case, residual trees can be effectively controlled both by physical and chemical means, however, killing or girdling by either chainsaw felling, injection, or basal spray can be a time consuming and expensive endeavor depending on residual stocking levels.

In northern hardwood types where there is a preponderance of valuable, tolerant species such as sugar maple (*Acer saccharum* Marsh.), it has been demonstrated that leaving very small residual basal areas (< 10 ft^2 per acre in the 3 to 8 inch size class) does not inhibit early regeneration of intolerant species. In fact there is a tendency to have higher densities of regeneration present under heavier residual overstories (Marquis 1981). The most noticeable negative affect has been a reduction in growth rate under the heavier residual overstories. Less is understood about the effects of a residual overstory on stand development for more xeric upland oak sites of the Southern Appalachians, as well as for other forest types of the southeastern United States, particularly bottomland hardwood types.

In 1984, the Hardwood Research Cooperative at N.C. State University initiated Regionwide Project #32, the objective of which is to determine the amount of residual basal area that can be tolerated following clearcutting before the number and quality of trees in the succeeding stand are significantly affected. Of primary interest is the effect of residual overstories across different site and stand types throughout the Southeast, including upland slopes and ridges, black river bottoms, red river bottoms, branch bottoms, and wet flats. The information discussed in this paper is for an upland slope and ridge site in the Southern Appalachians.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Associate Director, Director, Hardwood Research Cooperative, North Carolina State University, Raleigh, NC, and Project Forester, North Carolina Forest Service, Morganton, NC.

Materials and Methods

The study site is located near Ashville, North Carolina, on the Bent Creek Experimental Forest in the Pisgah National Forest. The stand selected for study is typical of the Chestnut Oak - Scarlet Oak Type found on poorer sites in the Appalachian Hardwood Subregion (Braun 1950). A preharvest inventory of the treatment plots was performed in 1986 using a 20% strip cruise. The stand contained approximately 13% mixed, upland oaks, 14% red maple, 11% white pine (*Pinus strobus* L.), with the remaining comprised of mixed hardwoods. The age of the stand was approximately 80 years, with an average merchantable basal area of 78.6 ft^2 and an average diameter at breast height (DBH) of 4.7 inches (Table 1). The site indexes for these stands are typically around 50 (base age 50).

Table 1. *Mean initial stand characteristics and postharvest residual stem densities.*

		Residual treatments		
	Initial	10 ft^2	25 ft^2	40 ft^2
Species	---------- Stems/ac ----------			
Red maple	63	20	34	49
White pine	51	0	2	0
White oak	40	4	17	27
Scarlet oak	36	2	2	12
Black oak	22	3	5	5
Chestnut oak	21	7	4	13
Blackgum	19	19	25†	12
Hickories	12	8	7	5
Yellow-poplar	3	0	0	2
Other	191	55	108	82
Total	458	118	204	207
Basal area (ft^2/ac)	78.8	7.0	19.4	35.6
Average DBH (inches)	4.7	3.2	3.7	5.0

† Residual stem densities may be higher than initial values, which represent the mean across all plots and replications.

Prior to harvest, eight plots of 2.0 acres each were established to allow for two replications of four treatments in a randomized complete block design. Plots were marked to achieve three residual treatments goals of 10, 25 and 40 ft^2 of basal area from stems 1.5 inches and larger (exclusive of "wolf" trees). A control treatment in which all residual stems greater than 1.5 inches DBH were felled was included. The stand was then operationally harvested in 1986 using conventional chainsaw felling and rubber-tire skidders.

Following the second and fifth growing season, all residual trees located within permanent strip plots were measured for DBH (inches), total height (feet), % cull of sawlog trees, and crown width and height (feet). The understory vegetation was measured using permanent 1/1000 acre plots located at ¼-chain intervals along the cruise center line. All trees from seedling size to 1.5 inches in DBH were tallied by species, height class ($\geq$ 4 feet or $<$ 4 feet), and origin (seedling or sprout). In the case of multiple sprouts, the number of sprouts emanating from one root system was recorded.

To examine treatment effects on regeneration, the number of trees, which is considered acceptable in stands less than 15 years old (Gingrich 1967), was used as a measure of stand density.

Results and Discussion

Residuals

Following the commercial harvest, the residual treatment plots contained 7.0, 19.4, and 35.6 ft^2 of residual basal overstory (RBO) per acre, which approximated treatment goals (Table 1). Much of the scarlet oak (*Quercus coccinea* Muenchh.), black oak (*Q. velutina* Lam.), white oak (*Q. alba* L.), and chestnut oak (*Q. prinus* L.) were removed, as they formed the larger size classes prior to harvest. White pine, which was underplanted in the stand in the early 1970's, was mainly in the 3-5 inch size class and was chainsaw felled. The remaining residual stand was composed mainly of red maple and blackgum, with increasing proportions of mixed oak present in the higher residual treatments. No attempt was made to control species composition or size distribution of the residual stand, with the exception of eliminating the white pine. The intention was to mimic what would typically be left following a commercial clearcut.

Over the five year period, mortality was 21%, 17% and 14% for the 10, 25 and 40 ft^2 treatments, respectively (Table 2). Mortality was generally highest during the first two years after harvest, and has decreased since then. Very little mortality of red maple and blackgum occurred, while mixed upland oaks, including scarlet, black, white and chestnut oaks, had mortality rates of 44%, 39% and 32%.

Diameter growth of the trees over the five year period was lower on plots having higher RBOs, and was lowest the first two growing seasons (Table 2). Periodic annual increments ranged from 0.16 inches in the 10 ft^2 treatments to 0.08 inches in the heaviest residual plots. Diameter growth was surprisingly good considering that many of the

Table 2. *Growth and characteristics of residual trees 2 and 5 years after harvest.*

Year	1986			1988			1991		
Treatment (ft^2/ac)	10	25	40	10	25	40	10	25	40
Trees/ac	118	204	207	103	195	187	93	170	177
DBH (in)	3.2	3.7	5.0	3.4	3.8	4.9	4.0	4.4	5.4
BA (ft^2/ac)	7.0	19.4	35.6	7.3	19.0	31.2	8.9	21.8	33.7
Total height (ft)	24.5	27.7	35.9	24.3	25.0	34.3	24.6	28.2	34.4
Crown width (ft)	7.8	9.1	10.1	10.1	11.3	11.6	12.0	13.5	13.9
Crown length (ft)	10.7	13.9	16.0	14.6	14.6	17.0	18.9	20.0	23.4
% live crown	43.8	50.1	44.9	60.0	58.1	49.6	76.6	71.0	68.2

residual red maple and blackgum were suppressed trees in the original stand. Marquis (1981) found similar results, in which diameter growth of suppressed sugar maple and American beech (*Fagus grandifolia* Ehrh.) was as high as 0.44 and 0.56 inches per year, respectively. In contrast, height growth of the trees in the current study was consistently poor across all treatments. For the 40 ft^2 treatments, average total height was less in 1991 than in 1986, indicating that some crown dieback was occurring. Also, height growth occurring in the younger trees may have been masked by mortality occurring in the larger size classes.

Epicormic branching is often of great concern when considering residual stocking guidelines. It is well accepted that these buds develop after sudden exposure to light, and that species vary widely in their development of dormant buds. Within a species, epicormic branching is more prolific in younger, smaller trees, and in suppressed trees (Kramer and Kozlowski 1979). Although a direct assessment was not made of epicormics in the present study, crown measurements suggest radical development of epicormic branches. The percentage of live crown increased over the five year period in all residual plots, ranging from as much as 75% in plots having only 10 ft^2, to 34% in the heaviest plots. This increase occurred without a concomitant increase in height growth. The largest increases in the percentage of live crown were observed in the various oak species. Oaks have previously been observed to sprout profusely following thinning (Ward 1966).

Regeneration

Previous work has suggested that even high RBOs (> 20 ft^2 per acre) do not affect stem density of the regeneration, but rather the rate of development. For example, over a five year period there was a significant relationship between RBO, which ranged from 0 to 20 ft^2/acre, and height of the tallest desirable stem per plot (Marquis 1981). Total height was shown to decrease from 4.2 feet in the clearcut plots to 2.2 feet where 20 ft^2 of RBO was retained. There also was an increase in the number of desirable stems with increasing RBO. In our study, the number of stems per acre, a useful indication of stocking during the stand initiation stage, was also greatest on the highest RBO plots, which contained over 40,000 stems per acre following the fifth year (Fig. 1). However, all treatments contained abundant regeneration, stem densities were found to vary little between treatments.

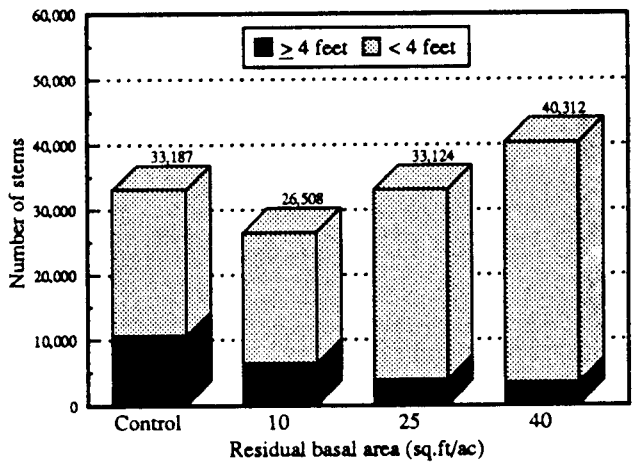

Figure 1. *Effect of residual stocking on total height of regeneration 5 years following harvest.*

The primary effect of RBO on regeneration was on growth. In general, species which express the most rapid early height growth form the upper strata in communities where height growth patterns vary greatly (Oliver and Larson 1990). Under the heaviest RBO, there was over a threefold reduction in the total number of stems ≥ 4 feet in height relative to the clearcut plots (Fig. 1). Among all treatments, the regeneration was dominated by trees < 4 feet in height. Since trees were separated into two different

height classes and height was not actually measured, mean heights cannot be calculated. However, chestnut oak and red maple accounted for the highest relative percentages of stems ≥ 4 feet, the highest occurring in the clearcut plots where 59% and 37% were found in the larger height class, respectively. Both of these species sprout profusely, although it is likely that many of the taller stems were already present as advance reproduction.

Relative densities of the primary commercial species show that red maple has decreased in abundance, but is still the dominant species in the regeneration (Table 3). Most of the mixed upland oaks have decreased in abundance as well, with the exception of northern red oak (*Quercus rubra* L.) and white oak, which have increased in the last three growing seasons. In general, there is no evidence of significant species differences or dominance as affected by varying levels of RBO. As sprouts continue to self-thin, effects of RBO on regeneration, if any, will become more apparent as overstory competition becomes more important.

Stands of mixed upland oak and red maple regenerate primarily by sprout production (Wendel 1975, Beck and Hooper 1986). Five years following harvest the stand is still dominated by sprouts (Fig. 2). A few species such as black cherry (*Prunus serotina* Ehrh.), sweet birch (*Betula lenta* L.), northern red oak, and yellow poplar (*Liriodendron tulipifera* L.) have regenerated almost exclusively from seedling. Red maple reproduction, although dominantly sprout-origin, has also contributed to seedling regeneration.

The number of stems of seedling-origin increased from 5,125 stems/ac in clearcut plots to almost 13,000 per acre in the 40 ft^2 plots. The conditions which exist under the 40 ft^2 treatments are not unlike those found under a heavy shelterwood system, the difference in this case being that the overwood is retained for the full rotation. The overstory not only provides a seed source, but also favors the development of faster-growing, shade intolerant species such as oaks.

Conclusion

Mixed oak and red maple stands growing on poor quality upland slopes and ridges in the Southern Appalachians respond to increasing densities of residual overstories. Diameter growth may be higher where residual stocking is low (< 10 ft^2 per acre), however epicormic branching and mortality can be much higher under the same condition. Less is understood about the effects of residual overstory on regeneration, and additional time and further measurements will be needed to provide definite guidelines concerning regeneration. Preliminary results, however, indicate growth of seedlings and sprouts is reduced under heavier overstories, with very little effect on both species composition or stem densities.

The main implications for land managers are that when considering leaving residual overstories, care must be made in which trees are chosen. Higher quality trees will maintain higher bole quality, have higher survival, and grow much faster than trees which were suppressed or of otherwise poor quality. This is particularly important when future goals include sawtimber, where higher residual levels may account for as much as 1/3 of future stand stocking.

Table 3. *Relative densities (%) of commercial tree species 2 and 5 years following harvest.*

Treatment (ft^2/ac)	Control		10		20		40	
Year	1986	1991	1986	1991	1986	1991	1986	1991
Species	% of total stems							
Red maple	27.2	22.4	49.6	30.1	38.9	14.0	45.6	26.0
Scarlet oak	27.9	10.3	12.9	6.8	21.0	7.9	14.5	6.8
Black oak	4.0	3.4	14.5	6.8	6.4	2.8	11.5	9.5
Chestnut oak	9.3	7.3	<1.0	3.8	1.9	3.4	5.5	5.8
White oak	2.9	3.6	3.2	1.9	4.9	6.0	8.4	9.6
N. red oak	--- †	7.2	---	7.1	<1.0	5.8	---	4.8
Yellow poplar	<1.0	3.0	<1.0	5.6	<1.0	4.0	<1.0	2.0
Blackgum	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Sassafras	1.4	5.1	1.9	3.3	2.4	6.0	<1.0	<1.0

† Dashed lines indicate species not present.

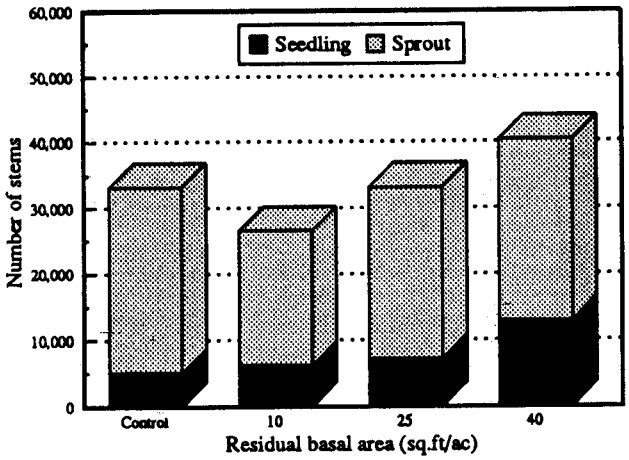

Figure 2. *Effect of residual stocking on stem origin of regeneration 5 years following harvest.*

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Ecophysiology

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SUCROSE METABOLISM AND GROWTH IN TRANSPLANTED LOBLOLLY PINE SEEDLINGS [1]

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Abstract. Loblolly pine (*Pinus taeda* L.) seedling height, root collar diameter (RCD) and the specific activities of three sucrose metabolizing enzymes, namely, sucrose synthase (SS), acid invertase, and neutral invertase, were measured to assess seedling responses to transplant stress. Bare-root nursery-grown loblolly pine seedlings were lifted and transplanted immediately into nearby nursery beds in February 1991. It was found that transplanted seedlings grew less in height and RCD and had lower SS activity than nontransplanted controls during the first 7 months after transplanting. However, the seasonal patterns for seedling growth and SS activity were not changed by transplanting. Stems, with SS as the dominant sucrose metabolizing activity, were a stronger growth sink than taproots between spring and early fall. Taproot SS activity decreased from spring to summer and increased again in late summer. Toward late fall when terminal buds were set and RCD growth stopped, taproot became a dominant growth sink. It was concluded that i) SS was the dominant enzyme for sucrose metabolism in actively growing pine stems and taproots; ii) there were decreases in seedling growth and SS activity in transplanted seedlings as compared with nontransplanted controls; and iii) SS can be used as a biochemical indicator for growth sink strength and for stress caused by transplanting.

Introduction

In the Southern United States nearly 1 billion loblolly pine seedlings are lifted from nursery beds and transplanted onto natural forest sites and former agricultural lands each year (Mangold and others, 1992). Successful plantings depend upon seedlings surviving the stresses imposed by the transplanting process. One of these stresses is water stress caused by loss and damage of fine roots and mycorrhizae, lack of hydraulic continuity between soil and root or within the plant transpiration system, and poor absorption by suberized roots (Burdett and others, 1984; Sands 1984; Marx and Hatchell, 1986; Grossnickle 1988; Johnsen and others, 1988). Thus, it is essential for transplanted seedlings to utilize carbohydrates for new root growth to reestablish soil and water contacts in a short period of time after transplanting (Johnsen and others, 1988).

The carbohydrate source for new root growth varies with tree species. For example, Sitka spruce (*Picea sitchensis* (Borg.) Carr.) seedlings use root starch reserves for new root growth whereas Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings depend on current photosynthates (Philipson 1988).

How transplanted pine seedlings metabolize carbohydrates to survive and resume growth in forest soils is not clear. Sucrose is the major form of translocated carbon in plants including *Pinus* species (Shiroya and others, 1962; Zimmermann and Brown 1971). The roles of three sucrose metabolizing enzymes have been reported with various annual crops (Claussen and others, 1986; Hubbard and others, 1989; Sung and others, 1989a; Xu and others, 1989a), deciduous tree seedlings (Sung and others, 1989b) and germinating *Pinus edulis* seedling (Murphy and others, 1992). The hypothesis we have proposed is that transplanted loblolly pine seedlings adjust their sucrose metabolism both spatially within the plant and temporally over the seasons in order to survive bare-root transplanting and to initiate growth. Here we will show that sucrose synthase (SS) was the major enzyme in pines for sucrose metabolism and that transplanting stress can be expressed biochemically with SS activity.

Materials and Methods

Plant Materials

Loblolly pine (*Pinus taeda* L.) seeds from mixed lots were stratified at 4 °C for 60 days and sown in April 1990 in beds (60 x 4 x 4 ft) at the Whitehall Nursery in Athens, Georgia. Nursery

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1991.

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cultural practices were as described by Kormanik and others (1992). Nursery practices were designed to meet but not exceed the biological needs of the seedlings. Pine seedling growth was regulated by manipulating regimes of water and mineral nutrition instead of mechanically clipping seedling tops or through repeatedly wrenching roots as many nurseries do. In late February 1991, 2000 1-0 nursery-grown seedlings with well-set terminal buds, root collar diameter (RCD) equal to or greater than 1.2 in, and at least four first-order lateral roots were selected and their tap roots trimmed to 8 in. These seedlings were immediately transplanted into adjacent unoccupied nursery beds to minimize possible confounding factors, such as seedling handling, storage, and variations in growth environments. Control seedlings remained in the original beds and were thinned from 26 seedlings/ft^2 to the same density, 6.5 seedlings/ft^2, as the transplanted seedlings. Thereafter, all seedlings received regular watering.

Sampling for enzyme assays began in March 1991 and lasted until December 1991. There were two replicates for each of the 13 sampling dates with 10 to 40 seedlings per sample. Results reported here are averages of the two replicates. Variations in enzyme activities between the two replicates were less than 15 percent at all times.

Two hundred seedlings from each treatment were tagged in June 1991 and heights and RCD were measured monthly. Additional seedlings from each treatment were measured and then lifted for enzyme analyses in order to establish relationship between growth and enzyme activities.

Tissue Preparation for Enzyme Extraction

Root cambial zone tissues were obtained by peeling the bark from taproots and scraping off the inner (xylem-side) cambial tissues with a razor blade. The reason for choosing cambial zone tissues over entire organs for enzyme studies was that cambial tissues are the tissues most indicative of radial tree growth (Zimmerman and Brown 1971; Sung and others., 1989b). The same procedures were followed to obtain stem cambial zone tissues. Stems from the seedlings sampled for root enzyme activities were used. Tissues were taken only from the portion of stem formed during the first year to ensure that tissues from control and transplanted seedlings were comparable. At each sampling date, about 3 g fresh weight of each cambial tissue was obtained.

Enzyme Extraction Procedures

Cambium tissues were immediately placed in liquid N_2 and powdered with a pestle and mortar. Extraction buffer was added to powdered tissues at a 5:1 ratio (v/w) along with 1 percent (w/v) insoluble polyvinylpyrrolidone (PVP), 1 percent (w/v) Dowex-1 chloride form, 0.1 mM phenylmethylsulfonyl fluoride, and sand. The extraction buffer was similar to that by Sung and others (1989b) with 200 mM Hepes/NaOH (pH 7.8), 3 mM Mg acetate, 5 mM dithiothreitol (DTT), 10 percent (v/v) glycerol, and 1 percent (w/v) soluble PVP-40. The homogenate was passed through one layer of Miracloth and centrifuged at 34,000 g for 20 min at 4 °C. The supernatant protein was concentrated with 70 percent ammonium sulfate. The pellet was resuspended in a solution of 25 mM Hepes/NaOH (pH 7.5), 3 mM Mg acetate, 5 mM DTT, and 15 percent (v/v) glycerol and then desalted on a Sephadex G-25 column equilibrated with the same suspension medium. Recovery from the ammonium sulfate concentration step was between 90 and 100 percent for all enzymes tested.

Enzyme Assays

Sucrose synthase (SS), acid invertase (AI), and neutral invertase (NI) were assayed from the same soluble extracts by previously described procedures (Xu et al., 1989a) with minor modifications. SS was assayed with 100 mM sucrose, 0.5 mM UDP, and 1 mM PPi in a two-step enzyme assay. Changes in OD at 340 nm at 25 °C were monitored continuously with a Beckman DU-7 spectrophotometer for SS. AI and NI were assayed with 25 and 100 mM sucrose, respectively. Reaction mixtures were incubated at 25 °C for 15 min and then boiled for 7 min to stop the reaction. All AI incubation mixtures were neutralized with 2 M NaOH before boiling. Activities for all enzymes were proportional to the amounts of each extract. Invertase activities were linear with up to 60 min incubation time. Enzyme specific activities were expressed as nmol per g fresh weight per min.

Results and Discussion

Field performance of transplanted seedlings is usually evaluated at the end of the first growing season based on the percent of seedling survival and seedling growth. Seasonal growth patterns of these transplanted seedlings are generally not followed. Furthermore, from the sucrose metabolism aspect,

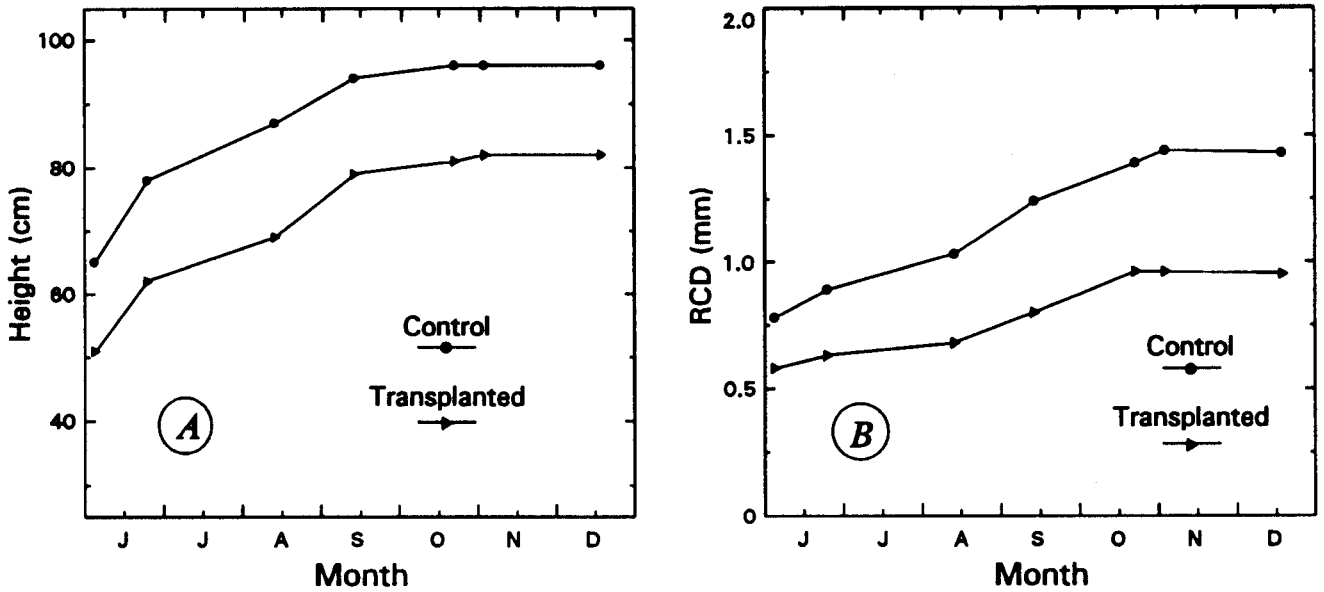

Figure 1. *Cumulative growth of nontransplanted (control) and transplanted loblolly pine seedlings. (A) Seedling height growth. (B) Seedling root collar diameter growth. Average seedling height and RCD at transplanting was 31 cm and 3.77 mm.*

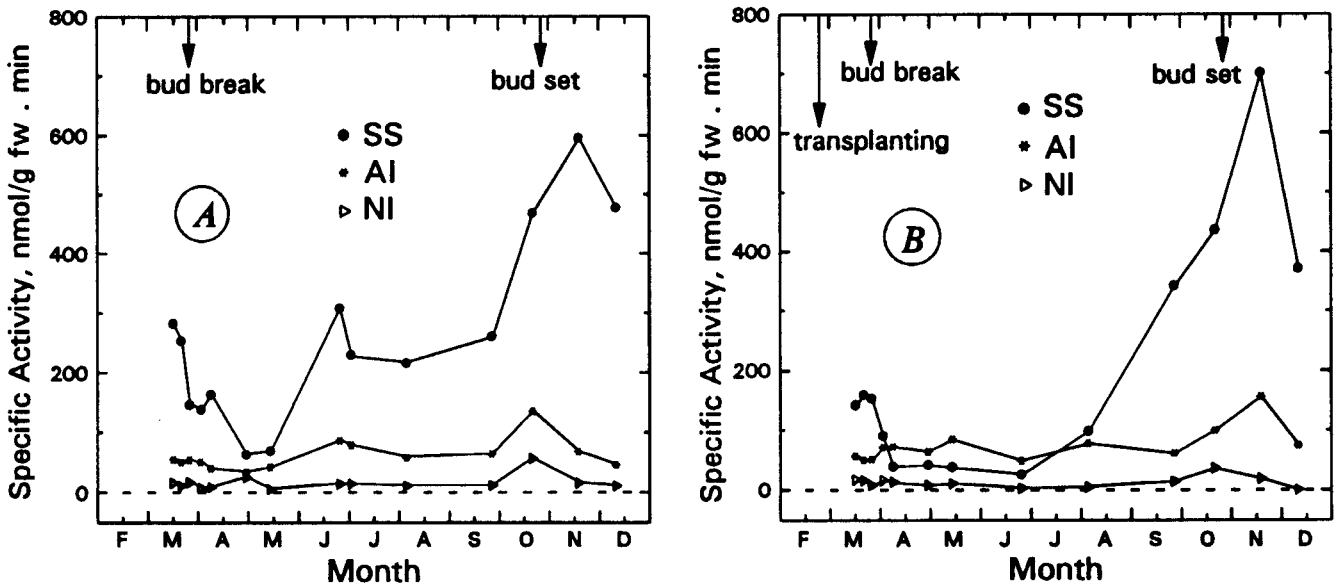

Figure 2. *Seasonal patterns of activity of sucrose metabolism enzymes in (A) nontransplanted control and (B) transplanted loblolly pine seedling taproot cambial tissues.*

Compared to taproots, nontransplanted loblolly pine seedling stems were active in sucrose metabolism from March to mid-November when RCD growth was also active (Figs. 1A & B, 2A, 3A). Thus, there was a spatial pattern with seedling SS activity in addition to temporal patterns observed with stem and root cambial tissues. These SS activity patterns coincided well with periodic growth patterns in loblolly pine stem and roots (DeWald and Feret 1988; Kuhn and Gjerstad 1991; Fig. 1A & B). Therefore, it is possible to biochemically assess the growth status of an organ or plant by measuring SS activity.

Compared with roots of transplanted seedlings, stems of transplanted seedlings were much less influenced by transplanting as measured by sucrose metabolizing enzyme activities (Fig. 3B). SS was still the dominant sucrose breakdown activity in the stems of transplanted seedlings. There was a 40 percent decrease in SS activity in transplanted stems as compared to a maximal 90 percent decrease in transplanted roots throughout the year (Figs. 2B, 3B). No differences in SS activity between stems of transplanted and nontransplanted seedlings were found 7 months after transplanting (Figs. 3A, 3B).

growth loss of transplanted seedlings when compared with nonlifted controls is not addressed. Figures 1A and 1B show the cumulative growth data of seedlings. Bud break of nontransplanted control seedlings occurred toward late March. Within the next 2 months seedling height doubled with another 50 percent increase by September when dormant terminal buds were set (Fig. 1A). Heights of transplanted seedlings increased at similar rates to those of controls from June to September (Fig. 1A). This indicates that height growth was only slowed down during the first three months after transplanting. RCD growth rate of nontransplanted seedlings increased until September, slowed during the following two months and stopped later in the year than height growth (Fig. 1B). Transplanting did not significantly change the temporal pattern of RCD growth except the amount of growth was less in transplanted seedlings (Fig. 1B).

Sucrose Metabolism in Taproot Cambial Tissues of Nontransplanted and Transplanted Seedlings

Throughout the study, SS was the dominant sucrose cleavage enzyme, followed by AI and NI, in nontransplanted loblolly pine seedling taproot cambial tissue (Fig. 2A). Neither invertases showed much oscillation with time whereas SS activity had a definite seasonal pattern (Fig. 2A). SS activity decreased 3- to 4-fold during the period from bud breakage to stem elongation in April and May. From July to September SS activity resumed to before bud breakage levels. There was 100 percent increase in root SS activity after bud set in late September and this activity remained constant through December. This seasonal pattern of SS activity in pine roots was similar to that of sweetgum (*Liquidambar styraciflua* L.) taproot except the latter decreased to minimal levels after leaf abscission in late November (Sung and others, 1989b). Since loblolly pine needles still photosynthesize in winter in the South (McGregor and Kramer 1963; Drew and Ledig 1981), there should be a continuous supply of sucrose to sink tissue, such as pine taproots, for growth in winter (Drew and Ledig 1981; DeWald and Feret 1988; Khuns and Gjerstad 1991). SS has been associated with growth and storage of starch in sucrose importing agriculture crop sinks (Claussen and others, 1986; Sung and others, 1989a). Our results indicate that active root growth in winter is associated with high levels of root SS.

There were no significant changes in either AI or NI activities throughout the season in roots of transplanted seedlings compared with their controls (Fig. 2B). However, there were 50 percent decreases in SS activity in taproots of transplanted seedlings two and half weeks from transplanting (Fig. 2B). These decreases were more pronounced during the period of active shoot elongation. In late June, nontransplanted seedling roots were 10 times more active in SS activity than the transplanted roots (Figs. 2A, 2B). It took taproots of transplanted seedlings 7 months to resume their SS activity comparable to the nontransplanted seedlings. The inability of a taproot of transplanted seedling to metabolize sucrose via SS is obviously a response to transplanting stress. Transplanting stress was also observed toward the end of the year when there was less SS activity than that of the nontransplanted controls. Therefore, our results suggest that growth loss and stresses experienced by transplanted seedlings can be expressed with SS activity.

From April to June when SS activity was at minimal level, AI activity was the dominant sucrose cleavage activity in transplanted seedling roots (Fig. 2B). It has been speculated that due to its higher affinity toward sucrose, compared to that of SS, AI could act as sucrose scavengers in tissues undergoing strong competition for sucrose (Loboda and others, 1990). For example, when there is a great demand for sucrose in actively elongating shoots during spring and summer, AI will be more efficient than SS in metabolizing limited amounts of sucrose available to roots of transplanted seedlings. Thus, transplanted seedlings could survive this critical period and become active when sucrose supply is more available during fall.

Sucrose Metabolism in Stem Cambial Tissues of Nontransplanted and Transplanted Seedlings

Besides roots and new shoots, stems also are a sucrose sink in loblolly pine seedlings. Similar to root cambial tissues, stem cambial tissues contained three sucrose metabolizing enzymes with SS the dominant activity throughout the year (Fig. 3A). Except in the month of December, SS activity was 9- and 25-fold as much as AI and NI activities, respectively (Fig. 3A). The latter two enzymes did not fluctuate with season. Stem SS activity, however, had a temporal pattern similar to root SS except the former decreased drastically to minimal level in mid-December. During April through August, the period of active new shoot growth, SS activity in previous year stems was maintained at constant levels and was only half that in spring and early fall (Fig. 3A).

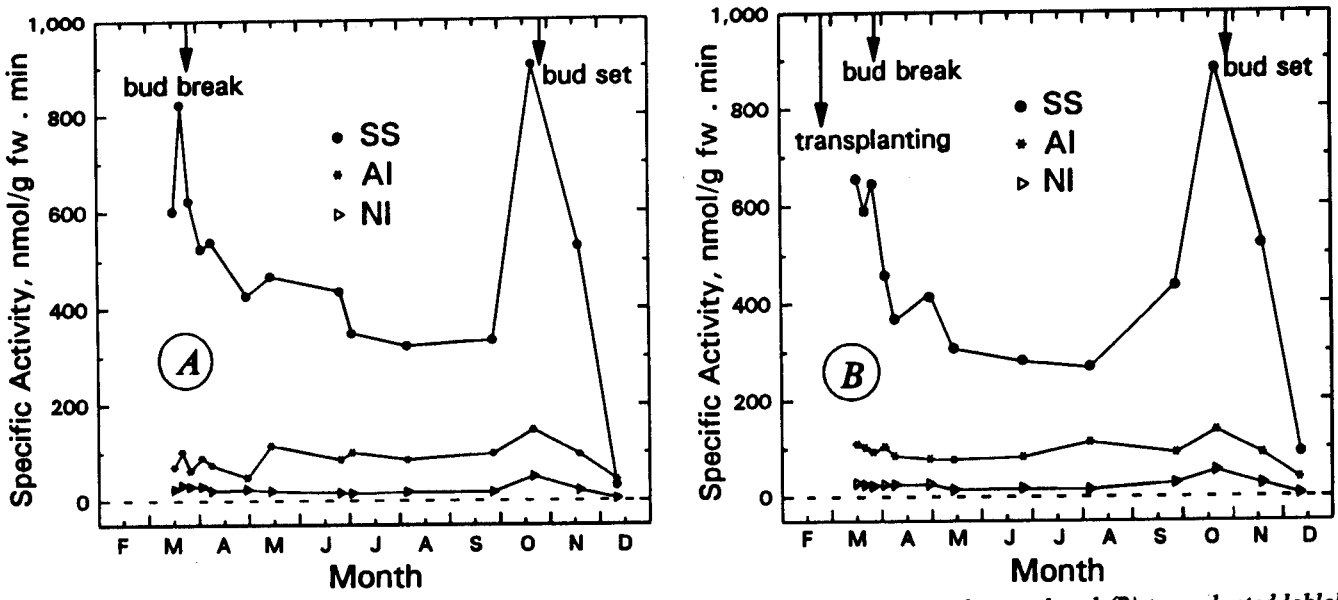

Figure 3. *Seasonal patterns of activity of sucrose metabolism enzymes in (A) nontransplanted control and (B) transplanted loblolly seedling stem cambial tissues.*

The transplanting process neither altered the spatial patterns of SS activity within a seedling nor did it affect the temporal patterns of SS activity in stems and roots. Only the level of SS activity was decreased by transplanting.

Use of Sucrose Synthase as Indicator of Physiological Status of a Seedling

To further demonstrate the feasibility of using SS activity as a biochemical indicator for the physiological status of seedlings under transplanting stress, individual seedlings were measured on June 4 and 24, 1991. Composite tissues from those seedlings with similar growth in RCD during these three weeks were collected and assayed for enzyme activities on June 24. Table 1 presents the relationship between RCD growth and sucrose metabolizing enzyme activities of nontransplanted and transplanted seedlings. Similar to results in Figs. 1B, 2A, 2B, 3A, and 3B, nontransplanted seedlings grew more in RCD and had higher levels of SS and AI activities than transplanted seedlings (Table 1). These data suggested further that SS can be used as an indicator for the physiological status of tissues. High SS activity is associated with rapid growth and low activity is associated with slow growth due to seasonal changes or transplanting stress.

Table 1. *Relationship between second year pine seedling growth and sucrose metabolism enzyme activities.*

Increase in RCD[a]		Enzyme Specific Activity		
		SS	AI	NI
		-------- nmol/g fw. min --------		
Nontransplanted				
mm				
1.67	Stem	518	99	16
	Root	326	99	15
Transplanted				
0.35	Stem	268	52	16
	Root	28	82	4

[a] RCD measurements were taken on June 4 and 24, 1992.

Conclusions

In this study, other stresses generally associated with transplanting process were minimized in order to examine transplanting stress more closely. It is obvious that even under these good growing conditions, transplanted seedlings still lagged 3 to 7 months behind nontransplanted controls in height growth, RCD growth, and sucrose synthase activity. From March to June a nontransplanted pine seedling allocates sucrose for growth between elongating new shoots, previous year stems and roots. Roots have the lowest activities within a seedling. Similarly, roots of transplanted seedlings were the least active in spring and summer. This trend lasted for almost 60 days longer than in the nontransplanted seedlings. This suggests that sucrose synthase may be used as a biochemical indicator for the physiological status of stressed loblolly pine seedlings.

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EFFECT OF ROOT ZONE TEMPERATURE AND WATER AVAILABILITY ON SHORTLEAF PINE LATERAL ROOT MORPHOLOGY [1]

Mary Anne Sword and John C. Brissette [2]

Abstract. The effects of root zone temperature and water availability on *Pinus echinata* Mill. (shortleaf pine) lateral root morphology was assessed. Two open-pollinated families from east Texas were grown in containers. Seedlings of uniform size were chosen, new roots were excised from root systems, and seedlings were transplanted into a seedling growth system. They were exposed to two root zone temperatures and three levels of water availability. After a 28-day treatment exposure period, new roots were severed from the root systems. The length of new roots and new root initiation were quantified.

The length of new roots of seedlings was significantly affected by water availability but not by root zone temperature. Water availability did not significantly affect the number of lateral roots initiated per unit length. The number of lateral roots initiated per unit length was significantly greater at 23°C than at 18°C. This relationship was caused by a significant increase in the number of short roots per unit length. The length of new roots of shortleaf pine families differed in response to water availability.

Results indicate that water availability influences shortleaf pine root elongation to a greater extent than root zone temperature, and root zone temperature influences shortleaf pine lateral root initiation to a greater extent than water availability. A prolonged change in root zone temperature or water availability during shortleaf pine seedling establishment and growth may affect root system development and subsequent seedling survival and growth.

Introduction

Conifer root system morphology is strongly influenced by genetic characteristics (Nambiar et al. 1982, Kormanik 1990). However, root system environment may also affect lateral root initiation and development (Torrey 1986). Moreover, the response of lateral root morphology to the root system environment varies with genotype (Bongarten and Teskey 1987, Nguyen and Lamant 1989, Theodorou et al. 1991).

Root system growth and development are influenced by changes in soil temperature (Nambiar et al. 1979, Andersen et al. 1986) and water availability (Bongarten and Teskey 1987, Nguyen and Lamant 1989). Effects of soil temperature and water availability on root system morphology may be partially attributable to modification of root carbohydrate availability.

Carbohydrate availability in the root system, in part, regulates the initiation and growth of root primordia (Torrey 1986, Coutts 1987). The development of root primordia into short or long lateral roots has been related to primordia size and therefore, is determined before emergence from the parent root cortex (Wilcox 1968, Coutts 1987). Thus, root carbohydrate availability during primordia development may regulate the formation of short and long lateral roots.

Researchers have predicted that a small but steady increase in global atmospheric temperature will occur within the next 40 years (Hansen et al. 1988, Peters 1990). This shift in atmospheric temperature may be accompanied by reduced precipitation (Hansen et al. 1988). Climate change and subsequent modification of soil temperature and water availability may alter lateral root elongation and initiation in the regeneration environment. In addition, the lateral root morphology of southern pine families currently used in artificial regeneration programs may respond differently to small, steady changes in soil temperature and water availability. The objective of this study was to obtain preliminary information on the effect of small changes in root zone temperature and water availability on the lateral root morphology of two open-pollinated families of *Pinus echinata* Mill. (shortleaf pine).

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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Materials and Methods

This pilot study is associated with a larger project designed to determine how seedling root growth and water relations are affected by root zone temperature and water availability after outplanting. Container-grown shortleaf pine seedlings were produced outside using the recommendations of Barnett and Brissette (1986). Eight-month-old seedlings of uniform size were chosen, the peat-vermiculite growth medium was washed from root systems, and new roots were excised. Seedlings were planted in a seedling growth system housed in a greenhouse.

Water baths were used in the seedling growth system to maintain three root zone temperatures: 13°, 18°, and 23°C. Root zone temperature was regulated by injecting cold water into water circulation paths and heating water that was currently circulating. Because little new root growth occurred at 13°C, only seedlings exposed to 18° and 23°C were used in this pilot study.

Soil water availability was controlled with a modification of the system described by Brissette and Chambers (1992), which was adapted from a system presented by Snow and Tingey (1985). Seedlings were potted in masonry sand in polyvinyl chloride (PVC) containers, 20 cm in length (9.8 cm outer diameter), which were sealed at the base with nylon filter cloth (20 μm). Potted seedlings were placed on water columns composed of four floral foam blocks stacked in a 45 cm section of PVC pipe (10.8 cm outer diameter) so that the nylon filter cloth was in contact with the upper floral foam block. Soil water availability was controlled by the height at which root systems were maintained in relation to irrigation reservoirs. Water was supplied from irrigation reservoirs through plastic tubing to the base of each column. The elevation of irrigation reservoirs determined the amount of water transported through the plastic tubing and, therefore, the level of water in the water columns.

This pilot study was conducted using a split plot, randomized block design. Blocks were repetitions in mid-December 1991, late February, 1992, and mid-March 1992. Root zone temperature (18 and 23°C) represented the whole plot treatment. Water availability and seed source were subplot treatments. Water availability treatments were absence of water stress and mild and moderate water stress, and corresponded to mean predawn stem xylem water potentials of −0.61 MPa, −0.62 MPa, and −0.74 MPa, respectively, after a 28-day cultural period. Seed sources were two open-pollinated seed orchard families. Seed was collected in the Texas Forest Service seed orchard from clones that were genetically improved for volume growth.

During each repetition of this study new lateral roots from three seedlings per treatment combination were collected and stored at 4°C. The length of new roots and numbers of short and long lateral roots initiated per unit length were quantified using the line intersect method of Giovannetti and Mosse (1980) which was developed initially for the quantification of vesicles in endomycorrhizal roots. Data associated with individual seedlings represent two perpendicular assessments of each of three random rearrangements of new roots. Short roots were defined as roots that visually appeared ≤ 3 mm in length; whereas, long lateral roots were defined as roots that visually appeared > 3 mm in length.

Data were subjected to an analysis of variance. Differences between treatment means were compared using the LSD test at $P < 0.05$.

Results

The length of new roots of shortleaf pine seedlings was significantly affected by water availability (table 1). The length of new roots of seedlings exposed to moderate water stress was 24 and 34 percent less than those of seedlings exposed to well-watered and mild water stress treatments, respectively. The length of new roots of seedlings increased 21 percent in response to an increase in root zone temperature from 18° to 23°C. However, this effect of root zone temperature was not significant.

Table 1. *Length of new roots of shortleaf pine seedlings exposed to three water availability treatments for 28 days (n = 36)*

Water Availability[1]	Length of New Roots (cm)
1	56.5 a[2]
2	65.0 a
3	42.8 b

[1] 1 = well-watered, 2 = mild water stress, and 3 = moderate water stress.
[2] Means followed by a different letter are significantly different at $P < 0.05$ using the LSD test.

Elevation of root zone temperature from 18° to 23°C significantly increased the number of new roots initiated per unit length (table 2). Seedlings grown at 23°C were characterized by a 107 percent increase in

the number of short roots initiated per unit length when compared to similar seedlings grown at 18°C.

Table 2. *Number of lateral roots initiated per unit length of new roots of shortleaf pine seedlings exposed to two root zone temperature treatments for 28 days (n = 54)*

Root Zone Temperature (°C)	Lateral Roots[1] (Number / 100 cm New Root) Short	Long	Total
18	7.1 b	0.98 a	8.0 b
23	14.7 a	2.22 a	16.8 a

[1] Means within a column followed by a different letter are significantly different at $P < 0.05$ using the LSD test.

A trend was detected between root zone temperature and the percentage of all roots initiated that were short and long lateral roots (table 3). At 23°C, seedlings exposed to well-watered and mild and moderate water stress treatments were characterized by 38, 82, and 104 percent increases, respectively, in the predominance of long lateral roots initiated when compared to similar seedlings grown at 18°C. However, these increases in long lateral root predominance were not significant.

Table 3. *Percentage of all roots initiated that were short and long lateral roots on new roots of shortleaf pine seedlings exposed to two root zone temperature and three water availability treatments for 28 days[1] (n = 18)*

Root Zone Temperature (°C)	Water Availability[2]	Percentage Short Lateral Roots	Percentage Long Lateral Roots
18	1	93.2	6.8
18	2	92.9	7.1
18	3	94.4	5.6
23	1	90.6	9.4
23	2	87.1	12.9
23	3	88.6	11.4

[1] Means within a column are not significantly different at $P < 0.05$ using the LSD test.
[2] 1 = well-watered, 2 = mild water stress, 3 = moderate water stress.

The length of new roots of shortleaf pine families was affected differently by water availability (table 4). The length of new roots of family 1 was significantly greater when exposed to mild water stress than when exposed to well-watered and moderate water stress treatments. The length of new roots of family 2 was not significantly affected by water availability.

Table 4. *Length of new roots of two families of shortleaf pine seedlings exposed to three water availability treatments for 28 days (n = 18)*

Family	Water Availability[1]	Length of New Root (cm)
1	1	52.4 bc[2]
1	2	72.1 a
1	3	34.9 d
2	1	60.7 abc
2	2	57.9 abc
2	3	50.7 cd

[1] 1 = well-watered, 2 = mild water stress, 3 = moderate water stress.
[2] Means followed by a different letter are significantly different at $P < 0.05$ using the LSD test.

Discussion

Our results indicate that small changes in soil temperature and water availability influenced shortleaf pine seedling root morphology as early as 28 days from the time of treatment initiation. Moreover, root zone temperature and water availability had differing effects on the lateral root elongation and new root initiation of shortleaf pine seedlings. Specifically, water availability appeared to have a greater influence on the length of new roots than root zone temperature; and root zone temperature had a more dramatic effect on new root initiation than water availability.

After 27 days, Andersen et al. (1986) found a 143 percent increase in the length of new lateral roots of *Pinus resinosa* Ait. (red pine) seedlings in response to an increase in root zone temperature from 16° to 20°C. Furthermore, Nambiar et al. (1979) reported that after a 32-day cultural period the length of new lateral roots of *Pinus radiata* D. Don (radiata pine) seedlings was 130 percent greater at 20°C than at 15°C. These investigators also found an inverse relationship between the number of new root apices per root system dry weight and root zone temperature. Andersen et al. (1986) suggested that this response may be caused by favored use of carbohydrates for root elongation rather than by new root initiation at the higher temperature.

In the present study, a contrasting pattern of root growth accompanied increased root zone temperature. The length of new lateral roots of seedlings exposed to 23°C was only 21 percent

greater than that of seedlings exposed to 18°C. However, new root initiation increased twofold with an elevation in root zone temperature from 18° to 23°C. This information suggests that species of *Pinus* may differ in their distribution of metabolic resources for lateral root elongation and new root initiation.

Root zone temperature had a dramatic effect on new root initiation of shortleaf pine lateral roots. The number of new roots initiated per unit length was more than 100 percent greater at 23°C than at 18°C. This increase in the intensity of new root initiation may be attributed to a temperature-induced increase in either lateral root primordia formation or the proportion of lateral root primordia that elongated as opposed to those that remained dormant.

Hurewitz and Janes (1983) studied the effect of root zone temperature on ^{14}C-allocation by *Lycopersicon sculentum* Mill. (tomato) and found that root zone warming from 15.6° to 35°C increased root metabolic activity and subsequently root sink strength. In the present study, temperature-induced stimulation of root metabolism may have triggered an increase in root sink strength and carbohydrate availability. As a result, root primordia formation and elongation into lateral roots may have increased.

Previous research has demonstrated that the pattern of root primordia formation within a parent root is genetically regulated (Mallory et al. 1970, Friedman et al. 1979). Formation of lateral root primordia is initiated by appropriate concentrations of auxin and cytokinin (Thimann 1936, Torrey 1956, Macisaac et al. 1989). Auxin is also required for the elongation of primordia into lateral roots (Thimann 1936, Wightman and Thimann 1980). However, in some species the auxin concentration that stimulates primordia formation may inhibit their elongation into lateral roots (Thimann 1936, Wightman and Thimann 1980, Macisaac et al. 1989).

A trend was apparent in the present study for increased short and long lateral root initiation at 23°C compared to 18°C. Using radioisotope techniques, Friedman et al. (1979) determined that newly formed roots, adjacent to root primordia, act as sinks for basipetally translocated auxin. Perhaps basipetal transport of auxin to newly formed shortleaf pine lateral roots reduced the concentration of this growth regulator in adjacent root primordia and allowed elongation of a greater number of primordia per unit length of new lateral root at 23°C than at 18°C.

Root respiration may be stimulated by elevated soil temperature (Barnard and Jorgensen 1977, Hurewitz and Janes 1983, Cropper and Gholz 1991). Conifer root growth is dependent on current photosynthate, however, if current photosynthate is limited, stored root carbohydrates may be used for new root growth (van den Driessche 1987). An increase in soil temperature associated with reduced photosynthesis, elevated respiration, or periods of rapid shoot growth may limit the availability of carbohydrates for root primordia development. This may reduce the abundance and size of lateral root primordia and subsequently increase the predominance of short as opposed to long lateral roots on seedling root systems.

The cultural conditions in our study present an alternative scenario. Seedlings in this study were characterized by negligible new shoot growth during the 28-day cultural period. Although photosynthetic rates were not quantified, cultural conditions in this study imply that these rates were relatively high. This information suggests that although root respiration may have been greater at 23°C than at 18°C, the root carbohydrate concentration was likely to be relatively high at both 18°C and 23°C. In addition, a temperature-induced increase in shortleaf pine root sink strength may have increased the rate of photosynthate translocation to the root system. These factors could have caused an abundance of root carbohydrates that facilitated the formation of larger root primordia. Subsequently, a greater proportion of long as opposed to short lateral roots may have developed, as seen in our study.

Past research has demonstrated that root system developmental processes may respond differently to simultaneous environmental influences. Teskey and Hinckley (1981) observed the root morphological characteristics of mature *Quercus alba* L. (white oak) over a 16-month period and found that the maximum root elongation rate was observed at a soil temperature of 17°C. At soil temperatures lower than 17°C, this soil characteristic appeared to regulate the root elongation rate. At soil temperatures greater than 17°C, soil water appeared to control the root elongation rate. These authors concluded that under field conditions, the most productive root growth occurred with a balance between the rate-limiting factors of soil temperature and water availability.

Theodorou et al. (1991) suggested that the expression of root morphology by radiata pine families exposed to different soil and climate conditions may vary with genotype. In our study, families 1 and 2 exhibited differing lengths of new roots in response to water availability. Our results as well as those of Theodorou et al. (1991) indicate that

the balance between the rate-limiting factors of soil temperature and water availability presented by Teskey and Hinckley (1981) may differ between families adapted to the same region.

Elevated atmospheric concentrations of greenhouse gases have been predicted and may result in an increase in global temperatures (Hansen et al. 1988, Peters 1990). Results of this preliminary study suggest that the root system morphology of shortleaf pine families currently used in artificial regeneration programs could be affected by this change in climate. In the event of global climate change, further study of southern pine root elongation and new root initiation in response to temperature and water availability, and resolution of this information at the family level, will benefit artificial regeneration in the South.

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USE OF STEM-FLOW GAUGES TO MONITOR WHOLE-PLANT TRANSPIRATION OF FIELD-GROWN TREES [1]

Andrew D. Barnes and Walter D. Kelley [2]

Abstract. In past studies seedling transpiration rates have been measured either gravimetrically using potted plants or by use of porometers. Porometers measure transpiration instantaneously on a small sample of leaf; and these readings are then extrapolated to estimate whole-plant transpiration. Transpiration measured gravimetrically gives a direct reading of whole-plant transpiration, but root systems in such studies may be limited by size and shape of the container. Greater understanding of seedling transpiration may be possible by using stem-flow gauges that allow continuous monitoring of transpiration from field-grown seedlings on a whole plant basis. Stem flow gauges monitor transpiration using a heat balance technique based on the dissipation of heat applied to the stem. The applied heat (Q) is dissipated vertically (Q_v), radially (Q_r), and by xylem mass flow (Q_f). Flow rate (g/s) is calculated as:

$$\text{Flow} = (Q - Qr - Qv) / (4.186*dT)$$

where 4.186 is the xylem sap heat capacity (J/g/K) and dT is the temperature gradient (K) across the heater. Stem-flow gauges have been used successfully on field-grown loblolly pine seedlings and are potentially valuable tools to assist our understanding of tree responses to environmental influences.

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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EFFECT OF MOISTURE STRESS ON PHOTOSYNTHESIS AND RESPIRATION IN MATURE LOBLOLLY PINE [1]

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Abstract. The fluxes of carbon dioxide and water vapor from forests are important components that must be quantified if reliable models are to be constructed to predict the effects of increased carbon dioxide, temperature, precipitation and water vapor regimes on forest health and productivity. In 1991, a study was initiated to measure the effect of moisture stress on seasonal and diurnal changes in photosynthesis (Pn), respiration (Rd) stomatal conductance (gs), needle water potential, needle chlorophyll, foliar nitrogen, and tree growth in 19-year-old loblolly pine trees. Two 0.1 ha plots (irrigated and non-irrigated) were established and monthly measurements were taken of physiological variables at lower, mid and upper crown positions by needle age and flush. Light response curves were developed under irrigated conditions to estimate needle quantum efficiency. Detailed climate records were produced. Results will be presented, including developed models of carbon exchange rate as a function of key environmental variables.

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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RESPONSE OF CAMBIAL ACTIVITY AND PHENOLOGY OF MATURE LOBLOLLY PINE TO SOIL WATER DEFICITS [1]

M.A. Said, R.T. Holeman, E.M. Lorenzi, and T.C.Hennessey [2]

Abstract. In 1990, a study was initiated to investigate the relationships between wood development, phenology, soil moisture and climate. Two 0.1 ha plots (one irrigated, one control) were established in a 19-year-old loblolly pine plantation. Year-end wood cores were obtained from the upper, middle and lower bole positions for determination of date of latewood transition, specific gravity, percent latewood and tracheid dimensions. Phenology measurements (needle and branch elongation, needle senescence) were taken every two weeks. Data will be presented to show the relationships between the degree of needle maturation, seasonal soil moisture stress, climate variables and wood development by bole position. In addition to providing knowledge about wood formation in plantation-grown trees, the results are expected to improve models to predict the effects of global change on forest productivity through a better understanding of carbon allocation in trees.

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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SHOOT AND FOLIAGE PHENOLOGY OF MAIN BRANCH TERMINALS OF 15-18 YEAR OLD LOBLOLLY PINE [1]

R.T. Holeman, T.C. Hennessey and P.M. Dougherty [2]

Abstract. Shoot flushing pattern, shoot elongation, needle elongation, and senescence of existing needles were measured annually on the main terminal of 12 branches in each of the upper, mid, and lower crown sections of a 15 to 18-year-old loblolly pine stand. The stand is located in southeast Oklahoma and was thinned to 11.5 m2/ha basal area in 1987. The results indicate that flushing patterns, shoot and needle development, and needle senescence vary widely between crown positions. Average total shoot length for branches in the mid and lower crown positions were 59% and 30% less than those in the upper canopy. Needle lengths of the same flush origin were similar in the upper and mid crown position while needles in the lower canopy positions were shorter. Second flush final needle lengths in the upper and mid crown positions were nearly as long as those formed during the first flush. Second flush needles in the lower third of the crown were shorter than those formed in the first flush. Total leaf area growth on the developing branch terminals at each of the crown positions was estimated using the method developed by Harms (1971). This method indicated that the mid and lower crown added 32% and 69% more new needle area than those in the mid and lower crown positions, respectively. Current work will relate variation in light intensity at each crown position to flushing patterns, shoot elongation, and needle elongation. Data from this study are expected to improve models of net carbon gain and provide a framework for interpreting the effects of air pollutants and global climate change on forest growth.

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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GROWTH AND WOOD QUALITY OF 14-YEAR-OLD LOBLOLLY PINE IN RELATION TO STAND DENSITY AND CLIMATE [1]

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Abstract. Foresters are becoming increasingly concerned about the quality of wood produced from rapidly-growing forest plantations. In 1984, a stand of loblolly pine was thinned to three target basal areas: 25,50, and 100 ft^2 per acre (control). Every two weeks from March to September wood cores were extracted at dbh, at the base of the live crown, and at an intermediate point on the bole between these positions. Date of transition from earlywood to latewood, percent latewood, growth and climate variables were measured during the second year after thinning. In addition, soil moisture was monitored with a neutron probe. Data will be presented to address hypothesis one (the timing of latewood initiation differs by bole position) and hypothesis two (stand density, climate and soil moisture interact to influence wood properties by bole position).

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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GROWTH AND PHYSIOLOGY OF LOBLOLLY PINE AND SWEETGUM SEEDLING STANDS IN RESPONSE TO ATMOSPHERIC CARBON DIOXIDE CONCENTRATION, WATER, AND NUTRIENT STATUS [1]

J.W. Groninger, J.R. Seiler, S.M. Zedaker, P.C. Berrang, and A.L. Friend [2]

Abstract. Loblolly pine (*Pinus taeda*) and sweetgum (*Liquidambar styraciflua*) were grown in mixed stands and in monocultures at 2.54 x 2.54 cm spacing in controlled environment chambers. Treatments consisted of present (ambient) and projected future (ambient + 400 ppm) carbon dioxide (CO_2) concentrations, droughted and well-watered conditions and low (20 kg N/ha) and high (74 kg N/ha) nitrogen application rates. Nine weeks after shoot emergence, photosynthesis (Ps) rates were measured under ambient and elevated CO_2 for seedlings grown under ambient and projected future CO_2 levels. Rates of Ps were higher under high CO_2 measurements regardless of the concentration where seedlings were grown suggesting that acclimation to elevated CO_2 had not yet occurred in either species. After one growing season, stem volume of both species was significantly greater under high CO_2 conditions. Sweetgum volume was significantly decreased under drought stress while pine was not. Water availability strongly influenced competitive interactions across both levels of CO_2. In mixed stands, sweetgum out-competed loblolly pine under conditions of high water availability. Preliminary results suggest that competitive outcomes under high CO_2 will continue to be strongly influenced by water availability.

Introduction

Unfavorable public perception of traditional single-species management of pines and the increasing market value of hardwood species has kindled interest in the management of mixed forests. The development of pine-hardwood stands over the next several decades will be accompanied by increased atmospheric carbon dioxide concentration. A doubling of current atmospheric carbon dioxide concentrations is projected to occur sometime near the middle of the 21st century (Clark et al. 1982). The impact of increasing atmospheric CO_2 on forest dynamics is presently poorly understood. Variation in response to CO_2 between tree species and interaction with other environmental factors could alter tree growth rate and, ultimately, forest composition.

A number of studies have been conducted to evaluate effects of increasing carbon dioxide concentrations on the growth and physiology of individual tree seedlings grown under a variety of environmental conditions. Sweetgum (*Liquidambar styraciflua* L.) seedlings grown under high CO_2 were larger than controls grown under ambient CO_2 (Tolley and Strain 1984b). Loblolly pine (*Pinus taeda* L.) in the same study were largely unresponsive to increased CO_2 concentration. However, both species maintained higher photosynthetic rates under high CO_2 (Tolley and Strain 1985).

The availability of water and nutrients can also affect tree growth response to elevated CO_2. Water stressed seedlings grown under high CO_2 were found to maintain growth further into a drought than low CO_2 controls. This response was stronger in sweetgum than in loblolly pine (Tolley and Strain 1984a). Nutrient availability may also mediate growth response to elevated CO_2. White spruce (*Picea glauca* (Moench.) Voss) and trembling aspen (*Populus tremuloides* Michx.) grown under a range of soil nitrogen concentrations showed a stronger positive early growth response to increased CO_2 as nitrogen availability increased (Brown and Higginbotham 1986).

Based on the studies summarized here, researchers have suggested that sweetgum will become more competitive relative to loblolly pine under future environments. Increased drought tolerance of sweetgum under high CO_2 may allow this species to become established on drier sites currently occupied by loblolly pine (Tolley and Strain 1984a). However, other research has suggested that the development of

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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natural stands in a high CO_2 environment differs from that of individual seedlings. In two studies with annual species, competition dampened the positive growth response to elevated carbon dioxide (Zangerl and Bazzaz 1984: Williams et al. 1988). No research of this nature has been conducted with temperate tree species grown in mixed and pure stands.

The objectives of this study were to determine the interaction of CO_2 enrichment, water availability, nutrient status, and stand composition on the yield and leaf gas exchange of sweetgum and loblolly pine seedling stands. Gas exchange was measured to determine whether physiological changes in leaves occurred in response to environmental conditions and stand type. The data reported here represent 85 preliminary results of a study to be conducted for one additional growing cycle. Physiology and yield data from the second growing cycle will be reported in subsequent publications.

Methods

This study is being conducted at the Center for Forest Environmental Studies (U. S. D. A. Forest Service) in Macon, Georgia. Plastic pots 30.5 cm in diameter and 36.8 cm deep were filled with a Cowarts series (fine loamy, silicious, thermic, Typic Kanhapludult) forest soil. Prior to potting, soil was sifted through a 0.25 inch hardware cloth screen and mixed with washed white sand at a 5:1 ratio to insure adequate drainage and amended with 200 kg K/ha, 100 kg P/ha and 50 kg Ca/ha. Stratified loblolly pine and sweetgum seed collected from open pollinated trees were planted in pots at a 2.54 by 2.54 cm spacing both as pure stands of each species and in a 50:50 replacement mixtures.

Following seedling establishment, pots were placed in Continuously Stirred Tank Reactors (CSTRs) maintained at one of two CO_2 concentrations: ambient and ambient + 400 ppm. CSTRs were enclosed in a greenhouse and exposed to full sunlight. Supplemental lighting was provided by 1000 watt metal halide lights to maintain a 16 hour photoperiod. After ten weeks of growth, photoperiods were reduced to eight hours per day and air temperature reduced to induce dormancy. All pots were well-watered with deionized water until one month following planting. At this time, water stress treatments were initiated. Drought-stressed pots received half the water given to well-watered pots. N-deficient treatments received the equivalent of 20 kg N/ha (based on the surface area and taper of the pots) with irrigation water as NH_4NO_3 five weeks following germination. N-sufficient treatments received 20 kg N/ha two weeks following germination and an additional 54 kg N/ha one month after germination.

Leaf gas exchange was measured with a Li-Cor 6250 portable photosynthesis system (Li-Cor Inc., Lincoln, NE) on one seedling per species in each stand ten weeks following germination. Gas exchange was measured for each seedling under CO_2 concentrations of 350 and 800 ppm. High CO_2 concentrations were established by injecting a small amount of pure CO_2 into the cuvette. Dry weight was determined for leaf material used in photosynthesis measurements.

Diameter and height determinations were made for the innermost 25 seedlings in each pot 21 weeks following germination. Each seedling measured in this portion of the study had at least a two-seedling buffer between itself and the edge of the pot. Diameter was measured with electronic calipers 0.5 cm below cotyledons. Height was measured from the root collar to the apical meristem in loblolly pine and to the top of the terminal bud in the hardwood species. Yield data were obtained by estimating stem volume as the volume of a cone.

The study used a split-split plot design where CO_2 concentration was the main plot and water and nutrient concentration were the split plots. All possible stand type, CO_2, water, and nutrient treatment combinations were replicated four times. Analysis of variance was used to determine significance of main effects and interactions. Competitive interactions between stand composition and CO_2 concentration were analyzed by comparing relative yield total (RYT) and Relative Crowding Coefficient (RCCP and RCCS for pine and sweetgum respectively)(Harper 1977). RYT expresses the change in yield for the two species in mixture relative to monoculture yields. RYT $>$ 1 indicates a synergistic relationship while RYT $<$ 1 indicates antagonism between the two species. Relative crowding coefficients are calculated to indicate aggressiveness of one species relative to another. These values are calculated by comparing relative yields of species grown in mixture with yields of monocultures of the same species. Values >1 indicate a species is more successful as in interspecific competitor than as an intra-specific competitor (deWit 1960). RCC values of $p < .05$ were considered significant throughout the study.

Results

Significant differences in photosynthetic rate were not detected within a cuvette CO_2 concentration in response to growth chamber CO_2 concentration, water availability, nutrient status or stand type for either species. Photosynthesis data were pooled within CO_2 treatments for loblolly pine and sweetgum (Figure 1). As expected, both species had higher photosynthesis rates under the higher cuvette CO_2 concentration regardless of CO_2 concentration where seedlings were grown. In both species, photosynthesis per unit leaf weight was slightly lower for seedlings grown under high CO_2 for both cuvette CO_2 concentrations.

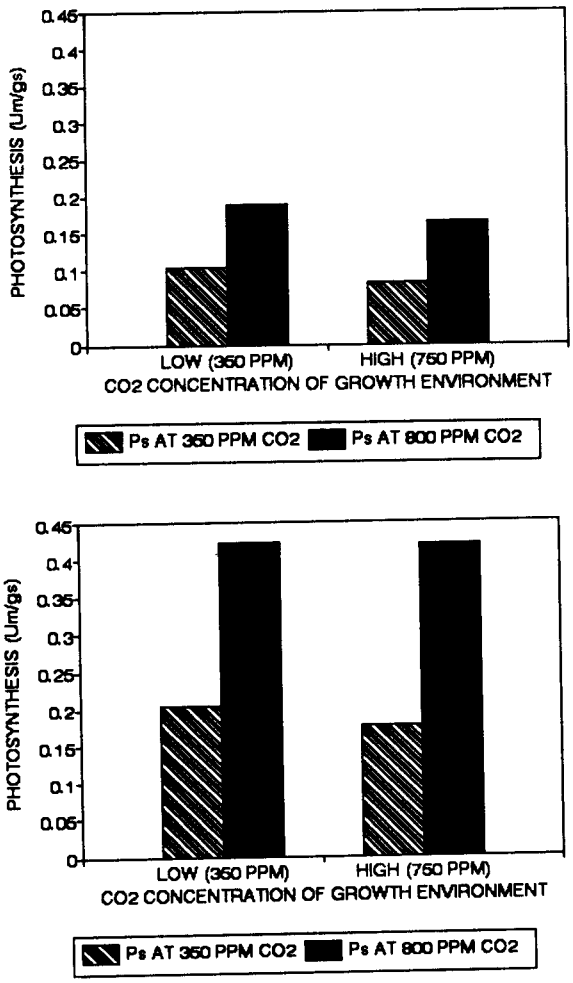

Figure 1. *Photosynthetic rates for loblolly pine (A) and sweetgum seedlings (B) grown under low (350 ppm) and high (800 ppm) CO_2 for ten weeks and measured under low (350 ppm) and high (800 ppm) CO_2.*

Sweetgum growth was increased significantly under high CO_2 and reduced significantly by the drought treatment while loblolly pine showed non-significant growth responses to both factors (Table 1). Both species were slightly larger, though non-significantly under the more fertile soil conditions. Due to non-significant differences in response to soil fertility, high and low fertility were pooled for further analysis.

Table 1. *Average stem volume of loblolly pine and sweetgum seedlings from greenhouse stands after one growing season. Seedlings were grown under two levels of atmospheric CO_2, water availablity and nitrogen fertilization.*

Main Effect	Loblolly Pine	Sweetgum
	---------(mm^3)---------	
CO_2		
800 ppm	50.9	129.3*
350 ppm	42.5	97.7
Water		
Well-watered	48.4	139.8*
Droughted	44.9	87.2
Nitrogen Fertilization		
74 kg/ha	49.0	119.9
20 kg/ha	44.0	107.2

Main effect treatment means within a species marked by an asterisk are significantly different ($p < 0.05$).

Slightly lower relative yield total is apparent in mixed stands under both CO_2 concentrations. Relative crowding coefficients for either species did not differ significantly between CO_2 treatments (Figure 2).

Loblolly pine had a stronger response to CO_2 increase in monoculture relative to mixture in the high water treatment (Table 2). The opposite occurs under low water wherein loblolly pine grown in mixture with sweetgum respond to increased CO_2 more strongly than do monocultures. The influence of water availability on stand type response of sweetgum to CO_2 displays trends exactly opposite those shown in pine. CO_2-induced volume increase of sweetgum in mixture was stronger under high water availability while monocultures showed a stronger response to CO_2 increase than mixtures under low water (Table 2). Despite the apparent strength of these trends, significant differences were not detected. A significant interaction was detected for CO_2 concentration, water availability and stand type on sweetgum yield. In sweetgum monocultures, volume of high CO_2 stands was significantly greater than controls only under low water conditions. However, mixtures showed a significant response to CO_2 only under the higher water level.

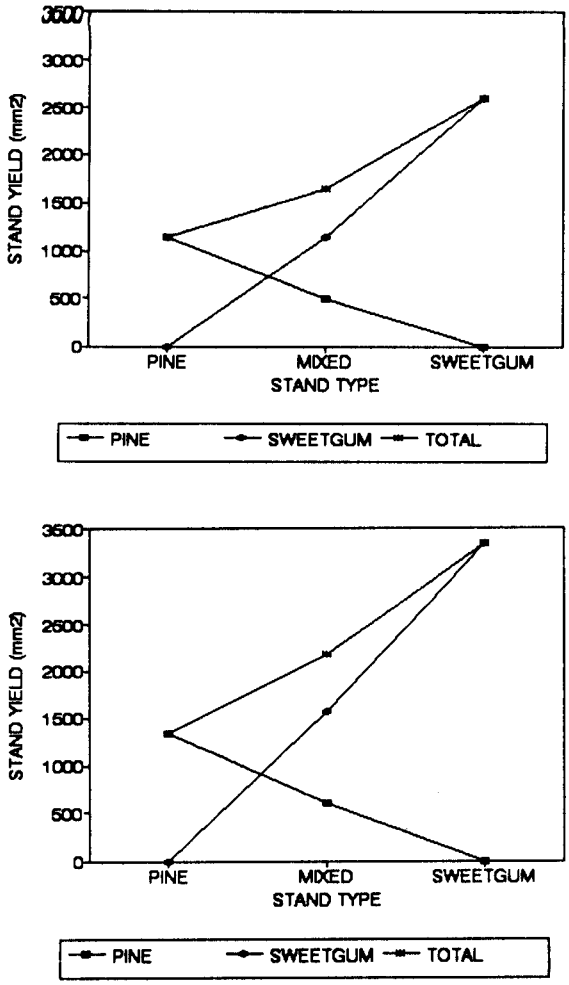

Figure 2. *Relative yield for loblolly pine and sweetgum grown under low (350 ppm) (A) and high (800 ppm) (B) CO_2 in monoculture and pure stands. Yield is presented in terms of volume per stand of 25 trees. For low $_2$, RYT=.884 ± .154, RCCP= .986 ± .154, RCCP= .986 ± .163, RCCS= 1.04 ± .180. For high CO2, RYT=.913 ± .150, RCCP= 1.019 ± .190, RCCS= 1.008 ± .191.*

Discussion

The response of gas exchange to both cuvette and growth environment CO_2 concentration was similar to those observed in other studies (Hollinger 1987, Fetcher et al. 1988). Loblolly pine and sweetgum seedlings grown under ambient and two elevated CO_2 concentrations showed a positive correlation between CO_2 concentration and photosynthesis when gas exchange was measured under CO_2 concentrations associated with the growth environment (Tolley and Strain 1985). The slight tendency of both species to show decreased photosynthetic capacity when grown under high CO_2 (acclimation) has been shown in a number of other species (Eamus and Jarvis 1989). This response is presumably caused by starch accumulation in leaves leading to disruption of chloroplast function (Cave et al. 1981; Wulff and Strain 1982). Fetcher et al. (1988) observed acclimation in sweetgum but not in loblolly pine following 15 months growth. Since our observations were made on much younger seedlings, comparisons with the earlier study would be premature. A correlation between acclimation to CO_2 and competitive ability is not apparent at this time.

Responses to CO_2 increase and water stress are similar to those found in other studies (Rogers et al. 1983, Tolley and Strain 1984) The small growth increase associated with fertilization may be explained by the relatively small nutrient dosage. As this study continues, nitrogen fertilization rate will be increased and differences between fertilization treatments may become more apparent.

The relative yield diagrams, relative yield totals and relative crowding coefficients suggest that competitive relationships between sweetgum and loblolly pine are not affected by increased atmospheric CO_2 concentration when water availability is unaccounted for. While not statistically significant, trends are present suggesting that increasing CO_2 improves the competitive ability of pine relative to sweetgum under conditions of low water availability. Under high water availability, sweetgum appears to become more competitive relative to pine.

Perhaps of greatest interest is that conclusions regarding the relative responsiveness of species to increased CO_2 and water availability would be contradictory if monoculture and mixed stand data were analyzed separately. In a study in which loblolly pine and sweetgum were grown as individual plants, mean biomass increment and net assimilation rate were significantly greater in sweetgum following drought stress grown at 675 ppm CO_2 concentrations compared to seedlings grown under present-day ambient levels (Tolley and Strain 1984a). Loblolly pine showed a positive but non-significant response under the same conditions. The differential response to drought shown by the two species led the authors to suggest that sweetgum may be able to occupy drier sites presently dominated by loblolly pine. Monoculture data from the present study concur with these findings wherein high CO_2, low water sweetgum show a 50% increase in growth compared to low CO_2 controls while pine shows a 9% growth increase. However, data obtained from mixed stands in our study display the opposite trend; sweetgum shows a 25% increase while pine growth is increased 32%

over low CO_2 controls. Comparison between the present study and Tolley and Strain should not be overemphasized since different drought regimes and growth criteria were used. Despite apparently strong trends, growth response differences were often not significant due to enormous variation in stand growth.

Based on the results of this study, species response to CO_2 is dependent upon stand composition and water availability. Pine monocultures on wet sites would benefit more strongly than those on dry sites. However, increased competitiveness of sweetgum in mixed stands could result in increasing importance of this species at the expense of loblolly pine. Sweetgum yield in monoculture would increase more strongly in dry versus wet sites under high CO_2 conditions. Increasing CO_2 appears to increase the growth of loblolly pine relative to sweetgum on dry sites.

The use of miniature stands to model the effects of global change on forest tree systems is still in its early stages. Questions remain regarding the validity of comparing stands grown in chambers at very high densities for short periods of time to natural stands. The greatest value of this method seems to be in the evaluation of stand dynamics in very young stands where eventual competitive success may be determined. Additional studies are being conducted to determine the potential miniature stands have for modelling forest dynamics.

Table 2. *Stem volume by species and relative increase in stem volume in response to elevated CO_2 concentration for loblolly pine and sweetgum grown in monoculture and mixed stands under well-watered and droughted conditions of high and low water availability following 21 weeks. Values are mm^2 volume per stand of 25 trees. Numbers in parentheses are percent increase in volume due to CO_2 increase.*

Treatments	CO_2 Concentration Low (350 ppm)	High (800 ppm)	difference
Well-watered			
Loblolly pine			
Monoculture	1245	1496	+251(20)
Mixture	471	514	+43(9)
Sweetgum			
Monoculture	2390	3244	+314(36)
Mixture	1456	2147	+691(47) *
Droughted			
Loblolly pine			
Monoculture	985	1069	+84(9)
Mixture	488	645	+57(32)
Sweetgum			
Monoculture	2029	3053	+1024(50) *
Mixture	755	944	+189(25)

Percent volume increases marked with an asterisk are significant at $p < .05$.

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RESPONSE OF BOTTOMLAND OAK SPECIES TO RHIZOSPHERE HYPOXIA [1]

Emile S. Gardiner, John D. Hodges, Alexander L. Friend, and James N. DeWit [2]

Abstract. Bottomland oak species are distributed along topographical gradients in floodplains. Because of the associated soil aeration with these gradients, the hypothesis that oak species will exhibit diverging adaptations to hypoxia in the growing season was investigated. First-year seedlings of overcup oak (*Quercus lyrata* Walt.), swamp laurel oak (*Q. laurifolia* Michx.), willow oak (*Q. phellos* L.), and water oak (*Q. nigra* L.) were grown in either a normoxic (dissolved oxygen (DO) > 15 mg/L) or hypoxic (DO < 0.2 mg/L) nutrient solution for 35 days. Hypoxia tolerance was evaluated from measurements of height and diameter growth, root length, transpiration, and stomatal conductance. Results indicated that overcup oak and swamp laurel oak were most tolerant, while willow oak and water oak were least tolerant to late-season rhizosphere hypoxia.

Introduction

The need for proper management of wetlands has been heightened by demands for multiple resources and responsibilities to protect wetland functions. But, southern forested wetlands are dynamic systems and their management can be complex, especially because of their tremendous tree species richness. In major river bottoms of the southern United States, there are several site positions on which more than 70 hardwood species grow in associations (Putnam et al. 1960). Since basic biological information is lacking on most of these species, research exploring their ecophysiology would contribute to the management of wetland forests.

Floodplains have little relief, but even slight elevational changes can affect vegetational cover (Tanner 1986). Relatively abrupt elevational changes, such as between a flat and a ridge, are marked by shifts in species associations (Hodges and Switzer 1979). Gradual elevational changes, occurring within flats, are noted by species continuums (Tanner 1986). Therefore, a cross-section from an active floodplain in a major river bottom would typically reveal several tree species changing in abundance along a topographical gradient (Tanner 1986). Overcup oak (*Quercus lyrata* Walt.), swamp laurel oak (or diamond leaf oak *Q. laurifolia* Michx.), willow oak (*Q. phellos* L.), and water oak (*Q. nigra* L.) are ecologically and commercially important species which are commonly stratified in associations with other bottomland trees along topographical gradients.

Overcup oak, a member of the white oak group, grows on temporal sloughs or low flats in the floodplain (Hodges and Switzer 1979, Tanner 1986). These sites are frequently flooded, can remain saturated into the growing season, and exhibit poor internal soil aeration (Putnam et al. 1960). Overcup oak has been classified as the most flood-tolerant of the southern oaks (McKnight et al. 1980). Swamp laurel oak is found on low flats near the periphery of temporal sloughs, and is among the most flood-tolerant of the red oaks (Hodges and Switzer 1979, McKnight et al. 1980, Putnam et al. 1960). Willow oak, another red oak, is typically found on low flats, but at a slightly higher elevation than swamp laurel oak. It is classified as more flood-tolerant than water oak (Putnam et al. 1960, Tanner 1986). Water oak, the least flood-tolerant of these red oaks, grows primarily on high flats or low ridges which are the least frequently flooded positions in the floodplain (Hodges and Switzer 1979, Tanner 1986). Soils on these sites are saturated for short periods and have the best internal aeration (Putnam et al. 1960).

The observed stratification of oaks in bottomlands, and the apparent association of flood frequency and soil aeration along topographical gradients has prompted us to investigate the ecophysiological mechanisms influencing bottomland oak distribution. Several soil properties such as

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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moisture, soil redox potential, or soil pH may contribute to this relationship, but we investigated the hypothesis that oxygen is the driving factor in this stratification. The research focused on two questions: 1) Do bottomland oak species vary in morphological or physiological responses to rhizosphere hypoxia? 2) If so, does this variation explain species-site adaptations?

Methods

A hydroponics network, which enabled us to subject overcup oak, swamp laurel oak, willow oak, and water oak seedlings to a rhizosphere hypoxia treatment, was constructed in a greenhouse. The network consisted of two storage reservoirs that supplied nutrient solution to 40, 18.9-L sealed pots. The nutrient solution was a modified, 1/10-strength Hoagland's solution (Jones 1983, p. 39) adjusted to pH = 5.5. It flowed out of the storage reservoirs at timed intervals so that each pot received 3.8 L of fresh solution over a 24-hour period. All hardware was coated with paint or aluminum foil to eliminate light penetration and algal growth.

Oxygen was supplied to each pot from pressurized storage tanks. The gas was regulated to a manifold which directed it to the appropriate pot. A YSI Model 51B dissolved oxygen (DO) meter and a Clark-type polarographic electrode (Yellow Springs Instrument Co. Inc., Yellow Springs, OH) were used to monitor DO in each pot.

In mid-August 1992, seedlings grown for 4 months in a 50% potting soil: 50% sand mixture (v:v) were selected for similarity in size and morphological development. Average seedling height at the start of the experiment was 22.9 cm and average diameter was 2.3 mm. Roots were carefully washed free of soil prior to placement of seedlings in the network. Four seedlings, one of each species, were randomly assigned to each pot (40 pots = 160 seedlings total). Each seedling was held in place by a styrofoam plug secured around the basal portion of the stem. Seedlings were acclimated to the system for two weeks in normoxic (DO > 15 mg/L) nutrient solution. At the end of this period, seedlings appeared to be acclimated to the system and had initiated new root growth.

After the acclimation period, half of the seedlings received a 35-day, late-season, rhizosphere hypoxia treatment. This was imposed by circulating nitrogen gas instead of oxygen in the nutrient solution of 20 randomly selected pots (Topa and McLeod 1986). The resulting nutrient solution had DO < 0.2 mg/L.

Morphological parameters measured during the experiment were seedling height, diameter, and new root length (root length grown after introduction to the hydroponic system). New hydroponic roots were distinguished from soil roots by their larger diameter and straighter growth habit. Height and diameter were measured on day 1 and day 35 of the treatment to determine relative growth of each seedling (n=20), i.e., relative growth = (final size - initial size) / initial size * 100. Five seedlings in each treatment and species combination were harvested on day 35 to assess root growth. New root length was measured with a Digital Image Analysis System (Dias II) (Decagon Devices Inc., Pullman, WA).

Effects on seedling physiology were assessed by measuring transpiration and stomatal conductance. These parameters were measured between 0900 and 1100 three days before treatment and on days 1-10, 15, 20, 25, 30, and 35 of the treatment with a Li-1600 Steady State Porometer (Licor Inc., Lincoln, NE). For each treatment and species combination, 4 seedlings were subsampled from those in the same phenological stage. This sampling criteria was established to reduce variation resulting from measuring seedlings of different phenological stages, but it often limited the number of seedlings available to subsample. A portable lamp was used to maintain photosynthetically active photon flux density on the measurement leaf between 400-800 $\mu mol/m^2/s$. Diurnal transpiration and stomatal conductance measurements were taken for each species by treatment combination at 2-hour intervals beginning at 0600, and finishing at 2000 on 4 days during the last week of the experiment (n=4).

Data were analyzed according to a completely randomized design with split plots. DO level was the main plot and species were the split plot. Analyses of variance were performed with SAS software (SAS Institute Inc., Cary, NC). Significantly different species means (α = 0.05) were separated with Student-Newman-Keuls multiple range test.

Results and Discussion

Survival was excellent for all species in the system. Only three plants died and this mortality was apparently not related to any treatment. No visible differences were observed between seedlings in either treatment, other than a slight chlorosis of leaves on seedlings in the hypoxic treatment.

During the experiment, relative height growth of overcup oak showed a slight increase in response to hypoxia (Table 1). However, this was probably not biologically significant because overcup oak height growth was small relative to the other species. Among the red oaks, swamp laurel oak grew equally well in either solution; however, willow oak and water oak seedlings in hypoxic solution grew to only one-third the size of seedlings in normoxic solution (Table 1). Many red oak seedlings were in a stage of flush expansion on day 1 of the hypoxic treatment. Contrary to what we expected, these flushes were not permanently damaged, and they completed development.

Table 1. *Relative height growth (% increase) for bottomland oak seedlings during 35 days of rhizosphere hypoxia.*

Species	Normoxic[1]	Hypoxic
Overcup Oak	0.1 B[2]	2.3 A
S. Laurel Oak	21.3 A	20.0 A
Willow Oak	40.8 A	11.9 B
Water Oak	37.5 A	12.4 B

[1] Normoxic nutrient solution had > 15 mg/L dissolved oxygen, and hypoxic nutrient solution had < 0.2 mg/L dissolved oxygen.
[2] Different letters in a row indicate significant differences (α = 0.05).

In hypoxic solutions, average overcup oak diameter growth was over 3.5 times larger than for seedlings in normoxic solutions (Table 2). Swamp laurel oak seedlings in hypoxic solutions grew over 1.8 times larger in diameter than seedlings in normoxic solutions (Table 2). Increased diameter growth has been observed on other species grown in flooded soil, and attributed to stem hypertrophy (Yamamoto et al. 1987). In the present study, enlargement of the basal portion of the stem resulting from the hypoxia may have occurred, but there was no excessive stem or lenticel hypertrophy as reported for other species subjected to soil flooding. Diameter growth differences between DO treatments were not found for willow oak and water oak seedlings (Table 2).

For all oaks, average root growth was about 5.8 m in the normoxic solution and 0.8 m in the hypoxic solution (Figure 1). Differences were not detected between species in a treatment. Roots in hypoxic nutrient solutions appeared to be non-functional by the end of the treatment because tissues were black and apparently dead. In contrast, unsuberized root tissue on control seedlings was cream-colored and succulent. The root growth observed for seedlings in the hypoxic solution probably occurred during the acclimation period. Our findings agree with recent work by Pezeshki (1991), who reported that overcup oak root growth was sensitive to low soil oxygen, as indicated by soil redox potentials.

Table 2. *Relative diameter growth (% increase) for bottomland oak seedlings during 35 days of rhizosphere hypoxia.*

Species	Normoxic[1]	Hypoxic
Overcup Oak	7.2 B[2]	25.8 A
S. Laurel Oak	19.2 B	36.3 A
Willow Oak	24.3 A	24.7 A
Water Oak	28.2 A	22.5 A

[1] Normoxic nutrient solution had > 15 mg/L dissolved oxygen, and hypoxic nutrient solution had < 0.2 mg/L dissolved oxygen.
[2] Different letters in a row indicate significant differences (α = 0.05).

Figure 2A illustrates oak transpiration by treatment during the experiment. Transpiration was not different on the three pre-treatment sample days, or on days 1, 2, and 20 of the treatment. A significant difference between treatments was first detected on treatment day 3. Some researchers have reported quicker decreases in transpiration for other plants subjected to soil flooding. For example, cherrybark oak (*Q. pagoda* Raf.) transpiration significantly decreased after one day of soil flooding (Pezeshki and Chambers 1985).

Significant species by treatment interactions were observed for transpiration on days 5, and 7-10 of the treatment. During this time, transpiration for normoxic willow oak and water oak seedlings was greater than hypoxic seedlings by about 3.1 and 3.3 $\mu g/cm^2/s$, respectively. Transpiration for swamp laurel oak and overcup oak averaged only 0.9 and 0.7 $\mu g/cm^2/s$ greater in normoxic solutions. Following this initial stress, there seemed to be a recovery or acclimation period up to day 20, followed by a second transpiration decrease (Figure 2A). We are not sure why this second decrease occurred, but a similar pattern was reported for flooded bur oak (*Q. macrocarpa* Michx.) seedlings (Tang and Kozlowski 1982). Perhaps the root mortality we observed occurred after day 20, thereby reducing water flux through the roots.

Stomatal regulation appeared to be the primary mechanism controlling transpiration for all seedlings (Figure 2B). Differences between lines in Figure 2B represents stomatal aperture differences. At 12 out of

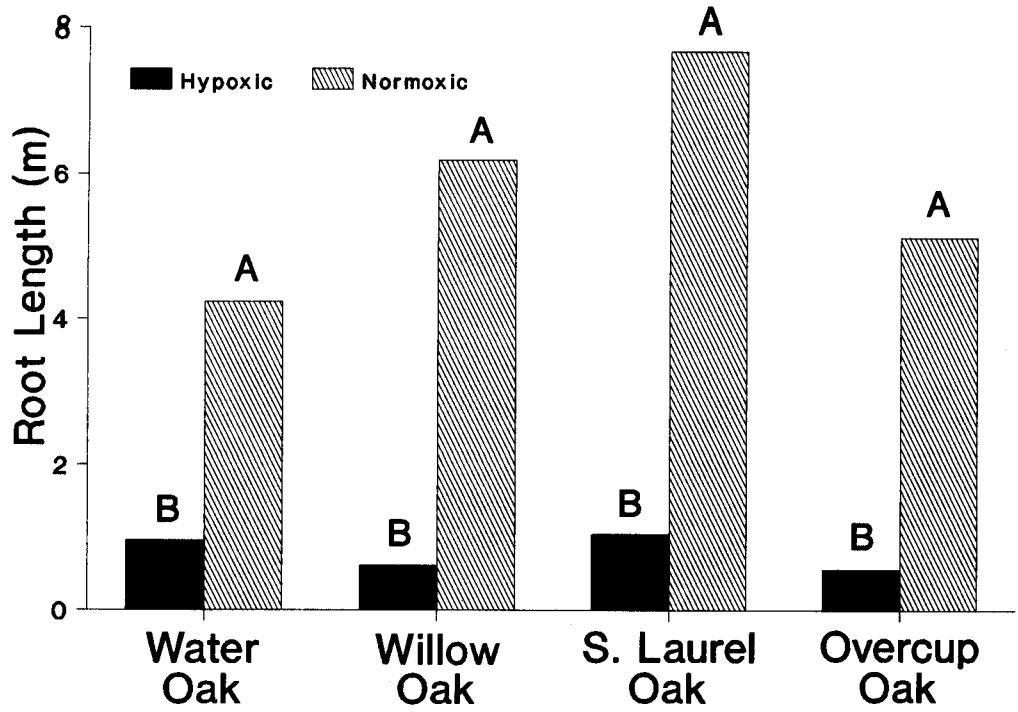

Figure 1. *Length of new roots for four species of bottomland oak seedlings after 35 days of rhizosphere hypoxia. Significant differences (α = 0.05) between dissolved oxygen treatments are noted by different letters on bars.*

15 treatment dates stomatal closure was significantly greater for seedlings growing in hypoxic solution. Stomatal closure is a common early response of plants subjected to soil saturation (Pereira and Kozlowski 1977, Sojka and Stolzy 1980). Swamp chestnut oak (*Q. michauxii* Nutt.), green ash (*Fraxinus pennsylvanica* Marsh.), and even hydric species such as baldcypress (*Taxodium distichum* (L.) L.C. Rich.) reduce stomatal conductance upon soil saturation (Pezeshki and Chambers 1986).

Diurnal patterns of transpiration and stomatal conductance were similar for all species, but magnitude differed significantly by DO treatment (Figures 3A, 3B). Seedlings in hypoxic solution had lower transpiration throughout daylight hours (Figure 3A). The diurnal transpiration pattern appears to be primarily regulated by stomatal control (Figure 3B).

Summary

To establish relationships between species hypoxia tolerance and distribution within floodplains, we grew seedlings of four bottomland oaks in low oxygen nutrient solutions for 35 days. Seedlings of these oaks apparently do vary in their response to late-season rhizosphere hypoxia. Judging from growth and transpiration results, the oaks may be classified into two groups of hypoxia tolerance (Table 3). Overcup oak and swamp laurel oak appear to be the most tolerant of rhizosphere hypoxia, while willow oak and water oak are the least tolerant. These results do not completely explain species distribution within floodplains, but are consistent with their topographic position. Other indices of seedling response to rhizosphere hypoxia, yet to be analyzed from this experiment, include root micromorphology, and carbon allocation and partitioning. Future research on bottomland oak site relations will focus on the role of rhizosphere hypoxia tolerance during seedling establishment.

Acknowledgements

Contribution No. PS-8185 of the Mississippi Agricultural and Forestry Experiment Station.

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Table 3. *Rankings for bottomland oak tolerance to rhizosphere hypoxia (1 = most, 4 = least). Rankings do not necessarily indicate statistical differences.*

Species	Flood Tolerance[1]	Height Growth[2]	Diameter Growth[2]	Root Growth[2]	Transpiration[3]
Overcup Oak	1	1	1	1	1
S. Laurel Oak	2	2	2	1	1
Willow Oak	3	3	3	1	2
Water Oak	4	3	3	1	2

[1] Based on observed topographical position in floodplains.

[2] Based on the ratio of hypoxic seedling growth to normoxic seedling growth during a 35-day rhizosphere hypoxia treatment.

[3] Based transpiration during the first 10 days of a 35-day rhizosphere hypoxia treatment.

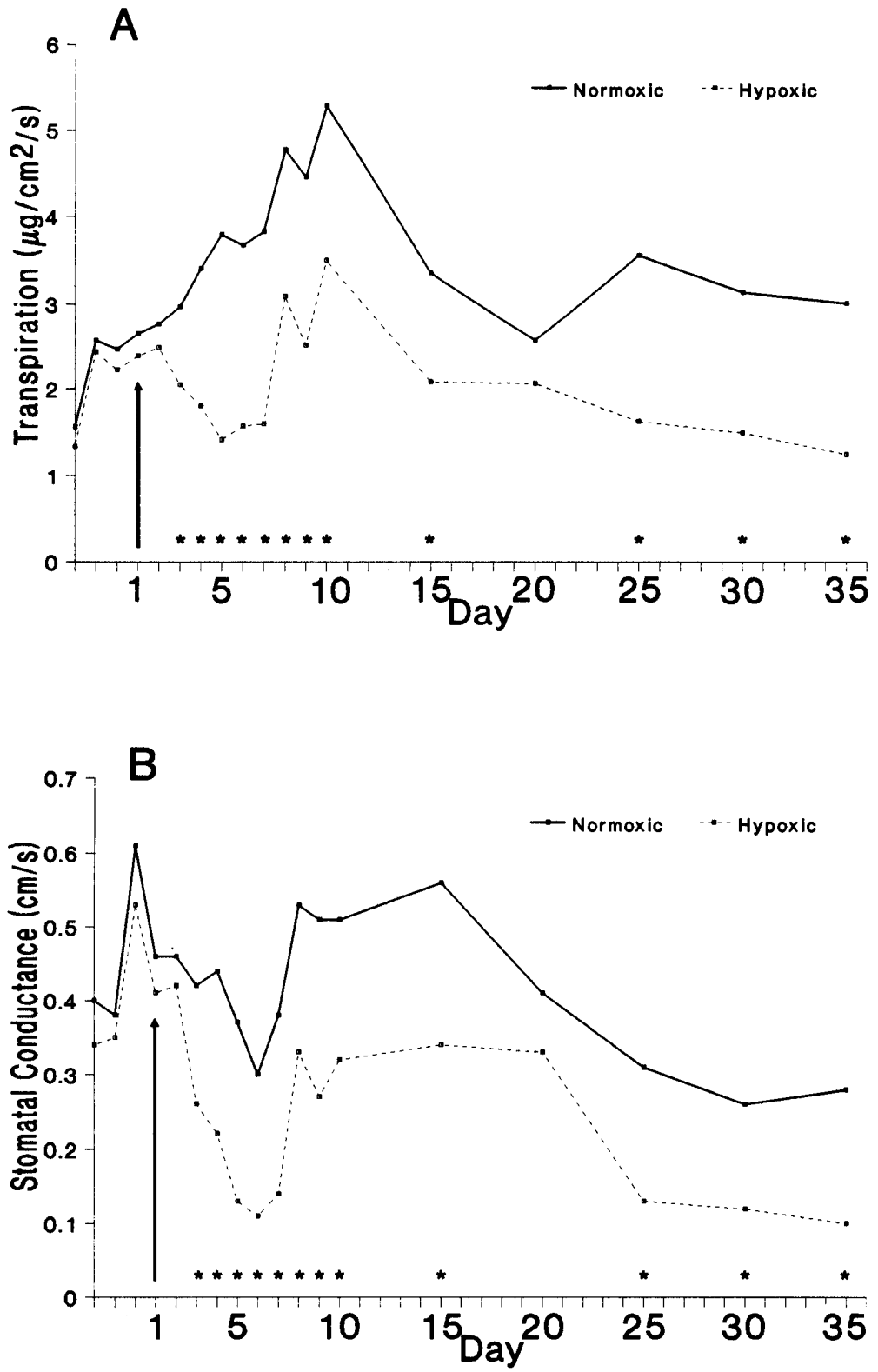

Figure 2. *(A) Transpiration and (B) stomatal conductance for four species of bottomland oak seedlings three days before treatment and during 35 days of rhizosphere hypoxia. Treatment initiation is noted by the arrow in each figure. Significant differences ($\alpha = 0.05$) between dissolved oxygen treatments are noted by an asterisk above the x-axis.*

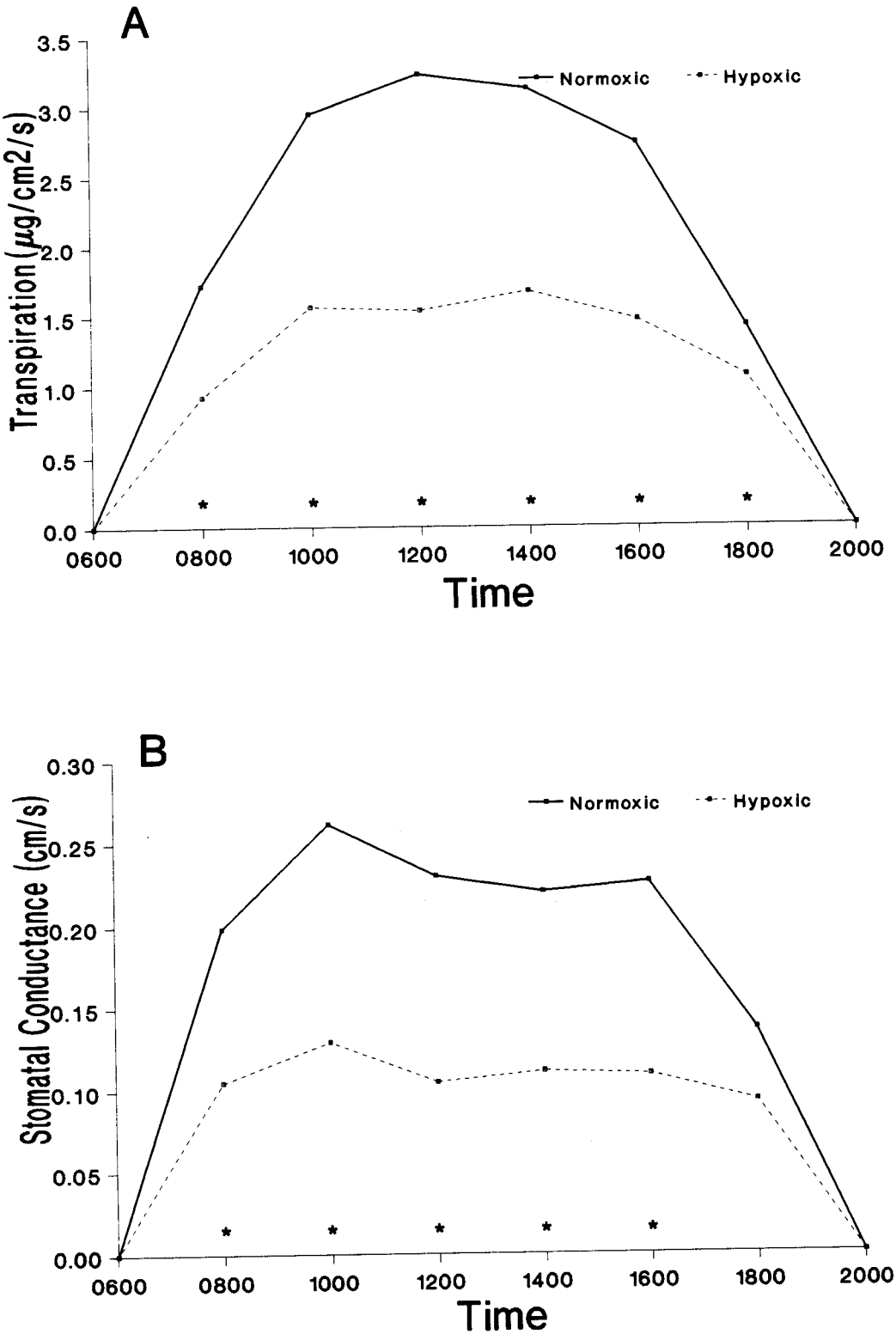

Figure 3. *(A) Diurnal transpiration and (B) stomatal conductance for four species of bottomland oak seedlings during 35 days of rhizosphere hypoxia. Significant differences ($\alpha = 0.05$) between dissolved oxygen treatments are noted by an asterisk above the x-axis.*

FLOOD TIMING, GROWTH AND MORPHOLOGICAL RESPONSES OF BOTTOMLAND OAK SPECIES [1]

J.L. Chambers, K. Velupillai, H. Williams, and H.E. Kennedy, Jr. [2]

Abstract. Controlled, somewhat regular flooding, over a period of years as is common in greentree reservoirs, appears to reduce successful regeneration of bottomland oak species. Therefore a study was designed to evaluate the effects of "dormant season" flooding on the growth and morphology of several important bottomland oak species. Five species were exposed to shallow water flooding under different flood-timing regimes. Flood periods included a control (not flooded), October 1 to June 1, October 15 to May 15, November 1 to April 15, and November 15 to February 15. Final heights in the most sensitive species, Cherrybark oak, averaged 46.5% less in the October to June flood treatment than in the control. Final heights in the most tolerant species, Overcup oak, averaged only 4.5% less in the October to June flood treatment than in the control. Swamp Chestnut oak response was similar to Cherrybark oak for the longer flood periods, while other species were intermediate between the less flood tolerant and the Overcup oak in their response. For flood sensitive Cherrybark oak even the November to February flood treatment heights were 17.8% less than in the control treatment. Similar responses were noted for diameter growth and final root volumes and dry weights. The effects of dormant season flooding on the development of hypertrophied lenticels and adventitious roots was contrary to the reported relationships with flood tolerance. This aspect will be discussed in relation the timing of growth events.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Associate Professor and Research Associate, Louisiana State University, Baton Rouge; Ecologist, US Army Corps of Engineers, Vicksburg, MS; and Principal Silviculturist, USDA Forest Service Southern Hardwoods Lab., Stoneville, MS.

FIRST-YEAR FIELD PERFORMANCE OF OAK SPECIES WITH VARYING FLOOD TOLERANCE PLANTED ON HYDRIC AND NON-HYDRIC SOILS [1]

Hans M. Williams, Barbara A. Kleiss, Monica N. Humphrey, and Charles V. Klimas [2]

Abstract. Bareroot 1-0 Nuttall oak (*Quercus nuttallii*, Palmer), water oak (*Quercus nigra*, L.), and cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.) seedlings were outplanted in January, 1992, on Sharkey, Forestdale, and Dundee soil series located at the Lake George Wildlife/Wetland Restoration Project, MS. Nuttall oak, water oak, and cherrybark oak are moderately flood tolerant, weakly flood tolerant, and flood intolerant, respectively. The Sharkey, Forestdale, and Dundee soil series are common to the Yazoo Basin and represent two hydric soils and a non-hydric soil, respectively. Considering all species, first-year seedling survival ranged from 85% on the Dundee to 69% on the Forestdale. Considering all soil types, Nuttall oak had 97% survival, while water oak and cherrybark oak survival averaged about 65%. The effects of soil series appeared greatest for cherrybark oak with survival decreasing from 90% on the Dundee to 50% on the Forestdale and Sharkey. Shoot dieback occurred during the first year with the least amount on the Dundee soil and for Nuttall oak. First-year results suggest that Nuttall oak and water oak can be planted over the range of sites found at Lake George. Cherrybark oak should be planted on the dryer sites typified by the Dundee soil series.

Introduction

The increase in economic activity and land development in the southern United States is predicted to cause a continuous reduction in timberland area (Alig et al. 1990). Included in the projection are bottomland hardwood wetlands (BLHW) in the Mississippi Alluvial Plain which are projected to decline from 4.8 million hectares in 1937 to only 1.6 million hectares in 1995 (MacDonald et al. 1979, Clark and Benforado 1981). The loss of BLHW to man-made factors means the loss of wetland functions such as wildlife habitat, timber production, flood flow alteration, sediment stabilization, sediment and toxicant retention, nutrient removal and transformation, and production export (Gosselink et al. 1990). The ability to perform many of these functions is dependent upon the BLHW hydrologic regime. Within the Yazoo Basin, MS, flood control projects have contributed to the loss of functioning BLHW either by clearing during construction or by reductions in flooding.

The US Army Engineer District, Vicksburg, initiated the Lake George Wildlife and Wetland Restoration Project to mitigate for terrestrial wildlife habitat losses resulting from the construction of the Yazoo Backwater Levee Project. The objective is to replace the lost habitat by reforesting agricultural land with bottomland hardwood tree species. Because of past agricultural activities, the Lake George site typifies future BLHW restoration sites within the Yazoo Basin by having significant man-made alterations in soils and hydrology. Consequently, it is difficult to select tree species for these disturbed sites using as guidance the natural interrelationships between species, soils and hydrology. An experiment was initiated at Lake George to study the effects of three soil types, with their existing hydrologic regimes, on the establishment of three oak species which vary in flood tolerance. Results from this and other experiments currently being conducted at Lake George may assist in making decisions on the location of species for other BLHW restoration projects within the Yazoo Basin.

Methods

The Lake George Wildlife and Wetland Restoration Project is located about 10 km east of Satartia, MS, and consists of 3400 ha of frequently flooded agricultural land. The site is situated between the Panther Swamp National Wildlife Refuge and the Delta National Forest. The site is bisected by the Will Whittington flood control channel and levee

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system. Agricultural crops grown on the site include rice, soybeans, and cotton. The site is an alluvial floodplain inundated periodically by backwater flooding from the Yazoo and Big Sunflower Rivers. Ponding of rainwater and surface run-off is also an important source of flooding. Climate is humid and warm with the daily average temperatures ranging from a maximum of 24°C to a minimum of 12°C. Average annual rainfall is about 137 cm which occurs mainly in the winter and early spring.

Bareroot 1-0 cherrybark oak (*Quercus falcata* var. *pagodaefolia*), water oak (*Quercus nigra*) and Nuttall oak (*Quercus nuttallii*) were purchased from a Mississippi state forest tree nursery in January 1992. These species are an important component of the Lake George reforestation effort and represent a range of flood tolerances from the intolerant cherrybark oak to the weakly-tolerant water oak and the moderately-tolerant Nuttall oak (Clark and Benforado 1981). The seedlings were cold-stored (3°C) for about 2-weeks prior to outplanting.

The seedlings were outplanted on a catena of three soil series common to the Lake George site and represent a range of topographic, hydrologic and soil texture conditions (SCS 1975). The Dundee silt loam 2 to 5% slope (Aeric Ochraqualfs) is a non-hydric soil usually found on the higher topographic positions. The Sharkey clay (Vertic Haplaquepts) is a hydric soil located in depressions (NTCHS 1991). The Forestdale clay loam (Typic Ochraqualfs) is a hydric soil which can usually be found between the Dundee and Sharkey series on the landscape.

The study was conducted as a randomized complete block design (RCBD) with blocks (replications) represented by the three soil series and treatments (plots) represented by the three oak species (Table 1). Because only one catena location was used in the study, the soil series were not replicated. The block effects, or the effects of soil series, were considered fixed. The interaction between soil series and species could not be statistically tested because an appropriate error term was lacking (Steele and Torre 1980).

Within each plot, 100 randomly selected seedlings of one species were planted using shovels on a 3 m by 3 m spacing (study total = 900 seedlings). Percent moisture content was calculated gravimetrically from soil samples periodically collected during the growing season from each soil series. Soil samples were obtained at a depth of 15 to 20 cm. Field measurements included first-year survival and height growth. It was hypothesized that the survival and growth observed could be explained by the relationship between soil moisture and seedling water relations. On September 9, 1992, the first expanded, undamaged leaf from the top of the shoot of 3 randomly selected seedlings from each plot was chosen for midday leaf water potential and stomatal conductance measurements. Water potential was measured with a pressure chamber (Model 600, PMS Instruments Co., Corvallis, Oregon), and stomatal conductance was measured with a steady-state porometer (Model LI-1600, LI-COR, Inc., P.O. Box 4425, Lincoln, NE).

Analysis of variance for a RCBD was conducted using Statistical Analysis System procedures (SAS 1988). Block and plot means were used as the observations. Block and treatment differences were discussed as significant at the 5% level of probability.

Results and Discussion

The recommended morphology for bareroot bottomland hardwood planting stock is stem height equal to or greater than 46 cm, root-collar diameter of at least 10 mm, and roots pruned to a length of 20 cm (Allen and Kennedy 1989). The cherrybark and water oak planting stock were generally taller and smaller in diameter than the published recommendations (Table 2). Their root systems were within the desired length and were fibrous. These attributes made them easy to handle and plant in less than ideal conditions. Saturated soils made access difficult, shovel holes of sufficient size difficult to open, and good root-to-soil contact difficult to achieve because holes would not close, especially in the Sharkey and Forestdale soils. These soils are montmorillonitic clays with high shrink and swell potential. Incomplete closure of planting holes may enhance the chance of root exposure when cracking occurs during drought. The small cherrybark and water oak seedlings required less handling time because the smaller shovel holes were easier to close. Nuttall oak seedlings averaged near the recommended diameter, but their root systems were heavy with only a few, large primary laterals which made them difficult and time-consuming to plant. Root pruning to a 20-cm length would have resulted in severe loss and wounding to the root system.

BLHW restoration success will be measured by the replacement of a suite of wetland functions. The need for reliable wetland hydrology will probably require sites to be within the two-year floodplain. In addition, only frequently-flooded sites which are

Table 1. *Analysis of variance for a randomized complete block design for the Lake George study.*

Source	df	Description
Blocks	(3-1) = 2	One catena location consisting of a Dundee, Forestdale and Sharkey soil series.
Treatment	(3-1) = 2	Three tree species consisting of cherrybark, water and Nuttall oaks.
Error	(3-1)(3-1) = 4	
Sampling Error	(3)(3)(100-1) = 891	100 seedlings for each plot.
Total	(3)(3)(100)-1 = 899	

Table 2. *Planting stock morphological characteristics for the Lake George study.*

Species	Height (cm)	Root Collar Diameter (mm)	Shoot Oven Dry Weight (g)	Root Oven Dry Weight (g)
Cherrybark Oak	71 (1.9)[1]	5.3 (0.2)	7.2 (0.8)	6.2 (0.6)
Water Oak	64 (1.3)	5.4 (0.2)	4.6 (0.4)	4.3 (0.3)
Nuttall Oak	93 (2.8)	12.1 (0.4)	21.9 (1.8)	20.7 (1.9)

[1] Values in parenthesis represent one standard error.

unproductive for agricultural crops may be available for restoration. During the normal planting season (usually between December and March), the fine-textured soils found on these sites will most likely be saturated resulting in difficult planting conditions. The desired seedling morphology should reflect the potential problems in handling during planting in addition to the concerns regarding the post-planting environment. For example, flooding depths which completely inundate the shoot are more detrimental to survival than shallower events (Whitlow and Harris 1979). The small diameter and fibrous root system of the cherrybark and water oak made handling easier while their tall shoots reduced the likelihood that late-spring floods, common to the Yazoo Basin, could over-top the shoot and reduce survival.

The 1992 growing season at Lake George appeared ideal for the establishment of seedlings. While conditions were dry during the spring, monthly rainfall amounts exceeded the average most of the summer (Figure 1). Percent soil moisture content within the root zone was highest for the Forestdale and Sharkey series. These soils remained moist throughout the growing season relative to the Dundee series which appeared dry in the early spring and in June. However, first-year survival and height growth did not reflect the dryer conditions on the Dundee soil (Table 3). Differences between soil types for first-year survival and height growth were not significant. Overall survival on the Dundee averaged 85% while the lowest survival occurred on the Forestdale. A net negative height growth was observed on each soil type with the least amount of dieback occurring on the Dundee.

Species differences in survival and height growth were not significant. Nuttall oak had the greatest survival and the least amount of dieback despite the difficulty in handling and planting. These results can be partially explained by the extraordinary care and time utilized during the planting of this species. The increased speed during an operational planting (especially for crews paid by the seedling) could result in lower survival for all the species studied (South and Mexal 1984). Survival and shoot

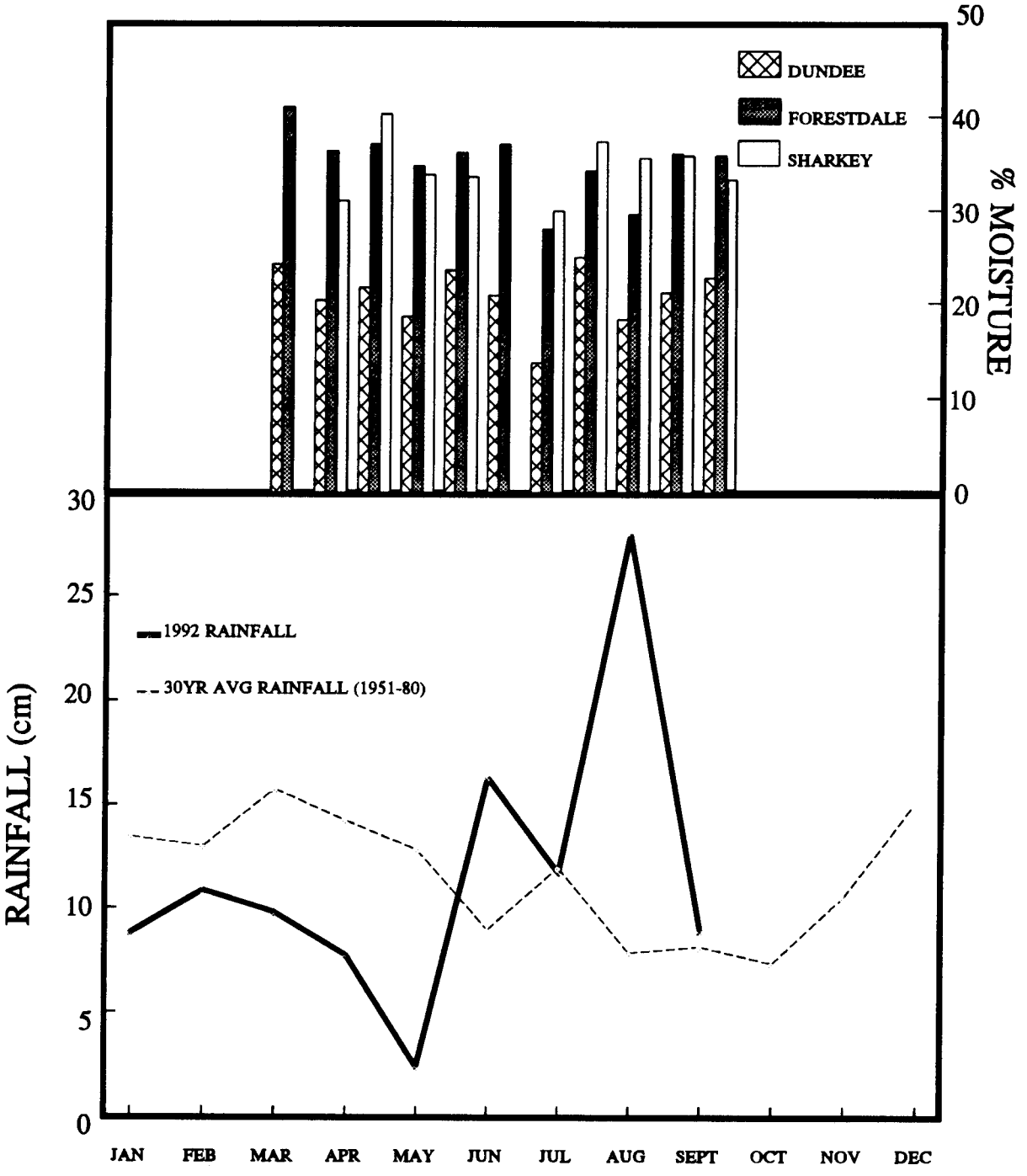

Figure 1. *Rainfall and percent soil moisture for the Lake George study site.*

dieback were similar between cherrybark and water oak.

Survival appeared to be consistent across soil types for Nuttall and water oak. Cherrybark oak survival was sensitive to soil type dropping from 90% on the Dundee to about 50% on the Forestdale and Sharkey. Shoot dieback was greatest for Nuttall oak (-12 cm) on the Dundee suggesting stress was greatest on the dryer site for these large seedlings. Height growth (or dieback) was negligible on the Dundee for cherrybark and water oak, but dieback ranged from -15 cm to -30 cm for these species on the Forestdale and Sharkey soils. For plantings in the Yazoo National Wildlife Refuge where all three species were on the same site, Nuttall oak grew faster than water oak and cherrybark oak (Allen 1990).

Leaf water potential differences between soil types were small, but stomatal conductance was about 0.30 cm/s lower on the Forestdale and Sharkey soils (Table 3). Nuttall oak had the lowest leaf water

Table 3. *First-year survival and height growth and plant water relations information sampled midday on September 9, 1992 by soil series and oaks species for the Lake George study.*

Treatment	Survival (%)	Height Growth (cm)	Leaf Water Potential (MPa)	Stomatal Conductance (cm/s)
Soil Series[1]				
Dundee	85	−3.8	−2.5*	0.78***[2]
Forestdale	69	−18.9	−2.1	0.48
Sharkey	72	−14.9	−2.1	0.43
Oak Species				
Cherrybark Oak	65	−19.8	−2.3**	0.42***
Water Oak	64	−16.3	−1.8	0.50
Nuttall Oak	97	−1.6	−2.6	0.77

[1] Values presented for soil series represent block (replication) means.
[2] * = Significant at the 5% probability level, ** = Significant at the 1% probability level, *** = Signficant at the 0.1% probability level.

potentials followed by cherrybark and then water oak. Cherrybark and water oak had stomatal conductances 0.35 and 0.27 cm/s lower than Nuttall oak. For each species, leaf water potential increased and stomatal conductance decreased from the Dundee to the Sharkey soils.

The seedlings of several bottomland hardwood species respond to flooding and anaerobic conditions by rapid reductions in stomatal conductance (Pezeshki and Chambers 1985, 1986). Stomatal closure during flooding does not appear to be water stress-induced. Flood-tolerant species appear to regain partial stomatal function under flooded conditions. Perhaps the moist conditions in the Forestdale and Sharkey soils throughout the summer resulted in anaerobic conditions sufficient to reduce stomatal function. The higher stomatal conductance rates for the moderately flood-tolerant Nuttall oak may reflect the ability to adapt to anaerobic conditions. Stomatal closure during flooding usually corresponds with reductions in net photosynthesis (Kozlowski et al. 1991). The potential for lower photosynthetic rates on the Forestdale and Sharkey soils may have created insufficient carbohydrate levels to maintain existing shoots or produce new shoots which resulted in the greater amounts of dieback observed for cherrybark and water oak.

It is recognized that the water relations results may be confounded by the sampling scheme. The Dundee soil was sampled first, followed by the Forestdale and then Sharkey soils. The decline in stomatal conductance and the increase in leaf water potentials from the Dundee to the Sharkey may be in response to short-term water stress from the midday high vapor pressure gradient (Kramer 1983). The continued absorption of water during stomatal closure would recharge the leaf raising the leaf water potential. Broadfoot (1967) reported that shallow flooding on Sharkey soils during the winter and early spring increased soil moisture contents throughout the growing season enhancing tree growth. During dry growing seasons at Lake George, seedling survival and growth could be greater on the Sharkey and Forestdale soils which are usually flooded or saturated during the winter.

In conclusion, the high first-year survival on all soil types suggests that Nuttall oak can be planted over the range of existing hydrologic and soil conditions found at Lake George. Water oak survival varied little between soil types, but dieback was severe on the hydric soils. Planting water oak across the range of soil types seems possible if poor early height growth can be tolerated. First-year performance of cherrybark oak on the hydric soils was poor, despite the lack of flooding or saturation stress during the growing season. Soil saturation at the time of planting may have been sufficient to stress this flood-intolerant species. Though long-term flooding or soil saturation during the growing season may occur infrequently at Lake George, cherrybark oak should still be planted only on dryer sites with more coarse-textured soils. To better understand the stomatal conductance and leaf water potential

response, the second-year measurements will focus on plant water relations.

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Site Preparation and Vegetation Management

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A LOW COST ALTERNATIVE FOR CUTOVER FOREST SITE PREPARATION: USING GOATS [1]

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Abstract. Forest site preparation activities are cost prohibitive in the South and prevent many cutover forest sites from becoming adequately reforested with preferred species. Goats offer landowners a potential low-cost alternative to conventional site preparation techniques in removing unwanted competitive vegetation. A site in Marengo County, AL, clearcut in 1989, was chosen for a preliminary study of the practice. Vegetation assessments were made in 1991, prior to any site preparation. Vegetation, water quality, animal health and condition, and economic data were gathered after goats began browsing the study area, April, 1992. Goats can effectively control competing hardwoods within their reach, 4 feet from the ground. In addition, preliminary data suggests that goats control taller vegetation by striping the bark and girdling the plant, but only after preferred green vegetation are consumed. For best results, goats may need to be introduced within two years of clearcutting, when most of the vegetation is within their reach. Goats showed a browsing preference with one plant species mostly consumed before other species were browsed. For optimal livestock production, conditions need to be regularly monitored to ensure availability of sufficient browse and optimal herd health. Using data generated in this study to project the economics of using goats to site prepare 40 ac tracts each year for 10 years requires an initial investment of $5,500 for equipment, fencing, buildings, and corals. Over this period goats can return a positive cash flow from the sale of mohair or meat. If forest site preparation costs are included in the economic analysis, returns could exceed $30,000, depending upon actual site preparation costs and the annual discount rates. These projections suggest these practices can offer substantial income to goat owners and lower costs to landowners, as compared to traditional site preparation methods. The use of goats also provides a potential ecological approach to site preparation without detrimental effects on surface soils and water.

Introduction

Lack of regeneration of desired tree species on recently harvested non-industrial private forestlands is one of the greatest problems facing forestry. Recently it was determined, that over a 10-year period, less than 55 percent of harvested pine or mixed pine-hardwood stands were successfully regenerated to pine on these lands (USDA Forest Service, 1988). A major factor in reforesting lands to pine is site preparation to remove competing vegetation. Generally, mechanical or chemical site preparation is expensive. Goats may prove to be a low-cost alterative for site preparation and may be profitable within themselves. The competing vegetation on the site could be converted into a meat or mohair crop, reducing the costs for site preparation.

The use of herbicides have gradually replaced mechanical methods for site preparation for pine trees because of their ability to suppress competitive hardwoods and herbaceous growth while creating less erosion and less cost than many other mechanical approaches (Michael et al. 1990). Increasing awareness of the environmental impact of herbicides have led to new schools of thought and practices dealing with the risk assessment in the use of herbicides and other pesticides for managing southern forests (Bush et al. 1989; Michael et al. 1990; Neary et al. 1984; Neary et al. 1986). Interest in using alternative vegetation management practices, particularly in environmentally sensitive areas, is therefore increasing.

The use of livestock as an integrated forest management tool has been considered for some time

[1] Paper presented at the Seventh Biennial Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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(Pearson 1991) with a primary emphasis on cattle. While the use of goats to control vegetation has been periodically used in the U.S.A. and abroad (e.g. Green et al. 1979; Merril and Taylor 1976; Radcliffe 1985), the potential efficacy of browsers (goats) as opposed to grazers (cattle) is being recognized as appropriate in many circumstances (Burton and Scarfe 1991). While few, well controlled studies using goats to manage forests have been undertaken, several recent preliminary studies have been reported (Bonsi et al. 1991; Burton and Scarfe 1991; Pearson and Martin 1991; Pinkerton 1991). As in most new areas of research numerous new questions have arisen.

The research reported here was intended as an exploratory study to: (1) investigate the potential effectiveness of goats for site preparation prior to pine reforestation, (2) determine the dietary preference, nutritional value, and impact of goats on different woody species, (3) determine the economic feasibility of using goats for reforestation site preparation.

Methods

The study was located on a privately owned, non-commercial 80 acre clearcut site (1989), in Marengo County, Alabama. Sixty head of yearling Angora wethers, intended for mohair production, and 62 yearling male Spanish goats, used for meat production, were browsed in separate compartments beginning in April 1992. The Angora stocking rates were about 12 goats/ac, and the Spanish goats at 6 goats/ac. During the 1991 growing season, prior to the introduction of goats, species composition, edible biomass, and height-growth of vegetation were measured. The nutritional value of each plant species was determined by measuring for partial dry matter, crude protein (CP) (Kjeldahl method), and acid detergent fiber (ADF), using standard techniques (Goering and van Soest, 1970).

Vegetation analysis was based on measurements taken from randomly chosen transects (3 ft wide by 520 to 700 ft long). Woody plants were measured for height, crown spread, origin and vigor class. For thirty different species the edible biomass was recorded in relation to height, stem diameter, crown spread, crown length, and origin. Height was found using regression analysis, to best predict edible biomass, therefore all subsequent estimates of biomass used height in the predictive equation. No measurements were made of the herbaceous vegetation. Edible biomass is defined as that portion of a living woody plant that could be consumed by a browsing animals including all leaves, twigs and branches under one-half inch in diameter within 48 inches of the ground.

Dietary preference measurements were also estimated on the transect lines. Each plant species was scored from one to five depending upon the amounts of browse consumed: (5) no browsing, (4) 1/4 or less edible portion consumed, (3) 1/2 edible portion consumed, (2) 3/4 edible portion consumed, and (1) total edible portion consumed. The scores were averaged and totaled for five measurement periods during the study to indicate the overall dietary preference for each plant species: the higher the score, the lower the dietary preference.

Animal performance was monitored by body weights (average daily weight gain) and body condition scores (BCS; 1 = thin/low, 5 = fat/high) measured every 28 days for 56 days, and every 14 days thereafter. Gastrointestinal parasite loads (eggs per gram of feces) were monitored periodically. Animals were brought into their respective corrals each afternoon using approximately 0.1 lb of corn feed as an attractive incentive, and enclosed overnight to reduce predation.

All facilities, housing, fencing and equipment were portable and easily erected and dismantled. Estimated serviceable life of all hardware was set at 10 years. Perimeter fencing consisted of portable electric fences powered by a 12 V DC pulsed energizer capable of generating 8.5 kV at 850 mA. Input current was generated by a 40 W solar panel and stored in a commercial heavy duty 12 V battery. Several combinations of portable fencing materials were tested ranging from electric wire mesh system (Flexinet) to a three strand system (Livestrand).

Shelter and working corrals were centrally located on level ground. Separate browsing units contained either Angora or Spanish goats could be accessed by opening a section of the corral. Shelter consists of three (10 ft x 20 ft x 6 ft high) portable sheds, made from 2 inch steel pipe and having a steel sheeting roof with all sides open. Two sheds were used as separate shelters for the Angoras and Spanish goats; the third was used as a storage and work area. Corrals surrounding the sheds were constructed of 0.25 inch galvanized welded mesh (4 in x 6 in) cattle panels (42 in high and 16 ft long) wired to 6 ft steel posts.

Water was supplied using a 550 gal plastic storage tank with two 15 gal gravity flow water tanks. The storage tank was refilled approximately every 21

days, from a second 500 gal portable tank mounted on a trailer.

Price and cost data were gathered from actual study records and from other available information to allow basic economic assumptions to be made (Table 1). The economic analysis projected the use of 120 head of either breed to site prepare 40 acre units, each year for 10 years. The Angora herder is assumed to purchase yearling goats, use the goats to site prepare forestland during a 6 month growing season, feedlot the animals during the winter, and sell the animals as culls after 5 years. A new herd would then be purchased and sold as culls at the end of the 10 year period. The Spanish goat herder is assumed to purchase the goats in the spring, use them to site prepare forestland for a season, feedlot the animals in the winter, and sell the animals at the end of the second site preparation season. Replacement animals would be purchased in spring on a two year cycle, repeated over 10 years. The analysis assumes the use of wethers rather than a naturally regenerating breeding herd.

Table 1. *Variable costs and returns used in economic analysis.*

Item	Angoras	Spanish
Herd size (number)	120	120
Purchase cost	$40/head	$0.90/lb
Sales price	$25/head	$0.80/lb
Mohair price ($/lb)	4.50	–
Weight (lb)	–	40
6 mo wt. (lb)	–	58
1.5 yr wt. (lb)	–	80
Mohair (lb/6 mo)	4.2	–
Site mortality (%)	3	2
Feedlot mort. (%)	2	1
Time on site (mo)	6	6
Forestland (acres)	40	40
Misc. cost ($/6 mo)	0.65	0.65
Medicine ($/6 mo)	2.00	1.00
Shearing ($/6 mo)	2.50	–
Feed ($/6 mo)	1.82	1.82
Feedlot ($/day)	0.05	0.05

Economic analysis excludes expenses for labor and capital associated with the herder's base property, and assumes the livestock owner has: (1) land to feedlot the goats during the winter, (2) transportation to get to the forest site each day, and (3) equipment to move the sheds, corrals, and fencing material to and from the forest sites. Included are costs for animal purchase and care, their transportation to and from the forest site, and initial cost of equipment required on a goat-site preparation operation (Table 2). The net present values calculated, are therefore the returns to labor and assets used but not accounted for in the analysis. Real, or after inflation, discount rates ranging from 0 to 10 percent was used to discount all cash flows. All costs and returns are expected to change the same as the rate of inflation.

Table 2. *Investment requirements for a goat site preparation job.*

Items required	Cost
Portable Fencing Costs	
Solar panel	$1,164
3000 ft. of Flexinet	1,840
Portable Housing	776
Portable Water System	1,708
TOTAL COSTS	$5,488

Results and Discussion

Woody vegetation grew rapidly after clear cutting. The average height of vegetation grew from 19 inches, 17 months after harvesting the timber (March 1991) to 48 inches when the goats were introduced (April, 1992; Figure 1). Effectively, this placed almost half of the potentially available goat forage above the direct reach of the animals when they were introduced 30 months after clear cutting, as 48 inches is the effective reach of the goats. At the time of introduction, about 2.9 and 3.5 tons per acre of vegetation were available in the Angora and Spanish goat units, respectively. Ninety five percent of this vegetation was removed by the Angoras in 85 days and in 132 days by the Spanish goats, at which time the animals were moved to new units to ensure adequate available feed. While not considering the dynamic changes occurring during the browsing period in vegetation growth and depletion rate, or changes in animal weights over time, this represent an average daily consumption of about 300 lbs (wet weight) of vegetation consumed by Angoras and about 500 lbs per day by Spanish goats. Assuming an average of 40% dry matter in all edible vegetation (Table 3) this equates to a 5% and 7% of body weight, dry matter intake, per head, per day for Angoras and Spanish goats, respectively. These results correspond fairly well to values of 4% body weight, dry matter intake per day in controlled experiments with balanced rations.

In neither unit was all vegetation completely removed by the goats, partially as a result of much of the edible vegetation being above the browsing height. Although future assessment of the site is necessary, it

Table 3. The average abundance, and chemical composition of dominant plant species on clearcut forest sites and average browsing preference of Angora and Spanish goats for these species.

Species	Abundance		Preference score[1]	Chemical composition		
	Number of Stems	Percent		Crude protein	Partial dry matter	Acid detergent fiber
	(number)	(%)		(%)		
Sweet Gum	1,810	19.0	32.50	9.6	34.3	50.2
Red Maple	927	9.8	20.75	9.0	43.7	48.1
Red Oaks	880	5.6	16.25	9.7	48.0	36.6
Redbud	528	5.5	27.00	10.3	44.2	25.9
Persimmon	520	5.5	25.50	10.7	37.8	39.0
Black Gum	467	4.9	19.50	8.1	46.8	39.7
Dogwood	435	4.6	29.75	7.4	43.2	29.8
Hickory	389	4.2	17.75	10.8	54.5	34.5
Wax Myrtle	383	4.1	33.00	10.4	32.5	23.0
Elm	312	3.4	24.25	7.8	40.6	33.0
Sumac	282	3.0	6.50	10.9	41.5	24.6
Cherry	262	2.8	19.77	14.9	50.0	39.5
Devils Walking Stick	234	2.5	7.00	13.4	36.5	33.5
Am. Beauty Berry	229	2.4	4.50	11.2	38.6	48.8
Sassafras	183	1.9	10.25	10.5	40.5	37.4
Green Ash	173	1.8	14.25	10.9	43.9	38.4
Yellow Poplar	169	1.8	13.25	--	--	--
White Oaks	158	1.6	25.70	11.1	48.7	32.3
Witch Hazel	151	1.6	27.00	--	--	--
Other	985	10.2	--	--	--	--
Totals	9,573	100.0	--			
Averages				10.39	40.3	36.14

[1] Low preference scores indicate a greater preference of a plant species as goat forage.

appears that the goats have effectively depleted much of the taller vegetation through bark removal and girdling. While the unwanted vegetation on the sites were not depleted to the extent that mechanical or chemical means would have, these results do demonstrate the potential effectiveness of using goats. It is also possible, although not tested, that other management practices may be more effective, such as placing animals on site early after clear cutting, high stocking rates for short periods, reintroduction onto previously browsed sites, limited hand cutting of tall vegetation or a combination of different practices.

Some of the most abundant browse species on the site were least preferred (Table 3). Observations showed that goats almost eliminate preferred plants before browsing the less desirable species, which were in turn eliminated. The goats browsed 95 percent of all available edible vegetation before they were removed (Figs 2a and 3a); consequently they eventually consumed even least preferred species. If a site has a high density of less preferred species, goats may need to be held on the site for a longer period to be effective in removing low preference species.

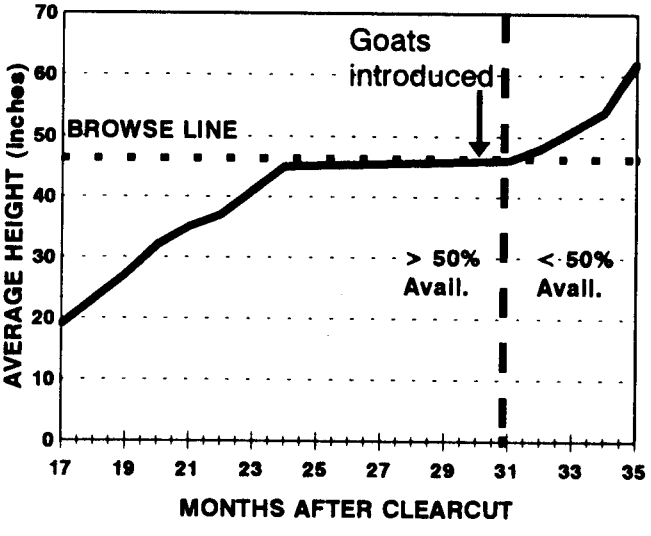


Figure 1. *Average heights of vegetation on the study area prior to and shortly after introducing goats to control vegetation.*

The chemical composition of the dominant plant species represent the nutritional value potentially available to the animals. Analysis of samples of these species taken during the 1991 growing season are used as interpretive data (Table 3.). Protein, normally an expensive constituent of livestock feeds and necessary for animal growth, averaged slightly above 10% in the dominant forage types. In less dominant species protein was as low as 6.4% (Beech) and as high as 20.5% (Poke Weed). Acid detergent fiber (ADF) represents the amount of fiber in the plants which relates to the nutritional quality of the forage; fiber increases with plant age which results in lower quality. The predominant plant species averaged 30% ADF. Partial dry matter estimates the proportion of the plant actually containing nutritional components available to livestock and averaged 40% in the dominant species. In general, the nutritional value of the dominant vegetation is adequate to support animal growth and weight gain. Although there does not appear to be any correlation between vegetation preference and nutritional quality, some of the most dominant species (e.g. Sweet Gum, Red Maple) have a low preference, a low protein value and are high in fiber, indicating older plant material with an overall low nutritional value. Preference for one species above another may also be influenced by palatability, taste, tannin content, toxins and numerous other factors yet to be determined. It is possible that younger vegetation that develops soon after harvesting a timber stand may have a different hierarchical preference and may be of higher nutritional value thereby better supporting livestock performance.

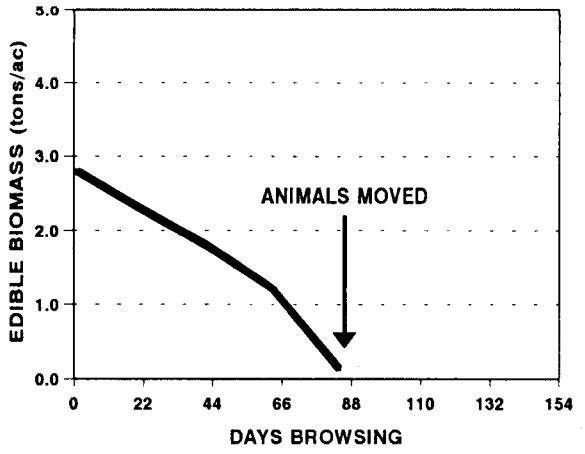
Angoras began the study weighing an average of 42.05 lb growing to 49.64 lb in 153 days, representing an average weight gain of 0.04 lb/day (Figure 2). Outbreaks of soremouth (Parapox virus) or parasitism (primarily *Haemonchus contortus*) caused periods of weight loss, and decreased hair production. Angora performance was also modified by the quantity and quality of available forage especially when the effects of parasitism occurred at the same time as forage abundance decreased near the end of the browsing period on the initial unit. Mohair production averaged 4.23 lb/head during the study period (Table 1).

Spanish goats began the trial weighing an average of 42.32 lb growing to 58.55 lb in 153 days, representing an average of 0.10 lb/day gain (Figure 3). Soremouth broke out in the herd early during the study but parasites did not affect this herd until late in the study period.

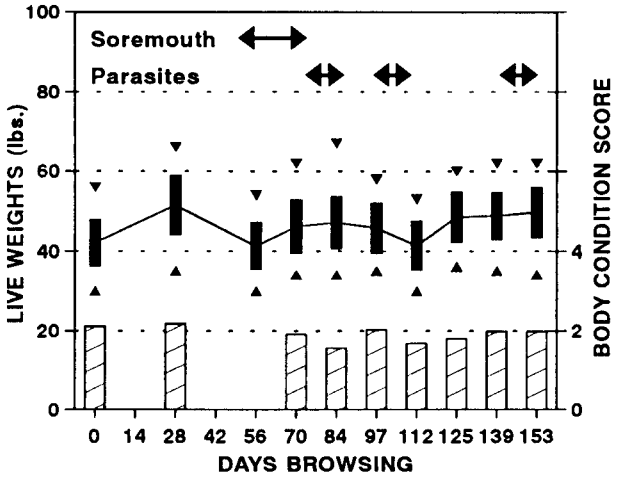
All shelters, corrals, water sources were found to be adequate to maintain the animals. The Flexinet mesh fence system completely prevented animal escape, although occasional movement of Angoras occurred through certain parts of the 3 strand Livestrand system when mohair length increased, apparently insulating animals from electric shocks. Adequate fencing is required when the browsing pressure is high, since the goats will attempt to move to adjacent sites where more vegetation exists, rather than browse the less preferred species.

Labor required to erect fencing and facilities for the 40 acre unit required approximately 96 man-hours. One hour per day was required to confine the animals overnight, check for possible health problems and body condition, and inspect forage availability. Fence and facility maintenance required 1.5 hours per week and restocking water and feed supplies occupied about four hours each three weeks. Two hours every four weeks were required to de-worm the Angora goats and two hours every three months were required to de-worm the Spanish goats.

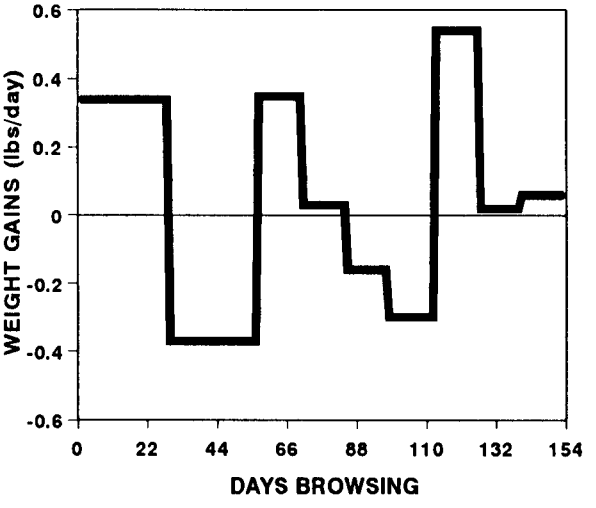
Economic returns must be positive to both the goat herder and the landowner in order for site preparation with goats to be feasible. Alternatives to the landowner include mechanical site preparation at an average cost of $87/ac or chemical site preparation at an average of $83/ac (Dubois et al. 1991). These amounts represent the maximum that the landowner would be willing to pay for having a goat herder site prepare their land. Therefore returns to the goat herder were calculated based upon a range of payments from the landowner varying from $0.00/ac to $80.00/ac treated (Table 4). If no payments are made for site preparation, returns, discounted at 4 percent, are negative for Spanish goat herders but positive for Angora goat herders. Long term (10 year) returns to the Angora owner range from $10,813 to $30,629 as payments for site preparation range from $20.00/ac to $80.00/ac treated. Similar returns for the Spanish owner range from $3,750 to $23,566, giving the edge to the Angora herder. These results should be tempered by the fact that Spanish goats have been shown to be much more resistant to parasites, and require less labor to maintain in good condition.



(a) Edible Forage Available

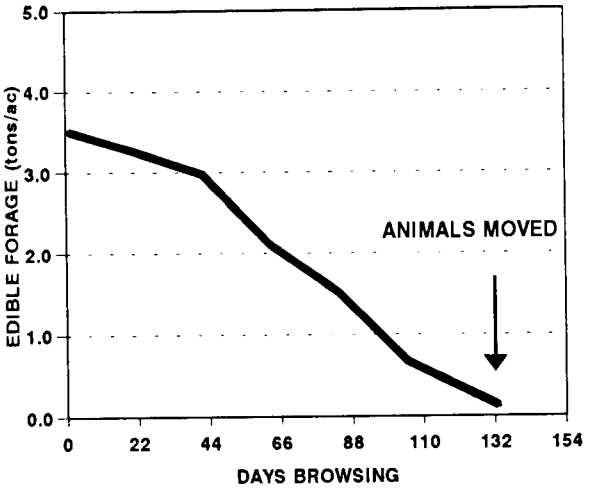


(b) Live Weights and Condition

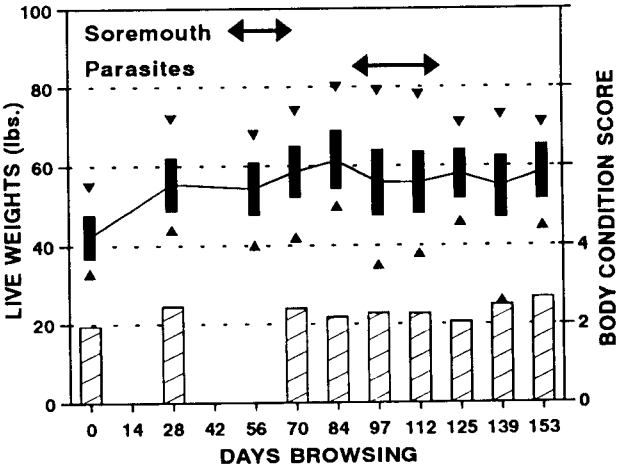


(c) Average Daily Weight Gains

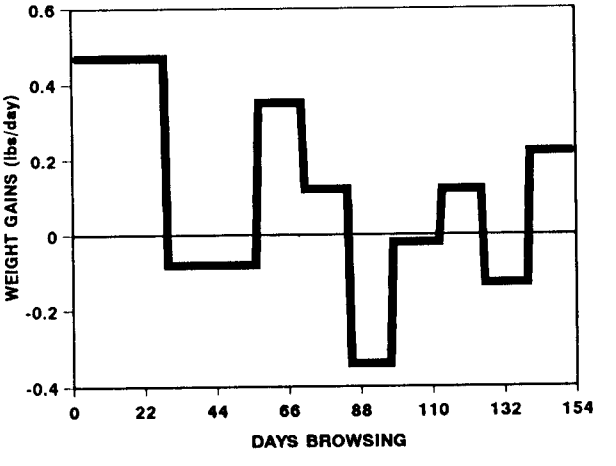
Figure 2. *Angora goat forage and animal condition changes: (A) Edible forage available; (B) Live weights and body condition scores; and (C) Average daily weight gains.*



(a) Edible Forage Available



(b) Live Weights and Condition



(c) Average Daily Weight Gains

Figure 3. *Spanish goat forage and animal condition changes: (A) Edible forage available; (B) Live weights and body condition scores; and (C) Average daily weight gains.*

Table 4. *Net present values of 10 year Angora or Spanish goat-site preparation operation.*

Site preparation payment	Discount rate					
	0%	2%	4%	6%	8%	10%
	Angora goats					
$0.00	$7,959	$5,930	$4,208	$2,739	$1,482	$401
20.00	15,959	13,184	10,813	8,778	7,024	5,507
40.00	23,959	20,438	17,418	14,817	12,567	10,614
60.00	31,959	27,693	24,024	20,856	18,110	15,720
80.00	39,959	34,947	30,629	26,895	23,653	20,857
	Spanish goats					
0.00	(649)	(1,850)	(2,856)	(3,701)	(4,416)	(5,021)
20.00	7,351	5,405	3,750	2,337	1,127	86
40.00	15,351	12,659	10,355	8,376	6,670	5,192
60.00	23,351	19,913	16,960	14,415	12,213	10,299
80.00	31,351	27,167	23,566	20,454	17,755	15,405

Conclusion

Goats have the potential to successfully prepare a pine reforestation site by reducing competing vegetation prior to planting pine seedlings. Both Angora and Spanish goats remove 11 to 16 percent of their body weight in fresh vegetation each day provided the forage is within their reach. In this study, animals needed to be removed from heavily browsed areas after 95 percent of the edible vegetation was consumed. Vegetation taller than 48 inches was not directly consumed but goats may have effectively eliminated much of this vegetation through bark stripping and girdling. For site preparation to be fully comparable to chemical or mechanical methods animals may need to be introduced within two years of clear cutting. Management practices such as high stocking rates or repeated rebrowsing may further enhance the control of unwanted plant species.

Goats showed a preference for one forage species over other species but if maintained on a site for sufficient time they consumed even the least preferred vegetation. Nutritional analysis of the dominant plant species indicated that most are of sufficient nutritional quality to support adequate livestock growth and weight gain.

In this study, insufficient daily care was provided by employed personnel resulting in animals not being regularly confined, watered, fed and observed. As a result, health problems ware not addressed as soon as needed and resulted in lower weight gains and reduced hair production. Although not experienced during this study, insufficient regular observation and overnight confinement of animals may also lead to high predation from coyotes, feral dogs or other predators. Predator problems have been found in other operations to be almost totally overcome when guard dogs, which have innate livestock guarding tendencies (e.g. Great Pyrenees, Komondor, Maremma and Anatolian Shepard breeds), are allowed to live with the livestock. Insufficient observation of the available forage vegetation can also lead to extreme over-browsing and insufficient feed to sustain optimal production. This is considered to be more critical in situations such at the approach described here, where the livestock carrying capacity of the land is purposely overstocked to obtain a rapid depletion of vegetation. While most of these adverse affects were not encountered in this study, they do emphasize the importance of regularly and reliable management to provide optimal returns to both the livestock and the land owners.

The surface topography on the site used in this study has an average surface slope of approximately 25 percent, with up to 40 percent in some areas. As such, it is considered highly erodible. A cursory, subjective assessment of the surface soils and waters was made on units carrying goats, raked and windrowed using a bulldozer, or not site prepared with either. Considerable surface sediment was washed from the bulldozed unit and created several large permanent gullies. No erosion was apparent as a direct effect of goats but some erosion occurred along bulldozed fence lines in areas that lack "water-bars" which divert runoff to less erodible areas. The effects of the surface erosion was very noticeable as sediment

in creeks draining the bulldozed, prepared areas, but almost nonexistent in creeks draining the goat browsed areas. In addition, surface soil compaction did not appear to be increased in areas housing goats and occasional sampling water runoff from areas carrying goats did not have any difference in nitrate, iron or pH and were comparable to areas site prepared using a bulldozer. Although preliminary, goats therefore show a potential for being "environmentally friendly" and my be an appropriate vegetation management method, particularly in environmentally sensitive areas.

Economic models generated in this study indicated a positive return to both timber land and livestock owners, as compared to mechanical or chemical site preparation methods. The positive relationship from a goat owner's perspective comes primarily from a reduction in feed costs, but added returns are generated from payment from timber land owners. While it is possible that greater returns can come from using a reproducing (breeding) herd producing offspring, rather that a whether or all male herd as was used in this study, the approach has yet to be tested. Producers using goats for site preparation should be fully aware of the need for diligent and regular observation of livestock performance as increased mortality or lower growth rates can negatively affect the profitability of such and endeavor. From the perspective of optimal site preparation it would be highly preferable to initiate these practices before re-growth of unwanted species reaches 48 to 60 inches as additional costs maybe incurred to remove vegetation not removed by goats.

Goats therefore, offer a potential for economically and ecologically control of unwanted vegetation on clear-cut timber sites prior to plantation planting. Preliminary data (Pinkerton, 1991, unpublished data; Scarfe, 1992, unpublished data) suggest goats are also useful in other timber land situations such as controlling kudzu or removing competitive vegetation in young pine stands. They also offer a potential for vegetation management in environmentally sensitive areas where traditional methods are economically or legislatively prohibited.

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EFFECTS OF CHEMICAL AND MECHANICAL SITE PREPARATION ON BOTTOMLAND HARDWOOD REGENERATION AFTER TEN YEARS [1]

Thomas A. Greene and W.J. Lowe [2]

Abstract. A mature, 30-acre red oak-sweetgum (*Quercus* spp., *Liquidambar styraciflua* L.) stand in southeastern Tyler County, Texas, was clearcut in 1981. Five site preparation treatments (shear, shear+burn, complete injection, partial injection, and control) were superimposed on the area in six randomized compete blocks. Five plot centers were established before the harvest in each treatment x block area and remonumented after site preparation. Overstory, midstory, and advance regeneration were measured before harvest, and height, dbh, and species of all woody stems taller than 1.37 m in four of the subplots were recorded during fall, 1991, ten growing seasons after site preparation. Basal area of residual trees at 10 years post-harvest was 35 ft.^{2}/acre on control plots, 5.2 ft.^{2}/acre on partial inject plots, and less than 4 ft.^{2}/acre on other treatments. Regenerated water oaks (*Quercus nigra* L.) and willow oaks (*Q. phellos* L.) were significantly larger on treated plots than on controls. Sweetgum stems were significantly more numerous on mechanically prepared plots than on control plots. Preharvest overstory basal area was consistently significant as a covariate in analyses of ten-year-old basal area and stocking of major commercial species. Although the composition of the regenerated stand depends in large part on the composition of the preharvest stand, this study indicated that the numbers and growth of selected species could be influenced by choice of site preparation technique.

Introduction

Natural regeneration of southern bottomland hardwoods has received increasing attention in the past two decades as establishment costs for hardwood plantations have outstripped economic returns and constraints have been imposed on evenage management. Concerns have focused on converting poor quality, overmature stands to vigorous, high quality stands of valuable species. Recent emphasis on the environmental effects of clearcutting has caused researchers to re-evaluate unevenage management in southern bottomland hardwoods. The group selection method is often recommended for managing wetland hardwoods when clearcutting is not desirable (Toliver and Jackson, 1989). Conditions in the small "patch clearcuts" created in this method approximate those of a clearcut.

Several questions about natural regeneration in clearcuts are still unanswered. While it is generally recommended, for example, that residual trees from the preharvest stand should be removed (Barrett, 1980), there is no general agreement on the best site-preparation method to accomplish this goal. Additionally, while the effects of residual overstory on regeneration are assumed to be negative, little work has been done to quantify these effects.

It is well known that the species composition of the preharvest stand influences that of the regenerated stand. Less obvious, however, are the mechanisms at work. While advance regeneration is thought to be the key to successful regeneration in bottomland hardwoods (Johnson, 1980), current knowledge does not allow the prediction of the outcome of a regeneration cut.

The objectives of the present study were:

1) to compare the effects of chemical and mechanical site preparation on the development of natural regeneration after ten years, and

2) to evaluate the roles of advance regeneration, midstory, and overstory components of the preharvest stand in determining the relative importance of selected species in the regenerated stand.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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Methods and Materials

Study Area

The experiment was conducted on three adjacent 10-acre tracts on the first terrace of the Neches River bottom in southeastern Tyler County, Texas. The area was dominated in 1981 by a red oak-sweetgum stand which was approximately 70 years old. A more detailed description of the study site was given by Morrissey and Ezell (1983).

Preharvest Data Collection

Before harvest, in May-July, 1981, each of the 10-acre tracts was divided into 10, square, one-acre treatment areas. Five permanently monumented plot centers were established in each treatment area in an "X" pattern (one near each corner and one in the center). The following preharvest data were collected from circular plots at these 150 systematically located plot centers:

1) Species and numbers of advance regeneration (stems shorter than 4.5 ft.) were tallied in mil-acre plots centered on each plot stake.

2) Species, dbh, and height of trees taller than 4.5 ft. and less than 8 inches in dbh were determined in 0.01-acre plots centered on each plot stake.

3) A BAF-10 prism was used at each plot center to tally trees greater than 8 inches dbh. Species, dbh, and height of each tallied tree was determined.

Harvest and Treatment Application

All merchantable timber was removed from the study area during August-October, 1981. Five site preparation treatments were applied in six randomized complete blocks (two per 10-acre tract). Treatments were: shear, shear + burn, partial inject, total inject, and control. Shearing was conducted on the shear and shear + burn plots during December, 1981, with a D-8 Caterpillar tractor equipped with a K-G blade. Woody stems were sheared at ground line, and debris was left in place. The shear + burn areas were burned during March, 1982. Residual stems taller than 4.5 ft. on total inject plots and larger than 3 inches dbh on partial inject plots were frilled and treated with Tordon 101R® (Picloram + 2,4-D, Dow Chemical Co.) during March, 1982 (Morrissey and Ezell, 1983).

After treatments were applied, plot centers were relocated and remonumented. Data were collected after one growing season (Morrissey and Ezell, 1983), and after five growing seasons (Byram et al., 1987).

Ten-year Data Collection

Height, dbh, and species of all woody stems taller than 4.5 ft. were recorded during October-November, 1991, within four, 0.02-acre circular plots centered on the four permanent plot markers in the corners of each treatment area. Height was measured to the nearest dm with a telescoping fiber glass height pole; dbh was measured to the nearest mm with calipers. Center plots in four of the areas were used because a corner plot was destroyed by deer hunters. This sampling scheme resulted in an 8% sample of the study area.

Data Analysis

Preharvest data from plots remeasured at age 10 were combined with year 10 data for analysis. Age 10 height and dbh data were subjected to analysis of variance to determine the effect of site preparation treatments on ten-year-old regeneration. Major species (those occupying at least 0.5 square feet per acre at age 10) were analyzed separately. Number of trees per acre and basal area per acre at age 10 were analyzed for each major species by analysis of covariance. Covariates used for each species were: number of advance regeneration stems per acre of the species, number of midstory stems per acre, basal area of midstory stems per acre, and basal area of overstory tallied at each plot center.

Results and Discussion

A description of the preharvest stand was given by Morrissey and Ezell (1983). Overstory and midstory basal areas totaled 90 square feet per acre. Red oaks made up nearly half of the overstory basal area, while sweetgum made up approximately one-quarter. Most of the noncommercial species were found in the midstory (64%) and the advance regeneration (36%). The bulk of these stems were bluebeech (*Carpinus caroliniana* Walt.) and deciduous holly (*Ilex decidua* Walt.). Twenty-nine percent of the advance regeneration stems were red oaks, mostly water oak and willow oak, while 36% were noncommercial species, 23% were miscellaneous commercial species, and 13% were sweetgum.

Red oaks declined as a percentage of the stand, both in terms of stems per acre and basal area,

across all treatments between ages 0 and 10 (Table 1). Of the total 2269 regeneration stems tallied per acre at age 10, 310, or 14%, were red oaks. Red oak basal area, likewise, was only 17% of the stand at age 10. Miscellaneous commercial species were less important in the regenerated stand than in the preharvest stand. Sweetgum density and basal area increased dramatically as a result of stand regeneration, increasing from one-quarter of the preharvest overstory to nearly two-thirds of the age 10 basal area.

Residual stems (trees remaining alive from the preharvest stand) were still present at age 10. Control plots (no site preparation) had 35.2 square feet per acre of residual stems. Partially injected plots had 5.2 square feet, completely injected plots had 3.9 square feet, and sheared plots had 0.4 square feet. No residual stems were tallied on shear + burn plots.

Effects of site-preparation treatments on growth of six species which occupied at least 0.5 square feet per acre at age 10 are presented in Tables 2 and 3. No treatment effects were detected on height or dbh of bluebeech, persimmon (*Diospyros virginiana* L.), or sweetgum. Willow oak height and dbh differences among treatments approached significance, as did differences between water oak heights. Water oaks were significantly larger in diameter on all treated plots than on untreated (control) plots (Table 3). When all red oaks were considered together, stems on the control plots were significantly shorter and smaller in diameter than those on all of the treated plots. These differences may have resulted because of competition from the residual overstory on control plots.

Stocking per acre for the six most common species at age 10 are presented in Table 4. Sweetgum stems were significantly more numerous on mechanically treated plots than on control plots. This difference was significant at the 5% level according to Duncan's Multiple Range test. Means from injected and partially injected plots were not different from any of the other means.

The increase in sweetgum density on mechanically treated plots may be attributed to root sprouting resulting from mechanical disturbance of the soil during site preparation. Persimmon, another prolific root-sprouting species, exhibited a similar trend in stem numbers significant at the 10% level. No differences in stem numbers among treatments were detected for other species.

Results from the analyses of covariance of density and basal area of the three most common commercial species on the study plots are presented in Table 5. Preharvest basal area was significant at the 5% level for water oak and willow oak and at the 6% level for sweetgum. Advance regeneration as a covariate was only significant for sweetgum density, while midstory basal area of water oak significantly affected stocking at age 10. Preharvest overstory basal area was the most consistent predictor of age 10 stocking and basal area per acre for the major commercial species on the site.

Table 1. *Percent of the stand in each of four species categories at ages 0 and 10 on the natural regeneration study plots in Tyler County, Texas.*

Component	Variable	Percent			
		Red oaks	Sweetgum	Misc. Comm.[1]	Non-comm.[2]
Advance regeneration	No. of stems per acre	29	13	23	36
Preharvest midstory	Basal area (sq. ft./ac.)	3	11	22	64
Preharvest overstory	Basal area (sq. ft./ac.)	48	26	22	5
Age 10 regeneration	No. of stems per acre	14	33	13	40
Age 10 regeneration	Basal area (sq. ft./ac.)	17	62	6	16

[1] Miscellaneous commercial species included green ash (*Faxinus pennsylvanica* Marsh.), American sycamore (*Platanus occidentalis* L.), hickories (*Carya* spp.), hackberry (*Celtis laevigata* Willd.), elms (*Ulmus* spp.), Maples (*Acer* spp.), baldcypress (*Taxodium distichum* (L.) Rich.), persimmon (*Diospyros virginiana* L.), and blackgum (*Nyssa sylvatica* Marsh.).

[2] Non-commercial species included red mulberry (*Morus rubra* L.), hollies (*Ilex* spp.), dogwoods (*Cornus* spp.), planertree (*Planera aquatica* Gmel.), buttonbush (*Cephalanthus occidentalis* L.), hawthorns (*Crataegus* spp.), bluebeech (*Carpinus caroliniana* Walt.), American beautyberry (*Callicarpa americana* L.), chinaberry (*Melia azedarach* L.), silverbell (*Halesia diptera* Ellis), tallowtree (*Sapium sebiferum* (L.) Roxb.), swamp-privet (*Forestiera acuminata* Poir.), baccharis (*Baccharis halimifolia* L.), elderberry (*Sambucus canadensis* L.), sebastianbush (*Sebastiana ligustrina* (Michx.) Muell. Arg.), sumac (*Rhus copallina* L.), Carolina ash (*Fraxinus caroliniana* Mill.), snowbell (*Styrax* sp.), and eastern redcedar (*Juniperus virginiana* L.).

Table 2. *Height[1] (m) at age 10 of six selected species and of all red oaks by site-preparation treatment.*

Treatment	Bluebeech	Dec. Holly	Persimmon	Sweetgum	Water Oak	Willow Oak	Red Oaks
Control	4.0 a	4.2 a	4.7 a	6.6 a	5.4 a	4.3 a	5.2 b
Partial Inject	4.5 a	4.1 a	5.3 a	7.2 a	6.4 a	5.1 a	6.3 a
Total Inject	4.5 a	3.5 b	4.0 a	7.3 a	6.3 a	6.7 a	6.4 a
Shear	4.0 a	3.1 b	4.5 a	5.8 a	6.5 a	7.4 a	6.6 a
Shear + Burn	4.2 a	3.1 b	4.1 a	6.4 a	6.6 a	5.9 a	6.5 a

[1] Means in the same column followed by the same letter are not different at the 5% level according to Duncan's new multiple range test.

Table 3. Diameter at breast height[1] (cm) at age 10 of six selected species and of all red oaks by site-preparation treatment.

Treatment	Bluebeech	Dec. Holly	Persimmon	Sweetgum	Water Oak	Willow Oak	Red Oaks
Control	2.1 a	2.7 a	2.7 a	5.0 a	3.1 b	2.3 a	3.0 b
Partial Inject	2.7 a	2.7 a	3.7 a	6.1 a	4.5 a	4.0 a	4.5 a
Total Inject	2.7 a	1.9 b	2.4 a	6.1 a	4.8 a	6.0 a	4.9 a
Shear	2.1 a	1.7 b	2.6 a	4.6 a	5.2 a	7.1 a	5.4 a
Shear + Burn	2.2 a	1.7 b	2.4 a	5.3 a	4.9 a	4.9 a	4.8 a

[1] Means in the same column followed by the same letter are not different at the 5% level according to Duncan's new multiple range test.

Table 4. Density[1] (trees per acre) at age 10 of six selected species and of all red oaks by site-preparation treatment.

Treatment	Bluebeech	Dec. Holly	Persimmon	Sweetgum	Water Oak	Willow Oak	Red Oaks
Control	483 a	269 a	67 a	542 b	308 a	48 a	369 a
Partial Inject	385 a	331 a	33 a	627 ab	294 a	29 a	340 a
Total Inject	435 a	281 a	38 a	735 ab	271 a	44 a	327 a
Shear	652 a	177 a	158 a	944 a	196 a	35 a	240 a
Shear + Burn	408 a	188 a	131 a	929 a	254 a	19 a	277 a

[1] Means in the same column followed by the same letter are not different at the 5% level according to Duncan's new multiple range test.

Conclusions

The following conclusions can be reached from the present study:

1. Preharvest overstory basal area of sweetgum, water oak, and willow oak determined, in large part, the stocking and basal area per acre of those species in the ten-year-old regenerated stand.
2. Removal of residual basal area resulted in significant increases in growth of regenerated red oaks after 10 years.
3. Mechanical site preparation caused an increase in the number of sweetgum stems, compared to no site preparation, after 10 years.

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Table 5. *Sums of squares and significance levels for three analyses of covariance for three commercial species on the ten-year-old natural regeneration study in Tyler County, Texas.*

Source	df	Sweetgum		Water Oak		Willow Oak	
		basal area	stocking	basal area	stocking	basal area	stocking
		Covariate = Advance regeneration trees/acre					
Cov.	1	54.1	2213935.6**	50.5	263686.1	10.5	1155.7
Rep.	5	7094.9*	3478274.6*	374.6	934918.3	134.9*	43571.9
Treat.	4	3969.9	2800695.8*	201.7	146175.7	80.3	11477.2
R x T	20	11461.0	4585416.0	1567.3*	3240862.4	394.8*	245549.0**
Error	89	39527.3	21581689.4	3742.6	10055688.9	1009.6	426344.3
		Covariate = Preharvest midstory basal area/acre					
Cov.	1	54.5	91504.0	326.6	3886441.0**	0.1	7500.0
Rep.	5	29678.7	18282918.0**	1463.5	3523380.2	517.3	192952.6
Treat.	4	15748.0	12387262.9*	872.7	457595.6	331.5	49911.3
R x T	20	45416.0	17838018.0	5926.2*	11867981.6	1540.3	979951.5**
Error	89	158271.2	95090996.0	14846.0	37391059.0	4080.6	1702500.0
		Covariate = Preharvest overstory basal area/acre					
Cov.	1	1564.6	921181.5	369.7**	673634.8*	49.0*	55677.2**
Rep.	5	7114.9**	4931260.4**	371.1	679234.9	124.6	34705.1
Treat.	4	2728.5	3176178.5*	127.2	237450.9	85.4	18259.5
R x T	20	8686.5	4768974.1	1228.0	2855323.5	315.0	156252.1*
Error	89	38016.9	22874443.5	3423.5	9645740.2	971.2	371822.8

* Significant at the 5% level.
**Significant at the 1% level.

THE EFFECT OF DIFFERENT SITE PREPARATION TREATMENTS ON SLASH PINE PLANTATION GROWTH IN THE ATLANTIC COASTAL PLAIN [1]

L.V. Pienaar and J.W. Rheney [2]

Abstract. This paper reports the results at age 11 of a study to evaluate the effects of commonly used mechanical site preparation treatments, in conjunction with an early fertilizer application and chemical control of competing vegetation, on the growth of slash pine (*Pinus elliottii* Engelm.) plantations in the Atlantic Coastal Plain. Analyses of height, basal area and volume growth, and of Cronartium stem infection are presented for two broad soil groups: spodosols and nonspodosols. Treatment effects differ for the two soil groups, but in all cases the most dramatic growth responses were observed when competing vegetation had been eliminated, especially on spodosols where average height was increased by as much as 40%, basal area by 95% and total stem volume by over 100%. The most intensive treatments produced more uniform results over the 16 locations, but resulted in higher stem infection rates.

Introduction

In 1979 cooperators in the University of Georgia Plantation Management Research Cooperative installed a designed study to evaluate the effects of different site preparation treatments on the growth of slash pine (*Pinus elliottii*, Englem.) plantations.

Study Design

Initially, ten sites with spodic soils and ten sites with nonspodic soils were selected. Poorly drained to moderately well drained Soil Conservation Service soil drainage classes were represented in each soil group. Only 16 installations, 9 spodosols and 7 nonspodosols remain available for analysis.

Each installation consists of 12 half-acre treatment plots that were located in existing non-old-field slash pine plantations scheduled for final harvest in 1978. The range of site indexes over the 16 installations was from 55 ft. to almost 80 ft. (base age 25 years).

Eleven treatments were accommodated at each installation with the 12th plot used to duplicate one of the treatments 2 through 11 as shown in Table 1. Existing plantations were harvested in 1978. Treatment plots were site-prepared in 1979 and hand-planted during the 1979/80 planting season with improved slash pine seedlings. Seedlings were planted on an approximate 10 ft. x 8 ft. spacing with two seedlings planted approximately 2 ft. apart at each planting location. Surviving doubles were removed at the end of the second growing season to ensure a reasonably uniform stocking of about 545 trees per acre over all plots. One plot at one of the 16 installations has since been abandoned due to damage sustained during company operations.

The control plots (treatment #1) were planted after the harvesting operation without any further treatment. The chop was a single pass with a rolling drum chopper, and the burn was a broadcast burn after the chopped brush had been allowed to dry for several weeks. Bedding was done by means of a double pass with a bedding harrow to ensure a well-formed bed. The fertilizer was 250 pounds of di-ammonium phosphate (DAP) applied in a 4-ft. band on the rows at the beginning of the second growing season. The herbicide treatment was complete control of competing vegetation to establish the maximum yield increase attainable from complete competition control. Competing vegetation consisted mostly of gallberry, wax myrtle, palmetto, wire grass and broomsedge. Vegetation was sprayed with a 3% solution of ROUNDUP prior to any site preparation. After pines had been planted they were shielded when further applications of ROUNDUP and GARLON were used as needed to maintain complete control until crown closure.

Each treatment plot was ½-acre with a 1/5-acre interior measurement plot. Every tree in each measurement plot was measured for dbh with a diameter tape and every other tree was numbered and measured for total height. Every tree was examined

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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Table 1. *Treatment definitions.*

Treatment #	Action
1	Control
2	Chop - Unfertilized
3	- Fertilized
4	Chop + Burn - Unfertilized
5	- Fertilized
6	Chop + Burn + Bed - Unfertilized
7	- Fertilized
8	Chop + Burn + Herbicide - Unfertilized
9	- Fertilized
10	Chop + Burn + Bed + Herbicide - Unfertilized
11	- Fertilized

for Cronartium stem cankers. Measurement plots have been measured and evaluated in this manner at ages 2, 5, 8 and 11 years.

Results and Discussion

This designed experimental study has a split-plot structure with soil groups representing whole plots, and was analyzed as such. Separate analyses were made of the age 11 measurements of average tree height, basal area per acre, total stem volume per acre, and percent of trees with Cronartium stem cankers.

Average Tree Height

Average height for spodosols over all treatments (31.3 ft.) was not significantly different from the nonspodosols (32.8 ft.). Table 2 shows average tree height for the treatments by soil group, and Figure 1 provides histograms of average tree height showing the difference in treatment effects on spodosols and nonspodosols.

Treatment had a highly significant effect on average tree height and there was a highly significant interaction between soil group and treatment. An average difference between treatment means of approximately 2.6 ft would be considered significant at the 95% confidence level. On spodosols chopping and chopping + burning had no significant effect, while the fertilizer resulted in an increase of 3-4 ft., as did the bedding, and these effects were additive. The effect from complete competition control, without bedding was almost 10 ft., and with bedding it resulted in an increase of 8 ft. With complete competition control the fertilizer effect was not significant. On nonspodic soils there was a fairly consistent and constant additive effect from chopping, from burning, from bedding, from competition control and from fertilizer, with the smallest effect from burning and the largest from competition control.

Table 2. *Average tree height at age 11 for different treatments on spodosols and nonspodosols.*

Treatment #	Spodosols (ft.)	Nonspodosols (ft.)
1	25.2	25.8
2	25.9	28.6
3	29.4	30.3
4	25.3	30.1
5	29.4	32.9
6	29.3	32.9
7	33.5	33.2
8	35.3	34.4
9	35.9	36.9
10	37.7	36.3
11	38.2	38.3

Average height growth curves from age 2 to age 11 are shown in Figure 2 for two of the treatments: treatment #6 - chop + burn + bed, and treatment #10 - chop + burn + bed + herbicide. These two treatments were chosen to illustrate the dramatic effect of competing vegetation on early height growth. While the difference in average height growth between treatments had declined by age 11, the curves were still diverging slightly. These two sets of curves also illustrate the interaction between treatments and soil groups. Nonspodosols performed better than spodosols with treatment #6, while spodosols benefited much more from the competition control of treatment #10, so that the situation was

actually reversed with spodosols performing better than nonspodosols with treatment #10.

Basal Area Per Acre

Table 3 shows average basal area per acre for the different treatments by soil group, and Figure 3 displays the results in the form of histograms. The average basal area over all treatments on spodosols (65.22 sq. ft.) was not significantly different from nonspodosols (67.74 sq. ft.). Treatment effects were highly significant overall, and also differed significantly between the two soil groups. An average difference between treatment means of approximately 9 sq. ft. would be judged significant at the 95% confidence level.

Table 3. *Average basal area per acre at age 11 for different treatments on spodosols and nonspodosols.*

Treatment #	Spodosols sq. ft./ac.	Nonspodosols sq. ft./ac.
1	42.8	39.8
2	43.4	48.0
3	55.1	48.1
4	43.5	55.3
5	56.1	70.2
6	55.2	66.6
7	69.6	71.4
8	85.0	75.7
9	86.4	84.9
10	87.7	87.6
11	93.6	95.6

On spodosols neither chopping nor chopping + burning had a significant effect on basal area per acre, but for both these treatments adding fertilizer had a significant positive effect, as did bedding, with the bedding and fertilizer effects being additive. The herbicide treatment (complete competition control) had the most dramatic effect with an increase of over 40 sq. ft. Both the bedding and fertilizer treatments had a diminished and nonsignificant effect on plots that received the herbicide treatment. On nonspodosols there was a more consistent additive effect from chopping, burning, bedding and competition control, with a somewhat less constant added fertilizer effect. The herbicide treatment had the highest added effect of just over 20 sq. ft.

Total Stem Volume Per Acre

Individual cubic ft. stem volumes were calculated with a standard volume equation (PMRC 1985-5)*. Heights of trees that were not measured for height were estimated with an appropriate height/dbh regression equation.

Treatment effects on total stem volume at age 11 are summarized in Table 4 for the two soil groups, and are displayed in the form of histograms in Figure 4. The average volume per acre over all treatments for spodosols (1165 cu. ft.) was not significantly different from nonspodosols (1241 cu. ft.). Treatment effects were highly significant and there was a significant interaction between treatments and soil groups. An average difference between treatment means of approximately 220 cu. ft. per acre would be judged significant.

Table 4. *Average total volume per acre at age 11 for different treatments on spodosols and nonspodosols.*

Treatment #	Spodosols cu. ft./ac.	Nonspodosols cu. ft./ac.
1	648	615
2	650	768
3	908	811
4	646	936
5	933	1269
6	903	1209
7	1264	1308
8	1606	1414
9	1656	1648
10	1755	1700
11	1879	1926

Results parallel those for basal area. On spodosols, chopping and chopping + burning did not affect total stem volume at age 11, but adding fertilizer did have a significant positive effect, as did bedding, and the bedding and fertilizer effects appear to be additive, each contributing about 300 cu. ft. An increase of about 900 cu. ft. resulted from the control of all competing vegetation and on these plots the bedding and fertilizer effects were less obvious and nonsignificant. On nonspodosols there is a more consistent additive effect from chopping, burning, bedding, fertilizing and herbicide treatment. The

* PMRC Tech Rep 1985-5, School of Forest Resources, Athens, GA.

greatest single effect was due to competition control (500 cu. ft.), but not as dramatic as on spodosols.

Cronartium Stem Infection

The percentage of trees with one or more visible stem cankers was calculated for each measurement plot. Table 5 shows the average percentage of infected trees for each of the treatments on the two soil groups. The average infection rate on spodosols over all treatments (12%) was half the infection rate on nonspodosols (24%), but this difference was not statistically significant given the high variability among treatments.

Treatment differences in infection rate were highly significant, but there was no significant interaction with soil groups. Herbicide treated plots, and in general, the treatments with the highest growth rates had significantly higher infection rates. Figure 5 shows the average infection rates for the treatments on the two soil groups in the form of histograms.

Table 5. *Average percent Cronartium stem infections at age 11 for different treatments on spodosols and nonspodosols.*

Treatment #	Spodosols %	Nonspodosols %
1	8	17
2	8	19
3	9	21
4	8	26
5	8	22
6	9	24
7	13	23
8	17	29
9	20	30
10	14	25
11	15	31

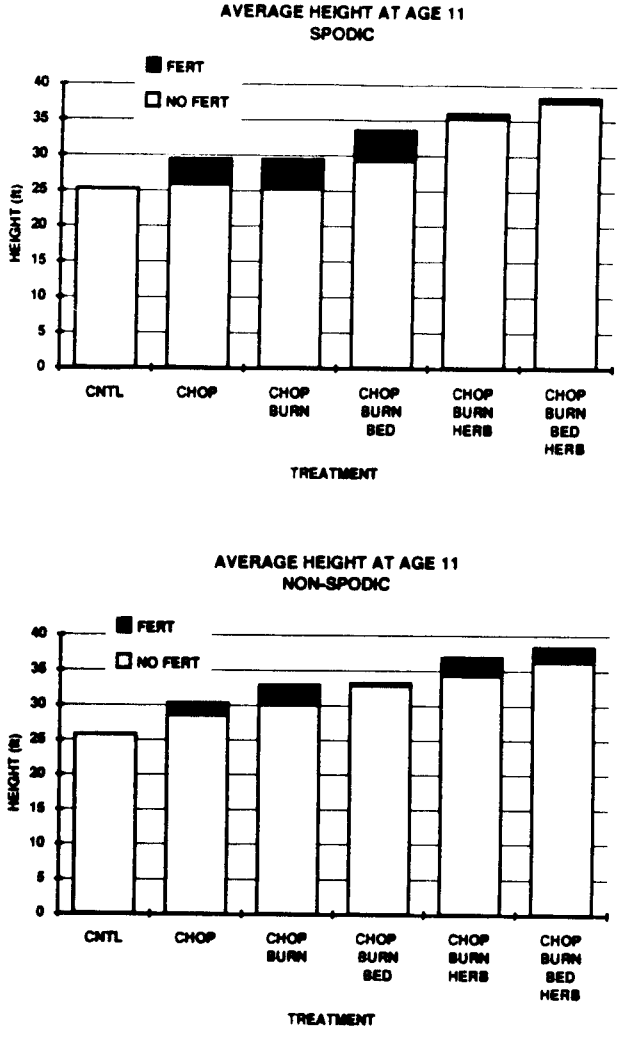


Figure 1. *Average height at age 11.*

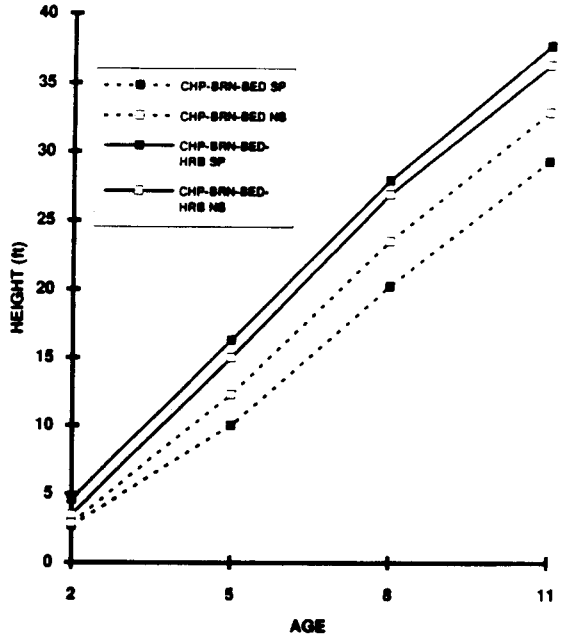
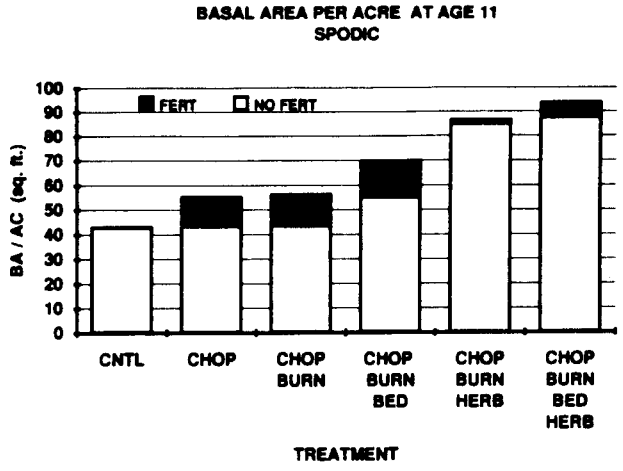


Figure 2. *Height growth curves.*



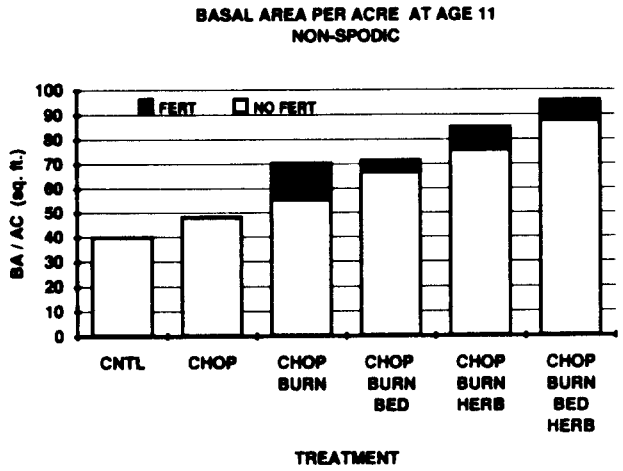
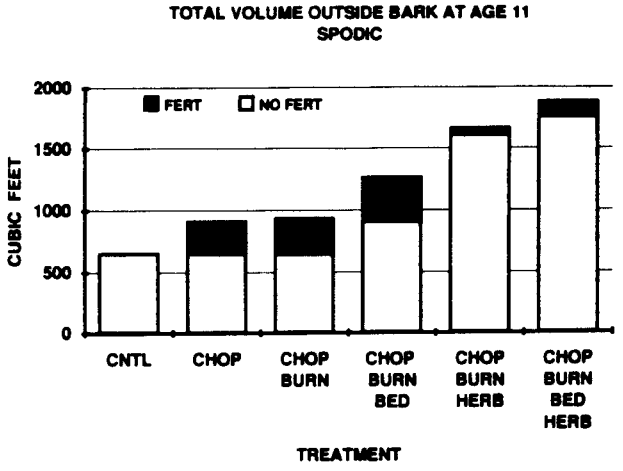


Figure 3. *Basal area per acre at age 11.*



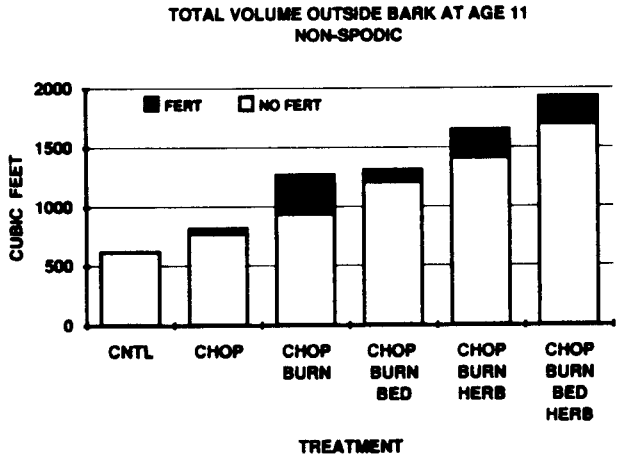
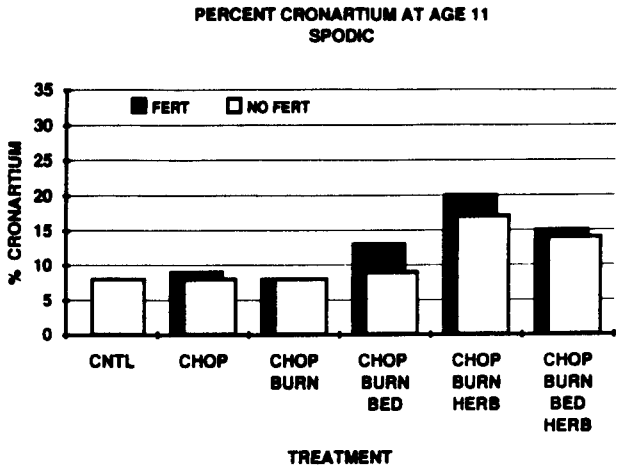


Figure 4. *Total volume per acre at age 11.*



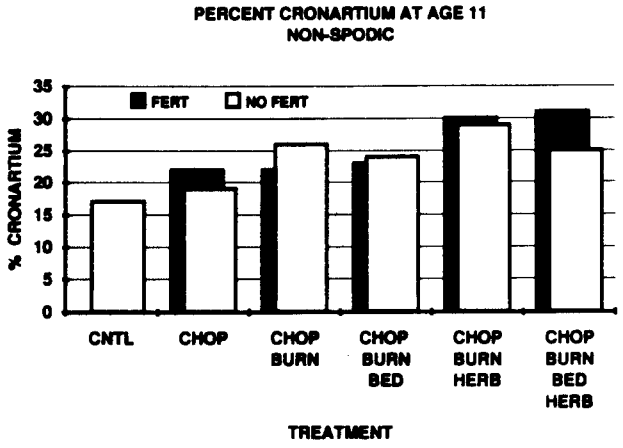


Figure 5. *Percent Cronartium at age 11.*

AGE SIX GROWTH RESPONSE TO SITE PREPARATION AND COMPETING VEGETATION BY PIEDMONT LOBLOLLY PINE PLANTATIONS [1]

J.W. Rheney and L.V. Pienaar [2]

Abstract. A wide range of site preparation techniques are at the disposal of forest managers for use in establishing loblolly plantations in the Upper Coastal Plain and piedmont regions of the Southeastern United States. Information from various studies within these regions indicates that growth patterns and yields vary considerably and that much of this variation may be associated with the method of site preparation used for stand establishment.

In 1985 the Plantation Management Research Cooperative at the University of Georgia installed a site preparation study in loblolly pine plantations in the South Atlantic Gulf Slope region of South Carolina, Georgia and Alabama. Treatments consisted of burn; chop/burn; chop/herbicide/burn; shear/pile/disk; herbicide/burn; and herbicide/burn/continuous control. Age-six pine and competition measurements show a significant treatment effect and significant correlations to residual competing vegetation. Treatment means ranged from 13 to 22 feet for height, 1.8 to 4.2 inches for DBH, and 8.8 to 48.5 sq. feet for basal area per acre.

Several million acres of natural pine stands have been harvested and planted with improved loblolly pine seedlings in the piedmont region of the southeast during the past 20 years. A variety of site preparation techniques have been used to establish these plantations and in 1986 the Plantation Management Research Cooperative (PMRC) at the University of Georgia initiated research to determine the effect of different site preparation treatments on subsequent growth and expected yields from these cutover site-prepared loblolly pine (*Pinus taeda*) plantations.

Study Design

A designed experimental study was installed at 25 locations throughout the Piedmont region of South Carolina, Georgia and Alabama. The existing stand at each location was harvested in 1984 with the area scheduled for planting during the 1985/86 planting season. Care was taken during site selection to avoid obvious site quality differences and to ensure reasonable uniformity of residual vegetation on the harvested site.

Each installation consists of seven 1/2 - acre treatment plots with an interior 1/5 - acre measurement plot. All treatment plots were at least 10 chains from adjacent stands to reduce problems with wildlings seeding in.

The following 6 site preparation treatments were randomly assigned to the treatment plots at each location.

1. BURN. This minimal site preparation treatment was a broadcast burn in August 1985.

2. CHOP & BURN. This mechanical treatment was a single pass with a drum roller chopper in June 1985, followed by a broadcast burn in August.

3. SHEAR, PILE & DISC. Plots that received this intensive mechanical treatment were sheared with a KG blade in June 1985. The debris was moved at least 2 chains away from the plot installation before the plots were flat-harrowed.

4. CHOP, HERBICIDE & BURN. This combined mechanical and chemical treatment consisted of a single pass with a drum roller chopper in June 1985, followed by a broadcast herbicide treatment of 3% ROUNDUP in August, after some resprouting had occurred, and a broadcast burn one month later.

5. HERBICIDE & BURN. This was a chemical site preparation treatment with 20 lbs of TORDON 10K and 20 lbs of PRONONE 10G per acre, applied in April 1985, followed by a broadcast burn in August.

6. HERBICIDE, BURN & HERBICIDE. This treatment was the same as treatment #5, but with annual spot spraying with ROUNDUP after planting to kill sprouting vegetation until crown closure. This

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[1] Paper presented at the Seventh Biennial Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Research Coordinator and Professor, respectively, University of Georgia, Athens.

treatment essentially eliminated all competing vegetation with only minimal effort after the second growing season.

One of the treatments 2 through 6 was replicated at each installation. All experimental plots were hand-planted with improved stock during the 1985/86 planting season at a 10' by 8' spacing. Two seedlings were planted about 2 feet apart at each planting spot, and if both survived after the first growing season, one was eliminated to ensure a reasonably uniform stocking of about 545 trees per acre for all treatments.

Results and Discussion

Tree heights were measured after the third and sixth growing seasons with a telescoping height measuring rod. All trees were inspected for the incidence of fusiform stem cankers. Tree dbh was measured at age 6 with a diameter tape and stem volumes were estimated with a simultaneous total and merchantable standard volume equation developed by Borders and others (1990):

$$V_m = 0.0040\ D^{1.8290}\ H^{0.9691} - 0.0025\ \left(\frac{D_m^{3.6847}}{D^{1.6847}}\right)(H - 4.5)$$

where V_m = stem volume with bark to an outside bark top diameter limit of D_m", in cu.ft.; D = tree dbh in inches; and H = total tree height in feet.

The age 6 measurements are summarized in Table 1, and are presented graphically in Figures 1 - 5. An analysis of variance for each of the variables is given in Tables 2-7.

Competing vegetation was measured on nine 4-foot radius subplots systematically distributed within each measurement plot. Herbaceous cover of andropogon, other grasses, and broadleaf weeds was estimated for percent groundcover and height was measured. Small woody vegetation, less than 6 feet tall and less than 1.0 inch DBH, was measured for total height, live crown height, live crown width and species. Large woody vegetation, 1.0 inch or larger DBH, was measured for total height, live crown width, base stem height, DBH, and species.

The cylindrical cubic foot volume of each competitor was calculated from base diameter and total height and these volumes were accumulated for each competitor class and across all classes for each treatment plot. All competitor volumes were transformed to a per-acre basis from known subplot sizes. Competition volume on a per pine basis was calculated from known pine density. Summaries of competition variables are given in Table 8.

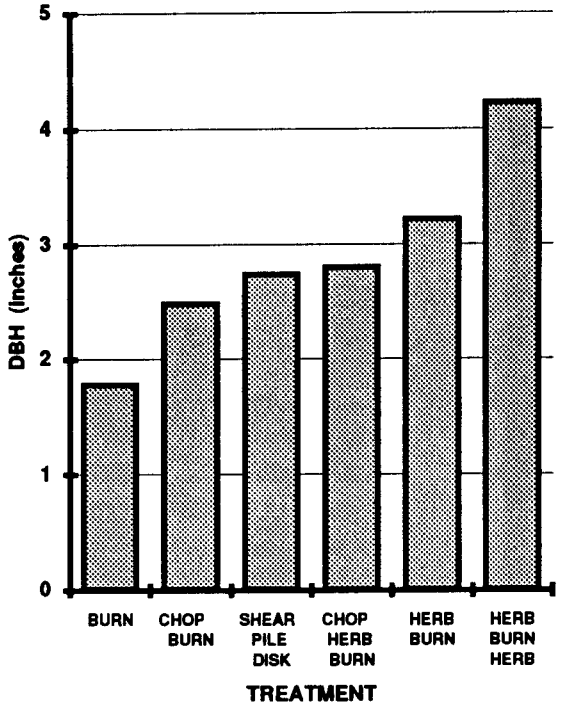

Figure 1. *Average DBH by site preparation method at age 6.*

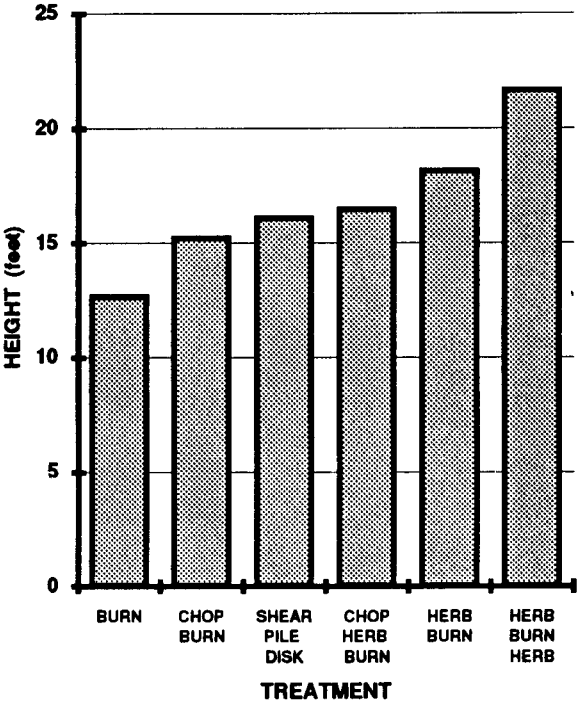

Figure 2. *Average height by site preparation method at age 6.*

Table 1. Summary of tree and plot measurements at age 6, by site preparation treatment.

Variable	Treatment Number					
	1	2	3	4	5	6
Dbh (in) Avg.	1.8	2.5	2.7	2.8	3.2	4.2
Std. Error	0.13	0.11	0.14	0.11	0.10	0.10
Height (ft) Avg.	12.6	15.2	16.1	16.5	18.1	21.6
Std. Error	0.60	0.55	0.66	0.56	0.54	0.55
Trees/ac Avg.	368	434	471	452	473	470
Std. Error	21.4	15.1	13.0	15.8	11.6	12.9
Ba/ac (ft^2) Avg.	8.76	17.54	22.65	22.68	29.47	48.46
Std. Error	1.28	1.71	2.23	2.11	2.11	2.59
Total vol/ac (ft^3) Avg.	82.4	179.1	240.8	243.3	334.6	617.0
Std. Error	14.4	21.1	28.9	28.5	31.3	41.8
Merch volac (ft^3) Avg.	19.1	52.5	99.2	87.3	132.6	471.8
Std. Error	5.6	13.6	24.4	24.4	28.5	40.9
% infected Avg.	9	6	6	7	4	6
Std. Error	1.4	1.5	1.3	1.9	0.7	1.4

Table 2. *ANOVA of average dbh at age 6.*

Source	DF	SS	F	PROB>F
INST	24	36.3080	12.77	0.0001
TRMNT	5	89.0760	85.41	0.0001
INST x TRMNT	118	24.6132	1.76	0.0515
ERROR	25	2.9628		
Total	172	159.1051[1]		

[1] SS not additive for unbalanced design.

COMPARISON OF MEANS (DUNCAN'S TEST AT $\alpha = 0.05$)

TREATMENT	AVG. DBH (in.)
1. BURN	1.8 A[2]
2. CHOP, BURN	2.5 B
3. SHEAR, PILE, DISC	2.7 C
4. CHOP, HERB, BURN	2.8 C
5. HERB, BURN	3.2 D
6. HERB, BURN, HERB	4.2 E

[2] MEANS WITH SAME LETTER NOT SIGNIFICANTLY DIFFERENT.

Table 3. ANOVA of average height at age 6.

Source	DF	SS	F	PROB > F
INST	24	1051.6536	17.71	0.0001
TRMNT	5	1212.2214	65.44	0.0001
INST x TRMNT	118	437.1752	1.50	0.1217
ERROR	25	61.8629		
TOTAL	172	2919.9648		

COMPARISON OF MEANS (DUNCAN'S TEST AT $\alpha = 0.05$)

TREATMENT	AVG. HEIGHT (FT.)
1. BURN	12.6 A[1]
2. CHOP, BURN	15.2 B
3. SHEAR, PILE, DISC	16.1 B C
4. CHOP, HERB, BURN	16.5 C
5. HERB, BURN	18.1 D
6. HERB, BURN, HERB	21.6 E

[1] MEANS WITH SAME LETTER NOT SIGNIFICANTLY DIFFERENT.

Table 4. *ANOVA of average basal area per acre at age 6.*

Source	DF	SS	F	PROB > F
INST	24	11471.45	12.42	0.0001
TRMNT	5	24983.51	70.02	0.0001
INST x TRMNT	118	8421.14	1.85	0.0378
ERROR	25	961.85		
TOTAL	172	47243.92		

COMPARISON OF MEANS (DUNCAN'S TEST AT $\alpha = 0.05$)

TREATMENT	AVG. BA/AC (FT^2.)
1. BURN	8.76 A [1]
2. CHOP, BURN	17.54 B
3. SHEAR, PILE, DISC	22.65 C
4. CHOP, HERB, BURN	22.68 C
5. HERB, BURN	29.47 D
6. HERB, BURN, HERB	48.46 E

[1] MEANS WITH SAME LETTER NOT SIGNIFICANTLY DIFFERENT.

Table 5. *ANOVA of total volume per acre at age 6.*

Source	DF	SS	F	PROB > F
INST	24	2318539	13.97	0.0001
TRMNT	5	4751371	66.68	0.0001
INST x TRMNT	118	1681772	2.01	0.0231
ERROR	25	177589		
TOTAL	172	9064866		

COMPARISON OF MEANS (DUNCAN'S TEST AT $\alpha = 0.05$)

TREATMENT	AVG. VOL/AC (FT^3.)
1. BURN	82.43 A[1]
2. CHOP, BURN	179.12 B
3. SHEAR, PILE, DISC	240.77 B
4. CHOP, HERB, BURN	243.29 B
5. HERB, BURN	336.64 C
6. HERB, BURN, HERB	617.01 D

[1] MEANS WITH SAME LETTER NOT SIGNIFICANTLY DIFFERENT.

Table 6. *ANOVA of merchantable volume per acre at age 6 (volume with bark to 3" top o.b.)*

Source	DF	SS	F	PROB > F
INST	24	1381848	8.23	0.0001
TRMNT	5	3806740	52.09	0.0001
INST x TRMNT	79	1154753	2.09	0.0443
ERROR	17	118960		
TOTAL	125	6122849		

COMPARISON OF MEANS (DUNCAN'S TEST AT $\alpha = 0.05$)

TREATMENT	AVG. VOL/AC (FT^3.)
1. BURN	19.08 A[1]
2. CHOP, BURN	52.46 A B
3. SHEAR, PILE, DISC	99.23 A B
4. CHOP, HERB, BURN	87.34 A B
5. HERB, BURN	132.65 B
6. HERB, BURN, HERB	471.81 C

[1] MEANS WITH SAME LETTER NOT SIGNIFICANTLY DIFFERENT.

Table 7. *ANOVA of average percent fusiform stem infection.*

Source	DF	SS	F	PROB > F
INST	24	0.5620	15.25	0.0001
TRMNT	5	0.0310	2.56	0.0079
INST x TRMNT	118	0.2864	1.58	0.0926
ERROR	25	0.0384		
TOTAL	172	0.9737		

COMPARISON OF MEANS (DUNCAN'S TEST AT $\alpha = 0.05$)

TREATMENT	AVG. % INFECTION
1. BURN	0.087 A[1]
2. CHOP, BURN	0.064 A B
3. SHEAR, PILE, DISC	0.061 A B
4. CHOP, HERB, BURN	0.069 A
5. HERB, BURN	0.040 B
6. HERB, BURN, HERB	0.059 A B

[1] MEANS WITH SAME LETTER NOT SIGNIFICANTLY DIFFERENT.

Table 8. *Cubic foot volume of competition for each treatment.*

	Treatment Number					
Variable	1	2	3	4	5	6
Herbaceous/acre	6789	9297	11657	12496	9482	0
Std. Dev.	4103	4843	4961	7445	4978	-
Small woody/acre	52448	41110	20611	19715	32324	0
Std. Dev.	52243	34796	21433	20984	34134	-
Large woody/acre	121334	9477	3367	9125	12946	0
Std. Dev.	161764	17680	10330	26971	52632	-
Total comp. veg/pine	499	140	73	96	123	0
Std. Dev.	502	107	51	121	186	-

Average DBH

The average dbh after 6 growing seasons differed significantly among the 25 randomly located installations, and the average dbh over all installations differed significantly among treatments. The interaction between installations and treatments was not significant at the $\alpha = 0.05$ level.

Chopping before burning, compared to burning only, resulted in a significant increase in average dbh of 0.7". The herbicide treatment before burning, the brown-and-burn treatment, resulted in an increase of 1.4" compared to burning only. Chopping before the brown-and-burn treatment resulted in a lesser increase of only 1.0" in average dbh. Treatments that involved chemical control of competing vegetation resulted in significantly higher average dbh than treatments that involved mechanical operations.

Average Height

Results for average height at age 6 were similar to those for average dbh. Chopping before burning resulted in a significant increase of 2.6' in average height. The brown-and-burn treatment #5 resulted in an increase of 5.5' in average tree height, compared to burning only. Chopping followed by the brown-and-burn treatment #4 added only 3.9'. Treatment #6 with the follow-up annual chemical control of competing vegetation resulted in an increase of 9.0'.

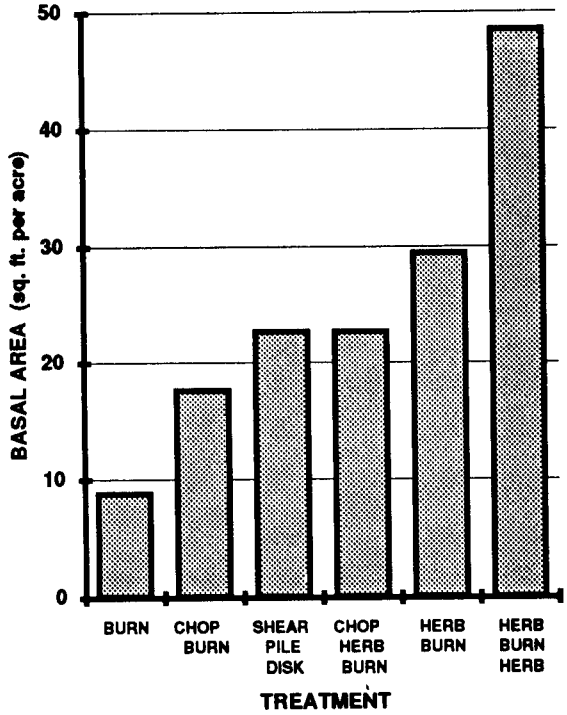

Figure 3. *Basal area/acre by site preparation method at age 6.*

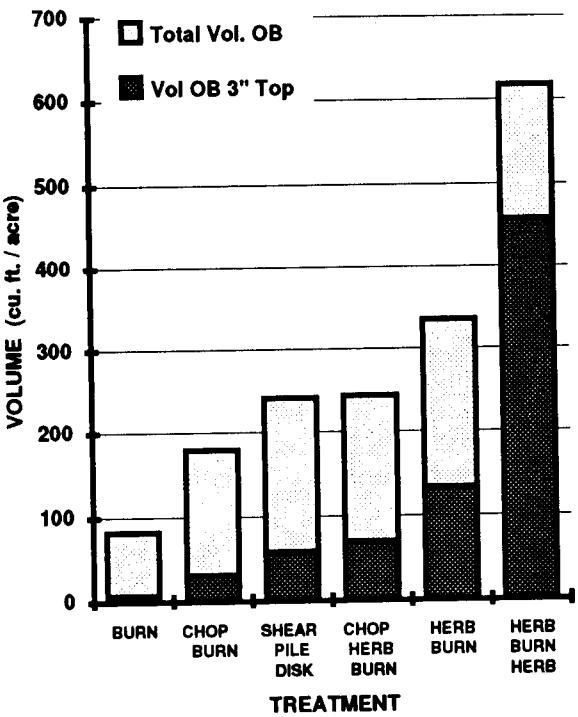

Figure 4. Volume per acre by site preparation method at age 6.

Average Basal Area Per Acre

Chopping before burning, as compared to burning only, doubled the basal area at age 6 from 8.76 to 17.54 sq. ft., partly as a result of better survival. The brown-and-burn treatment #5 averaged 29.47 sq. ft., which is significantly more than the intensive mechanical treatment #3, or the chop, brown-and-burn treatment #4. Continued control of competing vegetation with treatment #6 resulted in a further dramatic increase in basal area to 48.46 sq. ft. Survival at age 6 was not significantly different for treatments 2 through 6.

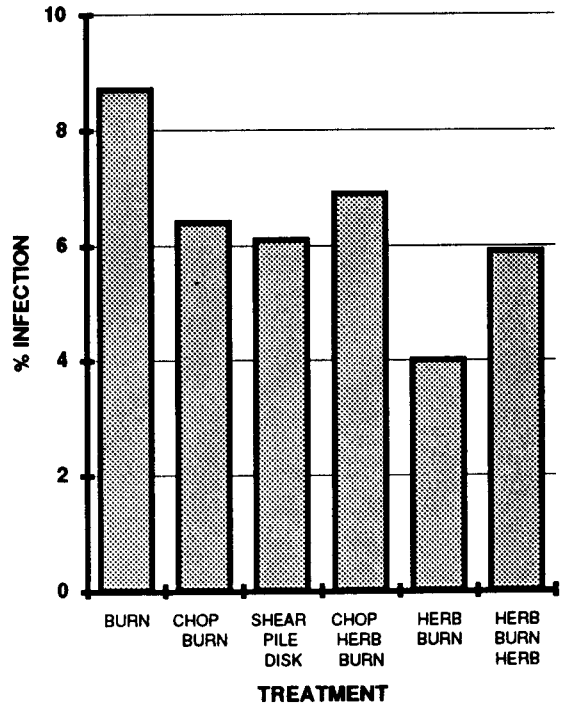

Figure 5. *% cronartium by site preparation method at age 6.*

Average Volume Per Acre

The total volume per acre at age 6 was not significantly different (α = 0.05) for treatments 2, 3 and 4. The brown-and-burn treatment #5 had significantly more volume, and the benefit from continued vegetation control on volume growth was even more dramatic than for basal area growth, particularly for early merchantable volume growth.

Average Percent of Cronartium-infected Stems

Contrary to expectation, the treatments that resulted in most rapid growth did not have a significantly higher rate of infection. In fact, the least intensive treatment #1 with the slowest growth rate had the highest average rate of 8.7%.

Competition Relationships

Simple correlations between competition classes and between competing vegetation and crop pine trees were calculated. An interesting relationship is that

relationship is that between herbaceous cover/ac (COVPA) and small woody/ac (SWPA). The inverse linear relationship between the treatment means for these variables is shown in Table 9 and Figure 6.

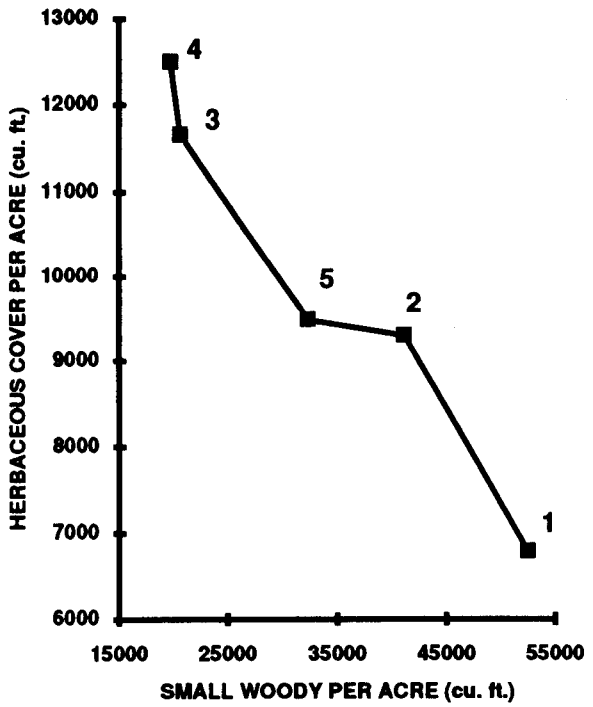

Figure 6. *Relationship of small woody and herbaceous cover at age 6.*

Table 9. *ANOVA of COVPA and SWPA at age 6.*

Source	DF	SS	F	Prob > F
SWPA	1	19043864.35	57.75	0.0047
Error	3	989286.45		
Total	4	20033150.8		

R^2 = .95
COPA = 15158 - .156844(SWPA)

Pine basal area per acre (BAPA) was chosen as a stand attribute to test for correlation with competition measurements and treatment. Results are summarized in Table 10. Treatment explained approximately 98% of the variation in BAPA. The log transformation of all competition variables improved the fit. LOG (CVPP) by itself explained 82% of the variation in BAPA, demonstrating the importance of competing vegetation on pine growth. Herbaceous and small woody competition classes each explained approximately the same amount of variation in BAPA, 72% and 73% respectively, when tested separately. Treatment effects are largely the result of different levels of competing vegetation.

This study should provide us with an indication of the relative importance of different levels and different components of competing vegetation at various stages of stand development.

Table 10. *Treatment and competition variables as predictors of pine basal area per acre.*

Variable	Prob > F	R^2
Treatment	0.0001	0.9796
Total CV/pine (CVPP)	0.0001	0.6362
Log (CVPP)	0.0001	0.8248
Herb/pine (COVPP)	0.0001	0.609
Log (COVPP)	0.0001	0.7188
Small woody/pine (SWPP)	0.0001	0.5751
Log (SWPP)	0.0001	0.731

Literature Cited

Borders, B.B., W.M. Harrison, D.E. Adams, R.L. Bailey and L.V. Pienaar. 1990. Yield prediction and growth projection for site-prepared loblolly pine plantations in the Carolinas, Georgia, Florida and Alabama. PMRC Research Paper 1990-2. 65 pp. The University of Georgia. Athens, GA.

EARLY RELEASE OF NATURALLY-REGENERATED CHERRYBARK AND SHUMARD OAK SEEDLINGS WITH HERBICIDES [1]

John F. Thompson Jr. and Larry E. Nix [2]

Abstract. Several methods of increasing the oak component in bottomland hardwood stands have been tried but have not always been economically or logistically feasible. In clearcut situations oak seedlings have been successfully regenerated but are quickly overtopped by woody pioneer species, sprouts, and herbaceous material. Several herbicides and methods of application were used to kill or stunt the competition to release four-year-old oak seedlings and allow them to develop in a rapid growth pattern. This should increase the oak component in the main canopy and reduce the rotation length for quality sawtimber. Results, after one year, of competition reduction and resulting height and ground line diameter increases are presented. Several simulated aerial broadcast sprays and one direct application spray show excellent results at present. Indices to evaluate the effects of the competition on oak regeneration were developed for this study.

Introduction

In the last few decades oaks (*Quercus* sp.) have been decreasing as a component in the bottomland hardwood stands of the Southern United States (Johnson 1984). Cherrybark oak (*Quercus pagodifolia* Ell.) and Shumard oak (*Quercus shumardii* Buckl.) are two of the large, high quality bottomland oaks (Miller and Lamb 1985) that are losing their place in the bottomland hardwood forest. The ecology and biology of bottomland oaks have been investigated to determine why the number of oaks are decreasing in new stands of the bottomland forests (Johnson 1979, Guldin and Parks 1989, Clatterbuck and Hodges 1988, Hodges and Janzen 1987). From these studies it appears that bottomland oaks are decreasing in number due to the slow growth of newly established oak seedlings which cannot compete successfully with sprouts and fast growing pioneer species. However, if released oak seedlings can respond and achieve a dominant position in the developing canopy (Nix 1989).

In most stands with an oak component, oak seedlings grow at a slow rate and often die back for 4 to 6 years after germination before they reach a stage of rapid height growth. In a clearcut situation the slow growth of oak seedlings after germination is compounded by animal predation and overtopping by briars, sprouts, and early successional trees and brush (Gingrich 1979, Watt 1979, Hannah 1987, Nix 1989). Some type of release of seedlings that germinate after clearcutting is usually needed to have oaks in the dominant canopy in a reasonable period with quality, size and grade (Beck 1970, Hannah 1987).

Release of crop trees with herbicides has been accomplished successfully for many years in the management of pine stands (Clason 1978, Nelson et al. 1985, Bacon and Zedaker 1987, Nelson and Cantrell 1990). Unlike pine stands, it is not necessary to produce a pure oak stand, but only to "enrich" the bottomland stand with a reasonable number (20 to 50 oak trees per acre) of high grade, quality oaks at the time of final harvest (Johnson 1984). "Enrichment" means that only 50 to 100 quality, well-distributed, seedling oaks per acre need to be released to obtain an adequate number of quality oaks in the final harvest (Hannah 1987).

During the winter months of 1987 and 1988 several bottomland hardwood stands with good oak components were clearcut along the Congaree River in South Carolina. These stands had a good seed crop prior to harvest, resulting in the establishment of a large number of oak seedlings (Nix and Lafaye 1993). When first examined, these oak seedlings were severely overtopped by a dense canopy of blackberry, herbaceous composites, and woody seedlings and sprouts. It seemed desirable at this time to release some of these oak seedlings to insure their survival and to shorten the rotation age required to reach quality sawtimber size. However, there were not many cost effective ways of releasing oak seedlings and little information about how to do so. This study is an attempt to evaluate several herbicides and application

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

[2] Graduate Assistant and Associate Professor, Department of Forest Resources, Clemson University, Clemson, SC.

methods, currently being used to release pines, which possibly could be modified and used for releasing overtopped oak seedlings.

The objective of this study was to determine which herbicide(s) and/or method(s) of application can be used to effectively release bottomland oak seedlings from an overtopped condition. Release has to be accomplished at an age (3 to 5 years) that will allow the seedling oaks to quickly catch up with the other woody species on the site (Beck 1970). Early release will hopefully allow the oaks to be a component of the dominant canopy at least by the time the stand is 25 years old. Release of this kind may also shorten the normal oak rotation by 10 to 15 years for quality oak products (Clatterbuck et al. 1985, Clatterbuck and Hodges 1988).

Procedure

Forty-two linear plots were located along narrow transects cut through the vegetation of two 3 to 4-year-old clearcuts approximately 1/2 mile apart in the first bottom of the Congaree River near Columbia, South Carolina. The transects were placed where adequate cherrybark and Shumard oak seedlings were found with a typical level of competition and with a range of seedling sizes normally found in such a clearcut. The plots were placed far enough apart to reduce the chance of one herbicide treatment influencing any adjoining treatment. Each plot contains 6 to 9 seedlings located along either side of a 2-foot-wide, cut, center line. Seedlings were chosen within approximately 10 feet of the cleared line, but far enough away such that the cleared line did not affect the seedlings' competitive status. The seedlings were selected to be approximately 6+ feet apart to accommodate the direct herbicide treatments. The length of the plots was determined by the distribution of the seedlings. The beginning and end of each plot center line was marked by a white, 4 foot, plastic pipe driven into the ground.

The treatments were blocked for replication according to the total level of competition that was evident on the plots (high, medium or low). Three replications of the treatments were arranged with each treatment randomly placed in each of the three blocks. The oak seedlings chosen for measurement were statistically similar in height on all plots. The preferred condition of the seedlings for release was overtopped, but at least 12 inches in height. Each plot contained at least two seedlings and if possible three seedlings in each of the three following height classes: (1) 1 to 1.9 feet, (2) 2 to 2.9 feet, (3) 3 feet and over. Each seedling chosen was marked by a wire flag and metal tag bearing a coded number.

The treatment to be applied to a plot in a replication (block) was randomly determined. Preliminary treatments with a quick-browning herbicide in 20% increments of the recommended release rates for pines were applied to refine the rates that were used in the treatments. The methods of treatment, herbicides and rates which were applied in late July/early August were as follows:

Control - no treatment.

Direct - Streamline application of 20% Garlon 4 (a triclopyr herbicide), 10% surfactant and 70% diesel fuel applied in a 3+ foot radius around the oak seedlings (Dow 1988, McLemore and Cain 1988, Yeiser et al. 1989). This application was accomplished with a Solo piston backpack sprayer equipped with a D2 orifice disc tip for stream application.

Direct - Spot gun application of Velpar L (a hexazinone herbicide) or Escort (a metsulfuron benzoate herbicide) applied in a grid pattern of 6 - 1 milliliter spots placed approximately 3.5 feet from the oak seedlings to be released. The spots of Velpar L consisted of a mixture of Velpar L and water that was 50% of the manufacturer's product strength. The application mixture of Escort consisted of 1 oz. of Escort mixed in 2 gallons of water. Due to the fine texture of the soils on the study site, the manufacturer's rate of application for use on this texture of soil indicates that there will be a 1.5 to 2-foot non-toxic zone around the oak seedlings (Du Pont 1987, Rachal et al. 1988, Du Pont 1988). These applications were accomplished with a standard spot gun applicator calibrated at 1 milliliter.

Broadcast - Simulated aerial broadcast sprays applied at one half and full label-recommended application rate of commercial herbicides for releasing pines with 3.2 oz. per acre of surfactant (0.25% v/v -- commonly recommended rate in release of pines) at 10 gallons total mix per acre (Dow 1988) for each of the herbicides in Table 1. The applications of the simulated aerial broadcast spray was accomplished with a CO_2-pressurized backpack apparatus with a boom extended well above the vegetation and equipped with a flood jet nozzle. The actual area treated was calculated by using the length of the plot and the spray width. The spray time, spray pressure and amount of herbicide to be used were predetermined. Measurements of the spray time and pressure were recorded for each plot so the actual rate of application could be calculated.

To determine effectiveness of the release treatments seedling height, seedling GLD (ground line diameter), herbaceous competition, woody competition and total competition were measured before and after treatment. The seedling height was measured to the nearest 0.1 foot and the seedling GLD was measured to the nearest 0.1 inch.

Table 1. *Simulated aerial broadcast applications that were used at 100% and 50% of standard pine release rates for oak release in clearcut bottomland hardwood stands in South Carolina.*

Herbicide	Standard pine release rate
Garlon 4	1.5 qt/ac
Escort	1 oz/ac
Accord	1.5 qt/ac
Velpar L	3 qt/ac
Arsenal AC/Escort	8 oz - 0.25 oz/ac[1]

[1]The rate of 0.25 oz/ac of Escort remains the same for both the 100% and the 50% rate plots.

Herbaceous competition was estimated by an index for each study seedling and a mean calculated for each treatment. The herbaceous index was determined by averaging the height of the herbaceous material within 3 feet of the study seedling (to the nearest 0.5 foot) on each quadrant (north, east, south, west) and multiplying that average by the average estimated percent coverage of herbaceous material (to the nearest 10 percent) for each quadrant. This estimate of herbaceous competition was then divided by the height of the study seedling to reflect its competitiveness.

$$\text{Herbaceous Competition Index} = \frac{\frac{An + Ae + As + Aw}{4} \times \frac{Pn + Pe + Ps + Pw}{4}}{\text{Ht(seedling)}}$$

A = Average height of herbaceous competition
n e s w = North, East, South, West quadrants
P = Estimated percent coverage by competition
Ht = Height of study seedling

Woody competition was also estimated by an index for each study seedling and a mean calculated for each treatment. A modification of Hegyi's Competition Index (Daniels 1976) was used to estimate competition from dominant woody stems by dividing their height (±1.0 foot) by their distance (±1.0 foot) from the study seedling. The total woody competition index for each study seedling was the sum of the highest stem indexes (greater than 1 and greater than or equal to the height of the study seedling) for each quadrant (north, east, south, west) divided by the number of quadrants containing a competitive stem. This average index was then multiplied by the total number of woody stems that had a competitive index greater then 1 and were greater than or equal to the height of the study seedling. This procedure gives an index of the woody material competing with the study seedling. The estimate of woody competition was then divided by the height of the study seedling to reflect its competitiveness.

$$\text{Woody Competition Index} = \frac{\frac{In + Ie + Is + Iw}{Q} \times TN}{\text{Ht(seedling)}}$$

I = Index (Height of competing woody stem divided by the distance from the study seedling) that is ≥ 1
n e s w = North, East, South, West quadrants
Q = Number of quadrants with an index ≥ 1
TN = Total number of stems with an index ≥ 1
Ht = Height of study seedling

It should be noted that by using the average index of the most competitive woody stem in each quadrant the index value could reflect an overestimate of competition. However, it was assumed that the competing woody stems that are shorter than the study seedling and those with an index less than 1 (not included in the estimate) would also contribute to the overall competition. This estimate of competition was used because to physically measure all of the competing woody stems around a study seedling would disturb the vegetation that would subsequently be needed to help shield (protect) the study seedlings from the applied herbicides. Total competition index consisted of the sum of the herbaceous competition index and the woody competition index.

Results and Conclusions

The effectiveness of any crop tree release treatment will ultimately be determined by the subsequent tree height (position in the canopy) and diameter growth. Consequently, in this study the released oak seedlings' height and diameter growth are the most important criteria in judging the success of these herbicide release treatments. As can be seen in Table 2, no treatment resulted in released oak seedlings exceeding the height growth of the control seedlings for the first full growing season (1992).

However, there are two reasons that could explain this lack of response. The first reason is that some of the seedlings in most of the higher rates of application sustained top damage from the treatments, therefore, these seedlings had to recover and develop a new terminal shoot before height growth could again commence. The second reason is that the seedlings that were released the most, whether with or without top damage, appeared (casual observation) to have a much fuller crown (more and longer side branches) than the seedlings with less release as found in an earlier study (Nix et al. 1985). These observations are supported by the increase in seedling GLD in some of the treatments (Table 2). The three treatments that induced significantly greater GLD growth than that of the control are Aerial Escort Low, Aerial Garlon 4 Low and Velpar L applied by spot gun. All three of these treatments resulted in significantly greater reduction in herbaceous competition than that of the control, both in the fall after treatment and as residual reduction in the spring of the following year (Table 3). The oak seedlings with higher aerial rates of herbicides (100% pine release rates) all had somewhat better GLD growth than did those of the control, although none statistically differed from the control seedlings.

Table 2. *Height and diameter growth for the 1992 growing season of cherrybark and Shumard oak seedlings following herbicide release in clearcut bottomland hardwood stands on the Congaree River in South Carolina.*[1]

Herbicide treatment	Height growth	Diameter growth
	— ft —	— in —
AERIAL[2]		
ACCORD HIGH	0.8	0.200
ACCORD LOW	1.4	0.185
ESCORT HIGH	0.8	0.193
ESCORT LOW	1.8	0.246*
VELPAR L HIGH	1.3	0.183
VELPAR L LOW	1.7	0.162
GARLON 4 HIGH	0.7	0.193
GARLON 4 LOW	1.0	0.217*
ARSENAL/ESCORT HIGH	1.2	0.159
ARSENAL/ESCORT LOW	0.6	0.102
SPOT GUN		
ESCORT	1.8	0.146
VELPAR L	1.5	0.222*
STREAMLINE		
GARLON 4	0.9	0.197
CONTROL	1.6	0.113

[1] Numbers with * differ from the control at the 0.05 level of probability.
[2] High indicates 100% pine release rates. Low indicates 50% pine release rates.

It should be noted that there appears to be a reduction of herbaceous competition with the control treatment (Table 3). This apparent reduction is a result of the general nature of the growth of blackberry briars (a major part of the herbaceous competition) and a wind storm that occurred in late summer. The original herbaceous measurements were made during the summer while the briars were still actively growing and vertical. As fall approached the briars naturally arched over, thus, reducing the herbaceous height estimates and implying that the herbaceous competition was reduced. This apparent reduction was compounded by a late summer wind storm that further reduced the height of the briars (originally 7 to 9 feet tall). Therefore, the three treatments that did not show significant competition reduction in comparison with the control treatment may have achieved better competition control than indicated by the values in Table 3.

Table 3. *Herbicide control of herbaceous competition in young clearcut bottomland hardwood stands on the Congaree River in South Carolina.*[1]

HERBICIDE TREATMENT	FALL AFTER TREATMENT	MAY AFTER TREATMENT
	— % —	
AERIAL[2]		
ACCORD HIGH	70*	82*
ACCORD LOW	67*	68*
ESCORT HIGH	60*	53
ESCORT LOW	65*	65*
VELPAR L HIGH	86*	67*
VELPAR L LOW	60*	47
GARLON 4 HIGH	100*	70*
GARLON 4 LOW	95*	81*
ARSENAL/ESCORT HIGH	48	54
ARSENAL/ESCORT LOW	40	37
SPOT GUN		
ESCORT	52	53
VELPAR L	89*	63*
STREAMLINE		
GARLON 4	100*	92*
CONTROL	38	48

[1] Numbers with * differ from the control at the 0.05 level of probability.
[2] High indicates 100% pine release rates. Low indicates 50% pine release rates.

There were only two treatments that provided a significant reduction in woody competition (Table 4). One was Aerial Escort (high rate) which caused no mortality, but damaged some of the study seedling tops, resulting in poor height growth. The other was the streamline application of Garlon 4 which achieved excellent control of the woody competition but caused

Table 4. *Herbicide control of competing vegetation in young clearcut bottomland hardwood stands on the Congaree River in South Carolina.*[1]

Herbicide treatment	Herbaceous	Woody	Total
	---------- % ----------		
AERIAL[2]			
ACCORD HIGH	70*	18	33
ACCORD LOW	67*	4	17
ESCORT HIGH	60*	50*	50
ESCORT LOW	65*	0	17
VELPAR L HIGH	86*	−31	7
VELPAR L LOW	60*	−36	−11
GARLON 4 HIGH	100*	45	58*
GARLON 4 LOW	95*	20	41
ARSENAL/ESCORT HIGH	48	18	26
ARSENAL/ESCORT LOW	40	17	23
SPOT GUN			
ESCORT	52	32	35
VELPAR L	89*	31	41
STREAMLINE			
GARLON 4	100*	94*	95*
CONTROL	38	−14	0

[1]Numbers with * differ from the control at the 0.05 level of probability.
[2]High indicates 100% pine release rates. Low indicates 50% pine release rates.

29% oak seedling mortality and generally poor height growth of the survivors. These effects resulted from the herbicide splattering off the stems of the competing vegetation. The herbicide splatter resulted from using too high an application pressure and can probably be reduced by simply lowering the pressure. Also, because of the excellent control of both herbaceous and woody competition with the streamline method (95% total competition controlled) the seedlings that were not injured (about 25%) appeared to increase in crown diameter (again, casual observation).

Aerial Garlon 4 (high rate) was the only treatment other than streamline Garlon 4 that had significant total competition control. Some of the study seedlings of this treatment also were injured and a 12% mortality resulted. However, due to the reduction in total competition this minor loss of seedlings should be acceptable because only 50 to 100 free-to-grow oak seedlings per acre are needed to satisfactorily enrich the stand (Hannah 1987).

In young, clearcut, bottomland hardwood stands such as used in this study, it is impractical at this stage of development to apply a release treatment by any of the directed application methods. However, at an earlier age before the severe overtopping occurs, a directed method of application such as streamline with Garlon 4 may be useful, especially on small tracts where aerial application is not feasible. The only practical method of releasing oak seedlings on a large scale in a severely overtopped condition would be by aerial application. From these early results (Table 4) it would seem that an aerial application of Garlon 4 at pine release rates would be a feasible method.

In conclusion, it appears feasible to release oak seedlings in a young clearcut without serious losses with careful application of selected herbicides if the oak seedlings are in an overtopped condition. This overtopping which is very common in such clearcuts seems to protect (shield) the seedlings from lethal amounts of the herbicides. Although a significant increase in seedling height growth has not been observed at present and only three of the treatments have induced a significant increase in diameter growth, some of these treatments appear to have potential. These are early results and the oak seedlings need several more growing seasons before the full treatment effects can be determined. Evaluation of the treatments is preliminary at present, therefore, future measurements will be needed to assess the full practicality of herbicide release of young overtopped oaks in recently clearcut bottomland hardwood stands.

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INFLUENCE OF SPECIES COMPOSITION ON NUTRIENT CIRCULATION IN FOUR VEGETATION COMMUNITIES [1]

R.J. Oates, J.H. Miller and B.G. Lockaby [2]

Abstract. The effects of vegetation communities on nutrient circulation through litterfall and decomposition are under examination in this study. Four treatments were applied when establishing what is now an 8 year old loblolly pine stand. The treatments include: 1)suppression of woody and herbaceous vegetation, 2)suppression of woody vegetation, 3) suppression of herbaceous vegetation, 4) no suppression of any vegetation. Litterfall and decomposition rates will be compared among the treatments. Litter was separated by species and put into litter bags to create representative samples of the forest floor prior to placement in the field. Weight changes over a two year period are being assessed to determine differences in decomposition rates. Nitrogen and phosphorus quantities in the litter bags are also being determined as well as LAI for the pine and hardwood components of the stands. These data should aid in the development of our understanding of the means by which vegetation community differences alter key processes such as decomposition and nutrient circulation. Because these processes greatly influence the rate at which nutrients are returned to the soil, the need to understand the factors affecting them is an important research topic in forestry.

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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CONTROLLING UNDESIRABLE STEMS USING LOW INTENSITY INJECTIONS OF IMAZAPYR [1]

Andrew W. Ezell, Larry R. Nelson, Stephen H. Schoenholtz, and J.G. Williams [2]

Abstract. In a study designed to evaluate the efficacy of limited injections per stem, approximately 1,500 stems were treated using three different concentrations of imazapyr. Principal target species included southern red oak (*Quercus falcata* Michx.) and post oak (*Quercus stellata* Wangenh.) in Mississippi and hickory (*Carya* spp.), dogwood (*Cornus florida* L.), and red oaks in South Carolina. In addition, a larger number of miscellaneous species were injected as available on the study areas. The trees received injections according to the following format: 1-4 in. d.b.h. = 1 injection, 4-8 in. d.b.h. = 2 injections, 8-12 in. d.b.h. = 3 injections, etc. Each species/diameter class/concentration combination was replicated three times for the principal target species. Two applications time were tested—dormant season and active season. In Mississippi, both post oak and southern red oak were controlled extremely well by growing season injections irrespective of diameter class or solution concentration. The least control exhibited was 94% crown reduction in the 8-12 inch d.b.h. class of post oak injected with a 10% solution. The difference in crown reduction between first year and second year evaluations was significant. In South Carolina, limited number of injections per stem provided nearly total control (96% or better) of hickory and red oaks regardless of the diameter class, seasons, or concentrations tested. Results with dogwood were affected by concentration and season. The 10% concentration provided less than 50% crown reduction compared to 80% and 75% for the 50% and 100% concentrations, respectively. Dormant season applications resulted in 58% crown reduction compared to 91% in the growing season.

Introduction

Forest managers have known for years that undesirable stems can significantly reduce the growth of desirable crop trees. Langdon and Trousdell (1974) reported that mixed stands with 30 percent hardwood basal area will have 50 percent less yield of pine timber. Controlling these undesirable stems will not only produce a larger and higher quality crop sooner, it will also facilitate the harvest operations (Miller, 1991) and enhance regeneration operations (Cain, 1989). The economic impact of hardwood stems on pine management begins very early, bur becomes more evident when the stands are 10-15 years old. Therefore, control is often delayed until these stems are too large for many of the cost-effective options (Miller, 1989).

To control larger undesirable stems, injection has long been recognized as viable and cost-effective method (Williston et al, 1976). Typically, individual stem treatment becomes more cost-effective when hardwood density is less than 800 stems per acre (Miller, 1988). Earlier reports noted that injection is most effective on trees which are 3-4 inches diameter with no more than 250-300 stems per acre (Nelson and Miller 1991; Williamson et al 1989).

Tree injection has historically been a very labor-intensive practice. Estimates for productivity ranged from 0.2-0.5 acre/hour (Miller, 1988) and cost-effective evaluations were based on the intensive labor input associated with conventional spacing of injection hacks.

The purpose of this study was to evaluate the efficacy of a limited number of injections per stem using various concentrations of Arsenal Applicators Concentrate in aqueous solutions. This reduced number of injections greatly increases productivity and decreases labor costs. If the methodology proved effective, the use of injection as a forest management tool could be drastically changed.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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Methods and Materials

Study Sites

Two adjacent sites were located on the Noxubee National Wildlife Refuge in East Central Mississippi. These were approximately 400 yards apart and nearly identical in soils, species composition, stand condition, and management history. The dominant hardwood species on both sites were post oak and southern red oak. Dormant and growing season injections were split between the two sites.

A third site was located on the Clemson University Experimental Forest approximately four miles north of the Clemson University campus in northwestern South Carolina. The dominant species on this site were southern red oak, dogwood, and hickory.

Treatments

Injection treatments included three concentrations of Arsenal Applicators Concentrate (10 and 50% v/v with water and 100% product) applied in both the dormant and growing season of 1990. Treatments were applied to at least two and up to four diameter classes, depending on stem class availability for each of the dominant species.

Tree injections were conducted with a hatchet and ACCUGUN® according to diameter classifications as follows:

1	- 4	inch DBH	= 1 injection
4	- 8	inch DBH	= 2 injections
8	- 12	inch DBH	= 3 injections
12	- 16	inch DBH	= 4 injections

For each combination of species/season of application/diameter class/concentration, crews attempted to locate three replicates of 10 trees of each dominant species. Trees were marked with permanent aluminum tags for later identification. A minimum of 5 stems per species was accepted per replication. Treatments were assigned according to a complete random block and a complete random experimental design in Mississippi and South Carolina, respectively. In Mississippi, a limited number of stems representing 13 miscellaneous species were also injected for observation.

Evaluation

In Mississippi, injected stems were evaluated in early fall following one and two growing seasons after treatment. In South Carolina, evaluations were conducted after one and three growing seasons. Evaluations were based on "percent crown reduction" of individuals stems. This was recorded in increments of 10 percent except at the upper and lower extremes of the scale. For example, if any foliage remained in the crown or as basal sprouts, the maximum rating possible was 95 percent reduction; conversely the minimal observable effect would have been 5 percent. Values of 0 or 100 percent were assigned when appropriate.

Results

Percent crown reduction one growing season after treatment is shown in Table 1. Dormant season applications appeared to be more effective than those conducted during the growing season. Season effect was significant ($P < .05$) for hickory, post oak, and southern red oak in South Carolina. Crown reduction was also effected by concentration (same probability level) in all species and by diameter class in hickory and the oaks. Crown reduction was generally lower with the 10% solution and in the 8 to 12 inch diameter class. Overall, first year crown reduction was relatively low with all treatments except dormant season applications to hickory.

Results changed considerably by the end of the second growing season in Mississippi and the third season in South Carolina (Table 2). Most treatments provided better than 95% crown reduction. The most notable exceptions included dormant season applications to dogwood and dormant season applications to the 8 to 12 inch diameter class oaks in Mississippi.

Table 3 shows the final evaluation effects of diameter class, season of application and herbicide concentration on crown reduction. Means for each factor are averaged over the other two factors. For example, a value for diameter class is averaged over both seasons and all concentrations.

Diameter class was a significant factor for large diameter oaks. Percent crown reduction was lower by 6 to 9 percentage points in these trees. However, season of application also had an effect. Reduced efficacy of the large oaks occurred primarily on trees injected during the dormant season (Tables 2 and 3). Crown reduction on dogwood was also lower with dormant season injections regardless of stem diameter.

Although herbicide concentration was a statistically significant factor for all species, it appears

Table 1. Average percent crown reduction from injection treatments on sites in Mississippi and South Carolina one season after application.

Species/ Diameter Class	Dormant Season Solution 10%	50%	100%	Growing Season Solution 10%	50%	100%
	---------- Mississippi ----------					
Southern Red Oak						
1" - 4"	79	92	89	51	68	86
4" - 8"	72	88	79	35	68	91
8" - 12"	13	31	27	5	43	45
Post Oak						
1" - 4"	98	98	100	61	88	88
4" - 8"	51	67	89	33	48	60
8" - 12"	11	17	22	13	29	26
	---------- South Carolina ----------					
Dogwood						
1" - 4"	62	92	81	55	94	96
4" - 8"	62	90	95	--	--	--
Hickory						
1" - 4"	98	99	100	24	55	62
4" - 8"	100	100	99	--	10	--
Southern Red Oak						
1" - 4"	85	92	98	41	77	82
4" - 8"	50	74	85	22	68	90
8" - 12"	19	33	62	--	--	--

to be of practical importance only on dogwood where the 10% concentration had a very moderate effect.

Final mean crown reduction for miscellaneous species is presented in Table 4. Means include all diameter classes and all concentrations with means separated by season of application. As with the principal species above, growing season applications resulted in greater crown reduction than those conducted during the dormant season. Nearly 100% crown reduction was achieved on those species of a sample size of 6 or more stems. Results indicate that growing season applications work quite well on black cherry (*Prunus serotina* Ernhn.), blackgum (*Nyssa sylvatica* Marsh.), dogwood, winged elm (*Ulmus alata* Michx.), hickory, red maple (*Acer rubrum* L.), red mulberry (*Morus rubra* L., and sweetgum (*Liquidambar styraciflua* L.).

Discussion

Results indicate that imazapyr injected at wide spacings can be very effective for controlling hardwood species sampled in this study. Growing season applications applied over the range of stem classes and concentrations provided nearly 100% crown reduction two and three years after treatment. However, as demonstrated in previous studies, (Peevey 1971 and Starr 1973) the effectiveness of tree injection can vary by species, tree size, and season of application. In this study, dormant season applications to large oaks (8 to 12 inches DBH) and to dogwood resulted in less than 90% crown reduction at all concentrations. Whether or not crown reduction under these conditions can be improved by closer injection spacings was not determined here. More studies will be required to determine overall efficacy on a wider range of species and whether the concept of using wide spaced injections will prove cost effective with this product.

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Table 2. *Average percent crown reduction from injection treatments on sites in Mississippi and South Carolina two and three seasons after application, respectively.*

Species/	Solution			Solution		
Diameter Class	10%	50%	100%	10%	50%	100%
	Mississippi					
Southern Red Oak						
1" - 4"	94	99	98	99	100	100
4" - 8"	94	98	95	99	100	100
8" - 12"	70	85	83	97	100	100
Post Oak						
1" - 4"	100	100	100	99	100	100
4" - 8"	94	98	100	100	100	100
8" - 12"	71	88	88	94	99	99
	South Carolina					
Dogwood						
1" - 4"	28	68	62	81	97	95
4" - 8"	38	76	77	--	--	--
Hickory						
1" - 4"	97	100	100	97	100	100
4" - 8"	99	100	100	--	100	--
Southern Red Oak						
1" - 4"	99	100	100	99	100	100
4" - 8"	96	99	100	99	100	100
8" - 12"	85	98	98	--	--	--

Table 3. *The individual effects of diameter class, season of application, and herbicide concentration on mean percent crown reduction resulting from injection treatments on sites in Mississippi and South Carolina.*

Species	Diameter Class			Season of Application		% Concentration		
	1-4	4-8	8-12	Dormant	Growing	10	50	100
	Mississippi							
Southern Red Oak	98	98	89	87	99	88	96	95
Post Oak	99	98	90	91	99	90	96	98
	South Carolina							
Dogwood	72	63	--	58	91	49	80	78
Hickory	99	99	--	99	99	99	100	100
Southern Red Oak	99	99	93	97	99	96	99	99

Table 4. *Average percent crown reduction of miscellaneous species in Mississippi after two growing seasons (means of all diameter classes and concentrations).*

Species	No. Stems	Application Time	
		Dormant Season	Growing Season
Black Cherry	7	86	100
Blackgum	10	--	100
Dogwood	1	--	100
Winged Elm	11	70	98
Eastern Redcedar	1	--	60
Hickory	55	83	95
Red Maple	6	100	100
Red Mulberry	6	--	100
Persimmon	2	--	100
Sweetgum	12	99	100
Willow Oak	3	--	93
Water Oak	3	--	100
Loblolly Pine	2	5	--

RESPONSE OF THINNED 12-18 YEAR-OLD LOBLOLLY PINE TO UNDERSTORY COMPETITION CONTROL [1]

R.A. Heinemann, R.T. Holeman, E.M. Lorenzi, and T.C. Hennessey [2]

Abstract. In 1987, an experiment was initiated to quantify the effects of understory competition control in a thinned 12-year-old plantation of loblolly pine growing in southeast Oklahoma as part of the Long-Term Loblolly Pine Intensive Forest Ecosystem Research (LTLPIFER) project. Six one-quarter acre treatment plots were established, each having a pine basal area of 11.5 m_2/ac (50 ft_2/ac). Understory vegetation in three plots was sprayed with a 4% mixture of Roundup and water for control of grasses and herbaceous plants, and a 6% mixture of Garlon 4E in diesel fuel with 1% Cidekick as a basal spray to control hardwoods. Three plots were left as untreated controls. Treated plots were re-sprayed with Roundup yearly from 1988-1991. Soil moisture was measured to a 220 cm (90 in) depth approximately monthly (February-December) each year. Understory biomass was sampled in August each year. Pine needlefall was collected monthly each year to estimate changes in canopy leaf area. Pine height and diameter were measured at the end of each growing season. Seasonal available soil moisture was similar between treated and control plots in 1987 and 1988, but was 10-15% greater in treated plots in 1989 and 1990. Although needlefall for all plots varied between years in response to differences in annual precipitation patterns, needlefall was greater on the control plots in all study years. Pine height, diameter, basal area and volume growth did not vary significantly between treatments in any year. Relatively high moisture-holding capacity of the soil at the site and the presence of few hardwoods may have contributed to the limited response of pines to the herbicide treatments.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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VEGETATION MANAGEMENT IMPROVES THE ECONOMIC POTENTIAL OF LOBLOLLY PINE PLANTATIONS [1]

T. R. Clason [2]

Abstract. Herbaceous weeds, hardwood brush, and excessive pine stocking impact loblolly pine plantations by reducing wood yields and decreasing harvest values. Long-term, chronosequential growth and yield studies at the Hill Farm Research Station, Homer, LA indicate that each of these competition components influences plantation growth during more than one stage of development. Actual growth data were combined with a pine plantation growth simulator to evaluate effects of various vegetation management regimes on economic potential of a 35-year-old loblolly pine plantation. Silvicultural practices included: two planting rates (680 and 450 TPA), site preparation with and without herbaceous weed control, age 7 hardwood suppression treatment, and two stocking control treatments (unthinned and thinned). The practices were combined to develop 16 management regimes of varying intensities. Present net value, computed at an 8 % discount rate from historic cost and revenue values between 1955 and 1990, was used to compare cost effectiveness of 16 management regimes. A 35-year multiproduct rotation planted at 450 TPA and using the most intensive competition management regime produced the highest net value.

Introduction

Commercial timber land should be managed in a manner that will optimize wood production and economic returns while conserving or enhancing the environment. Since the primary incentive of timber management is economic, a successful management system must sustain timber production continuity. Therefore, silvicultural practices used during a specified growing cycle should achieve full site utilization without limiting individual tree growth.

Negative effects of unwanted vegetation, herbaceous weeds, hardwood brush, and excessive pine stocking, on pine growth reduce wood yields and decrease wood values. Site preparation practices that suppress herbaceous weed and hardwood brush competition during plantation establishment, improve seedling survival rates (Metcalf, 1986; Grano, 1961) and increase early diameter and height growth (Clason, 1989; Miller et al., 1991). Pine growth responses attributed to herbaceous weed control increased merchantable volume yields 128% in 10-year-old loblolly pine plantations (Creighton et al., 1986). Nine years of annual hardwood brush control on mechanically prepared sites increased diameter and volume of 10-year-old loblolly pine by 1.1 inches and 1 ft^3 (Haywood, 1986). Hardwood brush suppression in a 6-year-old natural loblolly pine stand improved age 20 wood yields by 200% (Langdon and Trousdell, 1974).

Long-term chronosequential growth and yield studies at the Hill Farm Research Station, Homer, LA indicate that herbaceous weed and hardwood brush components influenced pine growth during more than one stage of plantation development. Herbaceous weeds significantly reduced age 7 pine dbh and height (Clason 1989). Early dbh and height growth reductions resulted in a 18% decrease in merchantable volume at age 20 with untreated and treated wood yields being 2,530 and 2,860 ft^3/acre, respectively. The competitive effects of hardwood brush during sapling and maturing stages of development lowered periodic pine growth between ages 7-12, 12-17, and 17-22 by 26, 37, and 22% (Clason 1991). After 15 years, hardwood brush reduced total merchantable volume growth by 630 ft^3/acre.

Suppressing herbaceous weeds and hardwood brush during early plantation development not only increases short-term wood yields but also intensifies intraspecific competition. Following a hardwood suppression treatment, periodic plantation growth was inversely related to residual pine stocking density (Rogers and Brinkman, 1965; Langdon and Trousdell, 1974; Oliver, 1979).

Craib (1947) reported that intense intraspecific competition reduced early pine diameter growth in

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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both the dominant and intermediate crown classes of a plantation. The impact of intraspecific competition on plantation development was illustrated by a pine spacing study (Sprinz et al. 1980). Growth comparisons between pine planting rate densities of 1,200 and 435 TPA showed that excessive pine stocking began to influence growth during the sapling stage of development. By age 12, the 1,200 TPA planting rate stocking density had decreased to 860 TPA and merchantable volume averaged 1,100 ft^3/acre, while the lower planting rate stocking density and merchantable volume averaged 401 TPA and 1,940 ft^3/acre. Although stocking density for the 1,200 and 435 TPA planting rates differed at age 22 (758 and 359 TPA, respectively), higher rate mean merchantable volume was 870 ft^3/acre less than the lower rate.

Since interspecific and intraspecific competition impacts growth throughout plantation development, competition for growing space will not be alleviated by a single vegetation management treatment. If an interactive relationship exists among the competing vegetation components, then vegetation management regimes should first suppress and then maintain unwanted vegetation at levels that will not impair plantation productivity, harvesting operations, or future regeneration practices. Therefore, the influence of various management regimes on the biologic and economic development of loblolly pine plantations was evaluated by combining actual growth data with a loblolly pine plantation growth simulator.

Methods and Procedures

Early growth data from the previously cited Hill Farm Research Station studies and a growth and yield simulator validated with data used by Sprinz et al. (Smith and Hafley, 1986) were used to initiate and project growth for 35-year-old loblolly pine plantations. Silvicultural practices such as site preparation, artificial regeneration, herbaceous weed control, pine release, and thinning were used to develop sixteen plantation management regimes (Table 1). Site preparation method selected for all plantations was a chop and burn that enhanced planter access. Additional silvicultural practices included: two planting rates (680 and 450 TPA), site preparation with and without herbaceous weed control, age 7 pine release treatment, and two stocking control treatments (thinned and unthinned).

Plantation growth was projected from age 7 to age 35 for each management regime. Age 7 growth data from untreated and treated plots in a herbaceous weed control study (Clason, 1989) provided the age 7 stand attributes for 680 and 450 TPA planting rates grown with and without weed control. Assuming a mortality rate of 15%, age 7 stand data for 584 and 383 TPA were subsequently incorporated into the growth simulator (Table 2). Assumed age 7 hardwood basal area for all management regimes was approximately 20% of total pine basal area with the pine release treatment removing 80% of the hardwood stocking. The pine release study data (Clason, 1991) indicated that without the age 7 pine release treatment, residual hardwood stocking decreased site index at age 27 by 4%. Therefore, the initial site index values with and without weed control (71 and 68) were decreased 4% for the regimes without pine release (Table 2).

Pine stocking control was accomplished with three thinnings (Table 3). The first thinning reduced pine stocking to 60 ft^2/acre, and age of the thinning, which was affected by planting rate and site quality, ranged between age 12 and 14. Depending on plantation growth the second thinning was applied at either age 20 or 21, leaving residual stocking of 100 TPA. The third thinning lowered stocking in all plantations to 50 TPA at age 28. Finally, a regeneration clearcut harvest was applied to all plantations at age 35. Product volume yields were expressed as cords (equivalent to 85 ft^3 of solid wood) and board feet Doyle scale.

The economic time line for the study ran from September 1955 to September 1990. All management costs (Table 4), except taxes, were derived from Dubois et al. (1991). Annual tax rate, which was obtained from the Claiborne Parish, LA tax assessor, averaged $1.00/acre. Timber harvest revenues were obtained from the "Quarterly Report of Forest Products" published by the Louisiana Department of Agriculture and Forestry. Present net value (PNV) in 1990 was computed for all management regimes by appreciating costs and revenues at a 8.15% discount rate (5% inflation and 3% real increase).

Results

Manipulating species composition and stocking density influenced productivity of 35-year-old loblolly pine plantations. Interspecific competition management increased total merchantable volume yields (Table 3). In unthinned plantations, mean yield increases for herbaceous weed control, pine release, and both practices combined (total control) were 980,

Table 1. *Loblolly pine plantation management regimes.*

Intensity Level	Planting Rate	Weed Control	Pine Release	Pine Thinning
1	680 TPA	NO	NO	NO
2	450 TPA	NO	NO	NO
3	680 TPA	NO	YES	NO
4	450 TPA	NO	YES	NO
5	680 TPA	YES	NO	NO
6	450 TPA	YES	NO	NO
7	680 TPA	YES	YES	NO
8	450 TPA	YES	YES	NO
9	680 TPA	NO	NO	YES
10	450 TPA	NO	NO	YES
11	680 TPA	NO	YES	YES
12	450 TPA	NO	YES	YES
13	680 TPA	YES	NO	YES
14	450 TPA	YES	NO	YES
15	680 TPA	YES	YES	YES
16	450 TPA	YES	YES	YES

Table 2. *Age 7 stand attributes for each management regime.*

Management Level	Site Index	Dom HGT	TPA	DBH	Ave HGT	Basal Area	
						Pine	HWD
	feet	feet		inches	feet	----------feet^2----------	
1	63	19	584	3.0	16.6	29	6
2	63	19	383	3.2	17.0	21	6
3	66	20	584	3.0	17.2	29	6
4	66	20	383	3.2	17.6	21	6
5	68	20	584	4.0	17.6	51	10
6	68	20	383	4.3	18.1	39	10
7	71	21	584	4.0	18.2	51	10
8	71	21	383	4.3	18.6	39	10
9	63	19	584	3.0	16.6	29	6
10	63	19	383	3.2	17.0	21	6
11	66	20	584	3.0	17.2	29	6
12	66	20	383	3.2	17.6	21	6
13	68	20	584	4.0	17.6	51	10
14	68	20	383	4.3	18.1	39	10
15	71	21	584	4.0	18.2	51	10
16	71	21	383	4.3	18.6	39	10

480, and 1,410 ft^3/acre, respectively. Although thinned merchantable volume yields were less than unthinned yields, similar mean yield increases were detected among the interspecific competition management practices (Table 3) . Stocking density control measures, lower planting rate and thinning, reduced total merchantable volume yields. Among the interspecific competition management practices, total yield for the 450 TPA planting rate averaged 200 ft^3/acre less the 680 TPA rate, while the unthinned and thinned yield differentials ranged between ranged from 800 to 1,000 ft^3/acre.

Pulpwood, chip-n-saw (cns), and sawtimber yields varied by management regime (Table 5). Interspecific competition management altered product yield distribution in both unthinned and thinned plantations. Total competition control in unthinned plantations maximized mean pulpwood and sawtimber yields, which averaged 33.6 cords and 5,000 bd.ft., while the largest cns volume (8.4 cords) was on the

Table 3. Plantation merchantable volume yield by management regime.

Intensity Level	First Thinning		Second Thinning		Third Thinning		Final Harvest		Total Yield
	Age	Yield	Age	Yield	Age	Yield	Age	Yield	
		ft^3		ft^3		ft^3		ft^3	ft^3
1	--	--	--	--	--	--	35	4130	4130
2	--	--	--	--	--	--	35	3969	3969
3	--	--	--	--	--	--	35	4501	4501
4	--	--	--	--	--	--	35	4362	4362
5	--	--	--	--	--	--	35	5098	5098
6	--	--	--	--	--	--	35	4961	4961
7	--	--	--	--	--	--	35	5535	5535
8	--	--	--	--	--	--	35	5394	5394
9	13	322	20	955	28	693	35	1264	3234
10	14	273	21	733	28	712	35	1300	3018
11	13	408	20	970	28	848	35	1646	3872
12	14	331	21	797	28	877	35	1658	3663
13	12	545	20	983	28	922	35	1772	4222
14	13	471	20	664	28	939	35	1809	3883
15	12	607	20	1031	28	1077	35	2063	4778
16	13	554	20	659	38	1122	35	2177	4512

Table 4. *Actual management costs for a 35 year rotation.*

	Year	Cost
Site Preparation	1955	$11.11/acre
Planting	1955	0.033/seeding
Herbaceous Weed Control	1955	6.50/acre
Taxes	Annual Average	1.00/acre
First Thinning	1967	3.83/acre
	1968	4.14/acre
	1969	4.45/acre
Second Thinning	1975	8.31/acre
	1976	9.23/acre
Third Thinning	1983	16.55/acre
Final Harvest (cruise)	1990	5.50/acre
Pine Release	1962	20.45/acre
Prescribed Burn	1965	1.60/acre
	1970	2.50/acre
	1975	2.50/acre
	1980	3.00/acre
	1985	7.00/acre

untreated plantations. Thinned plantation maximum pulpwood yield averaged 20.5 cords and was produced in the untreated plantation. Largest cns volume (5.8 cords) occurred in the herbaceous weed and pine release treatments, and total control yielded maximum sawtimber volume, averaging 6,450 bd. ft. Planting rate density had a greater influence on product volume in unthinned plantations with pulpwood and cns volumes being directly relate to planting rate and sawtimber inversely related. Among the interspecific competition management practices, pulpwood and cns volume differentials between 680 and 450 TPA were 5 and 5 cords, respectively. Sawtimber differentials, however, ranged from 500 to 2,000 bd. ft. (Table 5). Planting rate product volume differentials varied less in the thinned plantations, averaging 3 cords, 2 cords, and 300 bd. ft. for pulpwood, cns, and sawtimber (Table 5). Product volume distribution differed between the unthinned and thinned plantations. Unthinned product yields averaged 33.4 cords, 6.9 cords and 3,120 bd. ft. for pulpwood, cns,and sawtimber, while thinned plantation mean values were 18.5 cords, 5.5 cords, and 4,610 bd.ft. for the respective products.

The impact of the various management regimes on 1990 PNV was directly related to the intensity of the regime (Table 6). Planting rate had the greatest influence on PNV, 450 TPA PNV exceeding the 680 TPA PNV at every level of interspecific competition management, whether unthinned or thinned. In unthinned plantations, planting rate PNV differentials were $79.25, $147.72, $208.51, and $200.71/acre for untreated, pine release, herbaceous weed and total control treatments. The thinned plantation differentials for the respective treatments were $112.03, $51.29, $32.74,and $83.22/acre. Management regime with the highest PNV included 450 TPA planting rate, total interspecific competition control treatment, and thinning, while the lowest PNV occurred in the regime that included 680 TPA planting rate, no interspecific competition treatment, and thinning (Table 6).

Table 5. *Product harvest yields by vegetation management intensity levels.*

Management	First Thinning			Second Thinning			Third Thinning			Final Harvest		
	Pulp	C-N-S	ST	Pulp	C-N-S	ST	Pulp	C-N-S	ST	Pulp	C-N-S	ST
Intensity	Cords	Cords	Bd. Ft.	Cords	Cords	Bd. Ft.	Cords	Cords	Bd. Ft.	Cords	Cords	Bd. Ft.
1	-	-	-	-	-	-	-	-	-	33.2	10.9	1300
2	-	-	-	-	-	-	-	-	-	28.7	5.9	2400
3	-	-	-	-	-	-	-	-	-	34.4	10.5	1800
4	-	-	-	-	-	-	-	-	-	30.3	5.1	3300
5	-	-	-	-	-	-	-	-	-	36.2	8.5	3200
6	-	-	-	-	-	-	-	-	-	30.1	3.4	3700
7	-	-	-	-	-	-	-	-	-	36.9	7.8	4000
8	-	-	-	-	-	-	-	-	-	30.2	2.8	6000
9	4.8	-	-	7.4	4.7	-	5.3	0.2	500	5.0	-	1800
10	3.9	-	-	4.1	4.9	-	5.4	-	700	4.4	-	2100
11	6.0	-	-	6.2	5.9	-	4.8	-	1000	3.3	-	3200
12	4.6	-	-	4.0	5.8	-	4.7	-	1000	3.3	-	3400
13	7.8	-	-	4.7	7.1	-	4.3	-	1300	3.2	-	3700
14	6.4	-	-	2.9	4.6	-	4.5	-	1300	2.9	-	4000
15	8.5	-	-	4.9	7.0	100	4.3	-	1400	2.4	-	4700
16	7.5	0.3	-	3.3	4.0	100	4.3	-	1600	2.5	-	4900

Table 6. *Appreciated costs and revenues, and PNV in 1990 for a 35 year rotation by management regime.*

Management Levels	Appreciated Costs	Appreciated Revenues	Net Value
	dollars/acre		
1	716.92	1221.07	504.15
2	597.23	1180.63	583.40
3	890.00	1323.46	433.46
4	770.31	1351.49	581.18
5	819.42	1461.72	642.30
6	699.73	1550.54	850.81
7	992.50	1690.75	698.25
8	872.58	1771.54	898.96
9	796.19	1083.22	287.03
10	677.22	1075.28	398.06
11	969.27	1454.57	485.30
12	850.30	1386.89	536.59
13	898.71	1667.82	769.11
14	779.00	1580.85	801.85
15	1071.79	1909.65	837.86
16	951.85	1872.93	921.08

Conclusions

Although the projected yields did not indicate an interactive relationship among the competitive components on plantation biologic development, economic comparisons among management regimes showed that the components did affect economic development. Thus, the following conclusions were made:

1. Interspecific competition management increased merchantable volume and sawtimber yields, and improved the economic potential of a loblolly pine plantation;

2. Pine planting rate had no appreciable affect on merchantable volume yield, but 450 TPA rate increased sawtimber yields and improved the economic potential of a loblolly pine plantation; and

3. Thinning decreased merchantable volume yields, but increased sawtimber yields and when used with interspecific competition management improved the economic potential of a loblolly pine plantation.

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Intermediate Stand Management

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THREE-YEAR GROWTH RESPONSE OF YELLOW-POPLAR TO RELEASE AND FERTILIZATION [1]

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Abstract. With the southern encroachment of the gypsy moth, it is possible that species compositional shifts will occur in the southern Appalachian forest. Highly resistant and fast growing species such as yellow-poplar (*Liriodendron tulipifera* L.) may comprise a higher proportion of the future growing stock. Recent advancements in yellow-poplar lumber drying procedures have increased its value, and more intensive management is expected. To evaluate the growth response of yellow-poplar to crop-tree-release and fertilization, a study was initiated in 1989 in two ten-year-old stands in southwest Virginia. Although second year responses were positive but stand-specific, third year growth responses indicated that treatment effects were beginning to level out. Each stand responded differently to treatment. The stand growing on a cove site had no height response to either treatment, but had positive diameter and crown volume responses to release. The stand growing on a poorer quality slope site exhibited a negative height response to release, but had no diameter or crown volume response to either treatment. Fertilization increased the levels of available phosphorus and potassium in both stands, but did not increase available nitrogen in either stand. Due to modest responses, the stands were re-treated in the spring of 1992.

Introduction

Within the southern hardwood region, yellow-poplar (*Liriodendron tulipifera* L.) has received a considerable amount of attention. Because of its availability, rapid growth, excellent form, clear bole, and good working properties, this versatile species has long been one of the outstanding timber species in the eastern United States. On moderately productive sites, yellow-poplar can compete for vertical space with its associated species, and on sites with site indices greater than 95 (base age 50), it will outgrow all of its competitors (Doolittle 1958). Yellow-poplar is a widely distributed species which comprises over 13 percent of the hardwood growing stock in the Appalachian Mountains (Beck and Della-Bianca 1981) and its growth exceeds removal more than five-fold (Tansey 1988).

It is also possible that species compositional shifts will occur in the southern Appalachian forest due to the southern migration of the gypsy moth (*Lymantria dispar* L.) (Twery 1991). Because yellow-poplar is classified as *Immune*, and is rarely fed upon by the moth (Gansner et al. 1987, Twery 1991), it is likely that the relative proportions of this fast growing species will increase in outbreak areas. In addition, advancements in yellow-poplar drying techniques and recent efforts to educate the forest products industry of the potential of yellow-poplar as a construction lumber have increased the value of the species (Muench 1989).

Since 1984, there has been a renewed interest in the commercial use of yellow-poplar (Frame 1989). Because of this renewed interest, and the desirable characteristics of the species, intensive management of yellow-poplar has increased. Management regimes currently employed include fertilization, crop-tree-release, and to a lesser extent, thinning and irrigation. These methods are implemented to improve the competitive position of yellow-poplar on sites where less desirable species compete strongly with it, and to increase growth on sites where yellow-poplar has a competitive edge.

Because many forest soils are inherently deficient of certain nutrients, fertilization is often beneficial. Past studies of yellow-poplar show a consistently positive growth response to additions of nitrogen, and in some cases, phosphorus and potassium (Finn and White 1966, Van der Werken and Warmbrod 1969, Groton and Buckner 1985). Crop-tree-release, a more selective release method

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than "geometric" thinning (and presumably more applicable for variably spaced stands), has not shown consistently positive growth responses (Lamson and Smith 1978, 1989, Loftis 1985). These previous studies have examined either fertilization or crop-tree-release of yellow-poplar, but never the combination of the treatments. The objectives of this study are to (1) determine the response of yellow-poplar to factorial combinations of crop-tree-release and fertilization treatments on a range of yellow-poplar sites in southwest Virginia, and (2) determine the effect of treatments on the chemical properties of the soil, and discuss how this may be reflective of past and future growth. Third year results are reported.

Methods

Two adjacent stands were selected six miles southwest of Blacksburg, VA, in the ridge and valley physiographic province at an elevation of approximately 2070 feet. Stand one was located in a slight cove-like depression immediately north of the ridgetop. This site had a very slight slope and no detectable aspect. Stand two was located on a side slope above a minor drainage on a northerly aspect. The two stands were chosen such that a range of sites that support yellow-poplar would be represented. Forest Site Quality Indices (FSQI's) where determined, rather than site indices, due to the age of the stands. Stand one's FSQI was 14, while stand two's FSQI was 10 (Meiner et al. 1984).

Soil pits were dug in each stand to characterize the physical properties of the soils. The soil supporting stand one was a fine-loamy mixed mesic Typic Hapludult of the Clymer series. Clymer soils formed in residuum of sandstone, siltstone and shale, and are generally deep and well drained. The soil supporting stand two was a loamy-skeletal mixed mesic Typic Dystrochrept of the Berks series. Berks soils formed in residuum of shale, siltstone and sandstone, and are eroded and fairly shallow soils (Creggar et al. 1985) (Table 1).

Prior to the establishment of the present stands, the area supported a mature mixed-oak stand with some yellow-poplar present. The current stand was created in 1979 when the area was clearcut, removing all existing stems. The sites regenerated naturally, with most of the yellow-poplar stems being of seed origin while other species such as maples and oaks were of sprout and seed origin.

Prior to treatment, stand basal areas were 78 and 66 ft^2/acre for stands one and two, respectively. Mean tree sizes were also different, with stand one supporting more biomass (Table 1). Moreover, 51 percent of the basal area was composed of yellow-poplar in stand one, while only 15 percent of the basal area in stand two was yellow-poplar. However, in both stands, yellow-poplar was the dominant species in terms of basal area. Competing species included maples (*Acer* spp.), oaks (*Quercus* spp.), hickories (*Carya* spp.), sourwood (*Oxydendron arboreum*), white pine (*Pinus strobus*) and Virginia pine (*Pinus virginiana*).

In June of 1989, following canopy closure, release and fertilization treatments were randomly applied in factorial combinations to 48 individual crop trees in each of the two stands. To be considered for selection, prospective crop trees had to be either dominant or codominant, of seed origin, and show no evidence of mechanical or pathogen related damage, including crooks and sweeps. The treatments included (1) control, (2) release, (3) fertilization, and (4) release plus fertilization. Each treatment was replicated 12 times in each stand.

Release treatments were accomplished using a basal application of four percent triclopyr in diesel oil. All competing trees within a six foot radius of the crop trees were treated. Only competing yellow-poplar were removed mechanically to preclude translocation of chemical across root grafts. All grapevines within the stand were similarly treated.

Fertilizer was broadcast in a six foot radius band around the crop tree. A complete fertilizer was used to apply 200, 260 and 217 lbs/acre of elemental nitrogen (N), phosphorus (P) and potassium (K), respectively.

Prior to treatment, and again at the end of the third post-treatment growing season (1991), tree measurements of dbh, total height, height-to-live crown, and crown radius were made. Crown volumes were calculated using the following formula:

$$CV = \pi r^2 H/2$$

where: CV = crown volume
r = crown radius
H = length of crown = total height-height-to-live crown.

Soil nutrients, pH and organic carbon were assessed at the end of the 1991 growing season. The upper 6 inches of the soil were sampled adjacent to each tree with a soil probe. A total of eight soil cores were removed from the base of each tree - two in each cardinal direction, at both 1.5 and 3.0 ft from

the base of the tree. The eight soil cores were combined, air-dried and ground to pass a 2 mm sieve. Ground samples were tested for anaerobically-mineralizable nitrogen using the techniques set forth by Keeny (1982), and analyzed on a Technicon Auto Analyzer II (Technicon Instruments Corp., Tarrytown, NY) using the indophenol colorimetric technique. Soil samples were also analyzed for available phosphorus and potassium using the dilute double-acid extraction method (Olsen and Sommers 1982) and subsequent analysis was performed using an Inductively Coupled Plasma Emission Spectrophotometer (ICP). Total organic carbon was measured using the LECO Carbon Determinator CR12 (LECO Corp., St. Joseph, MI), and soil pH was determined using a 2:1 water:soil extraction.

The tree data were analyzed separately for each stand using a two factor factorial design. Analysis of covariance, with pretreatment measurements as covariates, was employed. Soil data were analyzed using analysis of variance.

Results and Discussion

Stand One

Stand one exhibited no treatment effect on height; however, diameters and crown volumes were significantly greater for the released trees (Table 2). The absence of a height response is not uncommon on high sites when dominant trees are released. Allen and Marquis (1970) and Lamson and Smith (1978, 1989) determined that when dominant and codominant trees are released there is often a slight diameter increase along with a slight reduction in height growth compared to unreleased trees. This in turn makes the maintenance of these higher crown classes problematic.

Regarding the lack of height response, the possibility that the trees were not adequately released, and the canopy once again closed, cannot be overruled. It may, however, be premature to conclude that future height responses will not be observed, as the larger crown volume for the released plots (Table 2) suggests that active crown expansion is occurring, and future height increases may become evident due to increased photosynthate production (Ginn et al. 1991).

The complete lack of response to fertilization suggests that mineral nutrients were not limiting in this stand (Table 2). Stand one was in a moist cove-like depression on a relatively deep soil allowing for a greater nutrient base and greater overall rooting volume (Table 1). This "rich" environment may have allowed the individual trees to maximize their site regulated growth potential.

This hypothesis may be further supported by examining the treatment effects on anaerobically-mineralizable nitrogen in the surface soil (Table 3). After three years there were no differences in anaerobically-mineralizable nitrogen between the fertilized and non-fertilized treatments. Because Rathfon et al. (1991), reporting on the second year results of this same study, reported no significant differences in foliar N concentrations, it is unlikely that the added N is being taken up and stored by the tree, and is therefore probably not limiting. Because it is no longer in the upper soil horizons, it was presumably lost from the system via leaching.

Although there were significantly greater amounts of P and K in the upper soil layers on the fertilized plots (Table 3), these elements were probably not limiting either, as second year results showed no foliar P and K increases (Rathfon *et al.* 1991). Rather, this suggests that these elements are not moving, or they are cycled back into the upper soil horizons (Brady 1984). Release x fertilization interactions were detected for both soil P and K, with the levels of P and K being significantly greater for fertilized plots, and non-released plots (Table 3). If superfluous uptake is responsible, rather than a loss from the system, it may be in part responsible for the decrease in crown volume for the release treatment (Table 2). This in turn may indicate some form of "nutrient antagonism" (Cain 1959). This possibility, however, requires much further exploration.

Stand Two

Stand two responded much differently to treatment than did stand one. The better site potential of stand one allowed for superior stand development, and greater competition at the time of treatment. With competition as the limiting factor to growth, the stand was able to respond to a release from competition (Table 2). Stand two, on the other hand, did not exhibit a positive response to release, rather it had a negative height response to release (Table 4). Diameter and crown volume responses were nonsignificant.

The height data suggest some form of negative release interaction on fertilization (Table 4), however, this was not the case ($p=0.28$). However, at the end of the second growing season, Rathfon et al. (1991) reported a significant negative release interaction,

possibly due to "thinning shock". Although treatment interactions were not detected in year three, this sudden exposure to the elements may still be responsible for the negative height response of the released trees (Kozlowski et al. 1991). Two years of post- treatment summer drought may also be a factor. Because of the shallow soil in stand two, increased levels of insolation in the released plots may have decreased the amount of soil moisture available for uptake, while the deeper soil in stand one precluded this from being a factor.

Also reported by Rathfon et al. (1991) were significant diameter and height growth responses to fertilization. Neither of these responses were detected at the end of the third growing season (Table 4). Since greater foliar N, P, and K concentrations were found on fertilized plots after two years, these vital elements were presumably limiting. Given this data (Table 4), it appears that the fertilizer effect has levelled off after three years. The literature generally supports this assertion, with most fertilizer effects lasting only 3 to 5 years (Beck and Della-Bianca 1981). Because only upper soil P and K concentrations were still significantly greater for fertilizer treatments, and treatment effects have levelled off, we can conclude that N was the major limiting factor to growth, at least during the first two growing seasons (Table 5). This is supported by past research that classifies yellow-poplar as N-demanding (Stone 1973) and typifies the species as being most responsive to additions of N (Van der Werken and Warmbrod 1969, Farmer et al. 1970).

Site Effects

Irrespective of the type or amount of fertilizer applied, the growth response of yellow-poplar is dependent on site, as the greatest response occurs on the poorest sites (Baker and Blackmon 1977, Francis 1977, Stone 1986). However, these responses may be short-lived (Table 4). Whether the site is good or poor, growth response to fertilization cannot be considered exclusively dependent on increased soil nutrients. Other factors including available soil moisture, soil rooting depth and volume, cation exchange capacity, and other chemical and physical properties of the soil directly affect the ability of the tree roots to extract, and the soil to supply, the required nutrients. This is evident in this study as site differences did exist (Table 1). The greater soil depth and overall better physical properties of stand one yielded no positive responses to fertilization; however, the shallower, lower site potential of stand two allowed for a positive fertilizer response through two years. However, if economically justifiable, re-application, or initial increased rates of application, may be necessary to maintain this advantage on less productive sites.

Site differences have in the past influenced the response of yellow-poplar to crop-tree-release, with higher quality sites eliciting a better growth response than poorer sites (Trimble 1971). This was found to be true in this study. The more productive site (stand one) was limited by competition, and once released had positive growth responses through the third year (Table 2). However, the release response was declining by year three and may be obscured over the course of the rotation if not repeated. The less productive site (stand two) appears to have been limited more by nutrient and moisture deficiency and was not able to take advantage of a release from competition (Table 4).

The results of this study suggest that performing a combined treatment of release and fertilization is not warranted; however, these results may be clouded by two years of summer drought. In general, each treatment appears to have site specific responses, with release treatments eliciting better responses on more productive sites, and fertilization invoking more positive responses on poorer sites (Tables 2 and 4).

Conclusions

Site differences appear to influence the manner in which yellow-poplar responds to crop-tree-release and fertilization. Crop-tree-release is a more effective growth stimulator on more highly productive yellow-poplar sites that are governed by competition. On less productive yellow-poplar sites, where nutrients and water are limiting, fertilization appears to be the more effective silvicultural treatment. In this study, nitrogen was the limiting mineral nutrient on the poorer site. The responses to all treatments appear to be levelling off by the end of the third growing season. Thus, to maintain any growth advantage due to treatment, either heavier initial treatments should be performed, or re-application may be necessary - providing long-term economic justification.

Table 1. *Pretreatment comparisons of stand and site characteristics of the yellow-poplar crop-tree-release and fertilization study, Fishburn Experimental Forest, Blacksburg, Virginia.*

Site	Mean DBH (in)	Mean Tree Height (ft)	Total Basal Area (ft^2/ac)	Litter Depth (in)	Depth to C Horizon (in)	Depth to Bedrock (in)	Soil Series
Stand One	3.2	31.8	78	3.1	31.1	55+	Clymer
Stand Two	2.1	24.9	66	1.2	18.9	31	Berks

Table 2. *Dimensions of experimental trees in stand one three years after treatment, Fishburn Experimental Forest, Blacksburg, VA.*

Treatment	DBH[1] (in)	Height[1] (ft)	Crown Volume[1] (ft^3)
No Release	4.1a	38.7a	726a
Release	4.2b	39.1a	978b
No Fertilize	4.1A	38.6A	880A
Fertilize	4.1A	38.2A	823A

[1] Means followed by same letter not significantly different at p=0.05 where means are adjusted for pretreatment data and analyzed using analysis of covariance.

Table 3. *Stand one mean soil chemical properties response to release and fertilization, Fishburn Experimental Forest, Blacksburg, Virginia.*

Treatment	pH[2]	Organic Carbon[2] (%)	N[1,2] (ppm)	P[2,3] (ppm)	K[2,3] (ppm)
No Release	4.69a	3.07a	48.73a	5.91a	24.66a
Release	4.80a	3.04a	42.10a	3.54b	22.72a
No Fertilize	4.66A	2.79A	45.97A	0.33A	19.99A
Fertilize	4.69A	3.32B	44.86A	9.19B	27.39B

[1] Anaerobically-mineralizable nitrogen.
[2] Means followed by same letter not significantly different at p=0.05 using analysis of variance.
[3] Significant release x fertilization interaction at p=0.01 for P, and p=0.06 for K.

Table 4. *Dimensions of experimental trees in stand two three years after treatment, Fishburn Experimental Forest, Blacksburg, Virginia.*

Treatment	DBH[1] (in)	Height[1] (ft)	Crown Volume[1] (ft^3)
No Release	2.8a	30.9a	8419a
Release	2.8a	29.7b	417a
No Fertilize	2.7A	30.1A	405A
Fertilize	2.8A	30.5A	431A

[1] Means followed by same letter not significantly different at p=0.05 where means are adjusted for pretreatment data and analyzed using analysis of covariance.

Table 5. *Stand two mean soil chemical properties response to release and fertilization, Fishburn Experimental Forest, Blacksburg, Virginia.*

Treatment	pH[2]	Organic Carbon[2] (%)	N[1,2] (ppm)	P[2] (ppm)	K[2] (ppm)
No Release	4.96a	2.35a	41.38a	3.44a	22.61a
Release	5.08b	2.38a	47.85a	4.21a	23.71a
No Fertilize	4.96A	2.41A	40.36A	0.42A	19.39A
Fertilize	5.08B	2.32A	48.87A	7.23B	26.94B

[1] Anaerobically-mineralizable nitrogen.
[2] Means followed by same letter not significantly different at p=0.05 using analysis of variance.

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GROWTH OF A CHERRYBARK OAK PLANTATION AFTER 29 YEARS ON A COASTAL PLAIN CREEK-BOTTOM SITE [1]

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Abstract. Cherrybark oak *(Quercus falcata* var. *pagodifolia* Ell.) seedlings were planted on a coastal plain creek-bottom site in 1962. The soil is of the Marietta series, a member of the fine-loamy siliceous thermic family of fluvaquentic eutrochrepts. Site index for cherrybark oak is about 110 feet in 50 years. Trees were planted at a 7- by 8-foot spacing or 778 trees per acre. During the winter of 1972, three treatments were applied to the stand, thinning, thinning plus pruning, and no thinning or pruning. Treatments were assigned randomly in three replicates. Precommercial thinning was accomplished by removing every other tree leaving a 10.6- by 10.6-foot spacing. Pruning was done to a height of 7 feet. In March 1983, plots were thinned from below to a 75 percent stocking level leaving about 75 square feet of basal area. In April 1988, again plots were thinned from below to a 75 percent stocking level leaving about 87 square feet of basal area. By December 1990, the plantation was 29 years old. Thinned and thinned plus pruned plots had mean dbh of 10.9 and 10.1 inches, respectively. Plots that received no thinning or pruning had a mean dbh of 7.3 inches. There was little variation in total height.

Introduction

Because of its high quality and good growth rate, cherrybark oak is considered the best bottomland red oak in the southeastern United States (Putnam et al. 1960). It is found in the Atlantic and Gulf Coastal Plain from southeastern Virginia to northwestern Florida to eastern Texas, and in the Mississippi Valley from southern Louisiana to southern Illinois and southwestern Indiana (Krinard 1990).

In recent years interest has increased in planting bottomland hardwood species on minor stream-bottom sites of the coastal plain. Some information is available about the growth and development of planted cherrybark oak. On Mississippi Valley sites Toliver (1987) reported mean heights for 5-year-old plantations on the Thistlewaite Game Management Area in Louisiana ranged from 4.5 to 8.5 feet, while Allen (1990) reported mean heights of 4 to 10 feet and mean dbh of 0.5 to 1.2 inches for 8-year-old plantations on the Yazoo National Wildlife Refuge Complex in Mississippi. In the Brown Loam Bluffs near Vicksburg, Mississippi, Francis (1983) found that 5-year-old plantations had mean heights of 6.5 to 8.2 feet. For the same plantations at age 20 mean heights ranged from 39 to 41 feet and mean dbh ranged from 4.2 to 4.4 inches. An 8-year-old plantation in a coastal plain minor stream bottom near Monticello, Arkansas, had a mean height of 15.8 feet and a mean dbh of 1.8 inches (Kennedy et al. 1986). The same plantation at age 10 had a mean height of 20.0 feet and a mean dbh of 2.3 inches (Kennedy et al. 1987). Greene et al. (1991) reported on the growth of cherrybark oak planted on a Marietta soil in a coastal plain minor stream-bottom site near Cass, Texas. The 10-year-old plantation had a mean height of 26.2 feet.

Little information is available regarding cherrybark oak plantings of more than 20 years duration. The present study of a 29-year-old plantation was designed to investigate the effects of thinning and pruning on the growth and development of cherrybark oak.

Methods and Procedures

The study area was an old field creek-bottom site adjacent to Terre Rouge Creek on the University of Arkansas Southwest Research and Extension Center in Hempstead County, Arkansas. Hempstead County is located in the Upper Gulf Coastal Plain. The soil is of the Marietta series, a member of the fine-loamy siliceous thermic family of fluvaquentic eutrochrepts. This soil has a site index for cherrybark oak of 110

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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feet in 50 years as measured on site by the Soil Conservation Service in 1989.

Bare root, 1-year-old seedlings of cherrybark oak were planted during the winter of 1962 at a 7- by 8-foot spacing or 778 trees per acre. The entire plantation was 39 by 39 rows and covered about 2 acres. For 10 years the trees were allowed to grow with no treatments applied.

During the winter of 1972, the plantation was divided into 9 plots. Each plot consisted of 169 trees in a rectangular grid of 13 by 13 rows. The interior 9 by 9 rows were designated as a permanent remeasurement plot, with the outer 2 rows as a buffer. The following three treatments were applied in three replicates: thinning, thinning plus pruning, and no thinning or pruning (control). Precommercial thinning was accomplished by removing every other tree in a "checkerboard" fashion so that the remaining trees were left at a 10.6- by 10.6-foot spacing. Trees were pruned to a height of 7 feet.

In March 1983, the plots were thinned from below to a 75 percent stocking level according to a stocking guide developed by Gingrich (1971) for central upland hardwoods. The residual basal area after thinning was about 75 square feet per acre. No further pruning was done.

In April 1988, the plots again were thinned from below to a 75 percent stocking level. The residual basal area after thinning was about 87 square feet per acre.

At ages 2 through 8 dbh and height were estimated for the entire planting by measuring four 9-tree plots. After the establishment of the treatment plots at age 10, all trees in the permanent remeasurement plots were measured each year for dbh, and nine trees were designated in each plot for annual measurement of total height. Total tree stem volumes outside bark were estimated using an equation suggested by Johnson and Krinard (1988), volume = $0.05 + 0.0023\ D^2H$, where D is the measured dbh of the stem and H is the mean total height for the plot. Stem volumes for each plot were summed to estimate cubic volume per acre.

Total height and dbh at age 29 were subjected to analysis of variance. The SAS GLM procedure was used for both analyses (SAS Institute 1985). Duncan's multiple range test was used to separate means.

Results and Discussion

The plantation exhibited good diameter and height growth for the first eight years (Table 1). When compared with results reported by others (Francis 1983, Kennedy et al. 1986, Toliver 1987, Allen 1990), mean dbh and height exhibited by the current study were greater at ages 5 and 8. Survival at age 10 was about 79 percent. By age 10, prior to thinning, mean dbh was 3.2 inches and mean height was 25.7 feet. These are greater than the mean dbh of 2.3 inches and mean height of 20.0 feet reported at age 10 by Kennedy et al. (1987) on a coastal plain minor stream-bottom site near Monticello, Arkansas; and the height is comparable to the 26.2 feet reported at age 10 by Greene et al. (1991) on the same soil series (Marietta) near Cass, Texas.

Table 1. *Early diameter and total height of a cherrybark oak plantation.*

Age (yr)	dbh (in)	Total Height (ft)
2	-	3.8
3	-	5.8
4	1.0	8.2
5	1.6	11.0
6	1.8	13.8
7	2.1	16.6
8	2.6	19.4

At age 10 thinning had little effect on dbh since the thinning was done in a systematic manner, and height was not measured after thinning. After thinning volume per acre and basal area per acre of the thinned and thinned plus pruned treatments were about one-half those of the control because the thinning treatments removed one-half of the stems (Table 2).

By age 21 and through subsequent thinnings the mean dbh of the thinned and thinned plus pruned treatments exhibited an increasing advantage over the control (Table 2). By age 29 the thinned and thinned plus pruned treatments had mean dbh significantly greater than the control. This illustrates the advantage gained by the thinning treatments. By age 29 there were no apparent effects of the early pruning treatment. Any differences in dbh appear to be more a function of the selections made during thinning than any effect on growth from pruning. It was noted that

Table 2. *Mean trees per acre, dbh, total height, basal area per acre and cubic volume per acre for a cherrybark oak plantation at various ages, both before and after thinning.*

Age (yr)	Trees per ac	dbh (in)	Total height (ft)	Basal area (ft^2/ac)	Cubic volume (ft^3/ac)
			Control		
10 unthinned	615	3.2	25.7[1]	37.1	433
21 unthinned	570	5.7	55.5	112.7	2,668
26 unthinned	505	6.6	64.8	134.8	3,713
29	448	7.3	73.1	143.1	4,433
			Thinned		
10 after thin	304	3.2	25.7[1]	19.0	222
21 before thin	304	6.9	56.4	90.6	2,172
21 after thin	176	8.7	56.7	74.1	1,783
26 before thin	173	10.1	67.6	98.3	2,815
26 after thin	154	10.1	67.7	87.8	2,515
29	154	10.9	76.2	102.5	3,302
			Thinned and Pruned		
10 after thin	282	3.3	25.7[1]	18.3	212
21 before thin	282	7.2	53.6	87.5	1,989
21 after thin	188	8.3	54.9	71.6	1,671
26 before thin	188	9.4	66.7	95.2	2,688
26 after thin	173	9.4	66.7	84.8	2,393
29	173	10.1	73.9	100.4	3,137

[1] Mean total height was estimated for the entire plantation, but not by treatment at age 10.

trees in the control plots appeared to have a much higher incidence of epicormic branching than those in the thinned plots. There were no significant differences in total height by treatment.

The control continued to exhibit greater basal area per acre and volume per acre throughout the 19 years since the treatments were applied (Table 2). This is likely due to the removals of basal area and volume during each thinning. However, the performance of the treatments may be viewed differently by looking at the periodic annual increments of basal area growth and volume growth Table 3). From age 10 to age 21 the control exhibited greater basal area growth per acre and volume growth per acre than the thinned treatments, because the thinned treatments had one-half the number of stems per acre. From age 21 to age 26 the periodic annual increments of basal area per acre and volume per acre are about equal for all treatments. But, for the period from age 26 to age 29 the thinned treatments had begun to exhibit greater growth rates of basal area per acre and volume per acre than the control; and this transition occurred just as the diameters of the trees in the thinned plots began to approach small sawlog size.

Conclusions

The plantation grew well in the early years of development when compared with results reported by others. The early pruning treatment had no apparent effects on growth. Thinning had no significant effect on total height of the trees, but increased diameter growth significantly. The incidence of epicormic branching may be lowered by thinning from below as compared to no thinning. By age 29 the thinned treatments had begun to grow faster than the controls in basal area per acre and total tree stem volume per acre. Because the trees in the thinned plots are beginning to approach small sawlog size, it will be possible in future years to compare merchantable product volumes per acre and value per acre.

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Table 3. *Total accumulated basal area, total accumulated cubic volume and periodic annual increments (pai) per acre for a cherrybark oak plantation at various ages.*

Age (yr)	Basal area		Cubic volume	
	Total accumulated (ft^2/ac)	pai (ft^2/ac)	Total accumulated (ft^3/ac)	pai (ft^3/ac)
		Control		
10	37.1		433	
21	112.7	6.9	2,668	203
26	134.8	4.4	3,713	209
29	143.1	2.8	4,433	240
		Thinned		
10	19.0		222	
21	90.6	6.5	2,172	177
26	114.8	4.8	3,204	206
29	129.5	4.9	3,991	262
		Thinned and Pruned		
10	18.3		212	
21	87.5	6.3	1,989	161
26	111.1	4.7	3,002	203
29	126.7	5.2	3,750	248

GROWTH RESPONSE OF UPLAND OAK STANDS IN THE BOSTON MOUNTAINS TO NITROGEN FERTILIZATION [1]

David L. Graney and Paul A. Murphy [2]

Abstract. Seventy 1-acre plots representing a range of site indexes and stand ages were installed on the Ozark National Forest between 1975 and 1977. Plots were selected so they could be paired according to similarities in age, site index, species composition, and stand structure. The 35 plot pairs were thinned to residual densities of 40 to 100 percent stocking. One plot in each pair was fertilized with 300 pounds per acre of nitrogen applied as ammonium nitrate in the spring of the second growing season following thinning. Plots were inventoried before thinning and 5 and 10 years after thinning. Regression analysis was used to analyze the effect of age, site index, residual basal area, growth period, and fertilizer treatment on basal area and total cubic foot volume growth. The fertilizer application affected survivor growth and ingrowth of both volume and basal area. However, mortality apparently was not affected by fertilization. Some growth components also differed by 5-year growth periods. The findings indicate that these stands will respond to fertilizer treatments for 5 to 10 years after application.

Introduction

In the early 1970's several hundred thousand acres of forest land in northern Arkansas supported overstocked, even-aged, pole-sized stands of oaks and associated species. Although many stands were on medium-to-good sites (with site indexes of 60 to 70 feet at 50 years), diameter growth averaged only about 1 inch in 10 years. Limited outlets for small diameter hardwoods discouraged intermediate cutting in these stands. However, because demands for hardwood sawtimber were increasing and inventories of mature sawtimber were small, some land managers started noncommercial thinning and fertilization programs to accelerate growth of potential crop trees. Results from preliminary fertilizer trials in the Boston Mountains indicated that northern red (*Quercus rubra* L.), black (*Q. velutina* Lam.), and white (*Q. alba* L.) oak crop trees would respond to nitrogen (N) fertilization (Graney 1983, 1987; Graney and Pope 1978a, 1978b). Between 1975 and 1977, the USDA Forest Service, Southern Forest Experiment Station research project in Fayetteville, Arkansas, installed a stocking and fertilization study in the Boston Mountains of northern Arkansas (fig. 1). The purpose of the study was to evaluate growth and yield responses of upland oak stands to thinning and N fertilization.

The objectives of this paper are to describe the 10-year growth response of upland oak stands to N fertilization and how this response is affected by stand age, site index, and residual basal area.

Methods

Study Region

The Boston Mountains are the highest and southernmost member of the Ozark Plateaus physiographic province (fig. 1). They form a band 30 to 40 miles wide and 200 miles long from north central Arkansas westward into eastern Oklahoma. Elevations range from about 900 feet in the valley bottoms to 2,500 feet at the highest point. The plateau is sharply dissected, and most ridges are flat to gently rolling and are generally less than one-half mile wide. Mountain slopes consist of an alternating series of steep simple slopes and gently sloping benches.

Soils common to mountain tops and slopes are shallow to medium in depth and are represented by medium-textured members of the Hartsells, Linker, and Enders series (Typic Hapludults). They are derived from sandstone or shale residuum and are rated medium to low in productivity. In contrast, soils common to mountain benches are deep, well-drained members of the Nella and Leesburg series (Typic Paleudults) that developed from sandstone and shale colluvium. These soils are rated medium to high in productivity.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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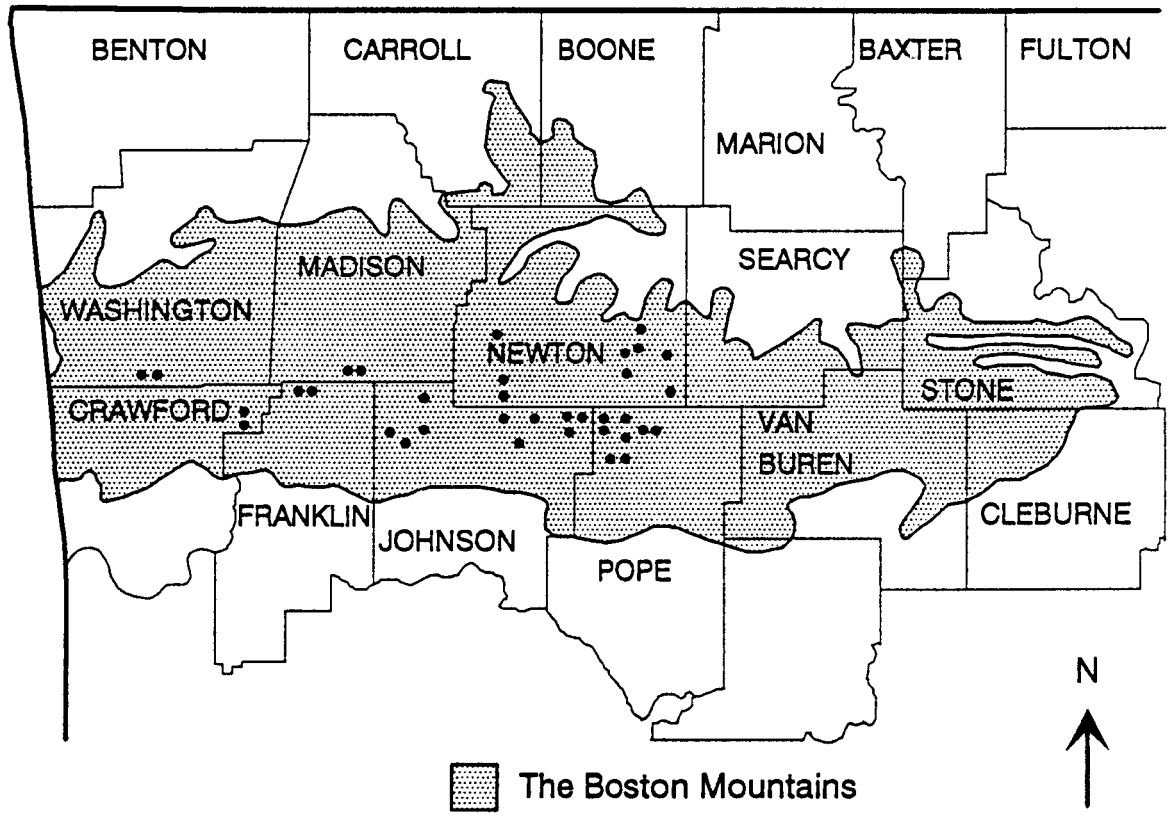

Figure 1. *Study plot locations in the Boston Mountains of Arkansas.*

Rocks in the area are sedimentary and of Pennsylvanian age and consist of alternating horizontal beds of shales and sandstones. Annual precipitation averages 46 to 48 inches, with March, April, and May being the wettest months. Extended summer dry periods are common, and autumn is usually dry. The frost-free period is normally 180 to 200 days long.

Study Description

This study is based on 70 permanent, 1-acre plots (a 0.4- or 0.5-acre net plot plus a 33-foot buffer) distributed across the Boston Mountains in Arkansas (fig. 1). Stand age at the time of initial thinning varied from 36 to 75 years. Site indexes for northern red or black oaks ranged from 46 to 82 feet (with a base age of 50 years). All plots were established in fully stocked, even-aged upland hardwood stands that showed no evidence of recent fire or cutting. Plots were installed over a 3-year period between 1975 and 1977.

Measurements consisted of a complete inventory of trees larger than 0.5 inch in d.b.h. measured to the nearest 0.1 inch. Total heights of sample trees, which were selected at random in proportion to the number of stems in each 1-inch d.b.h. class (before and after thinning), were obtained for each plot. Four levels of stocking were created by thinning. Residual stands were left with 40, 60, 80, or more than 100 percent of full stocking based on a tree-area equation for upland oak stands by Gingrich (1967). Thinning was mostly from below. Culls and poor quality stems were removed first, followed by intermediate and suppressed stems of low quality and vigor. High quality stems of desirable species were cut only to attain the residual stocking goal and a uniform spatial distribution.

Although 43 tree species were represented on one or more plots, black, northern red, and white oaks account for 90 percent of the total basal area over all plots after thinning (table 1). Plots with site indexes of 50 and 60 were predominantly occupied by white oaks, those with a site index of 70 were occupied by both red and white oaks, and those with a site index of 80 were predominantly occupied by red oaks. Other desirable species such as black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus americana* L.), and black walnut (*Juglans nigra* L.) were present only as scattered individual trees on most plots and account for only about 1 percent of the total basal area. Hickories (*Carya* spp.), blackgum (*Nyssa*

sylvatica Marsh.), and other species represented 9 percent of the total basal area after thinning, but these species were more common in the midstory and understory positions on most plots.

Table 1. *Average number of stems and basal area per acre by tree and shrub species group[1] for study plots after thinning.*

Species	Stems /acre	Basal area (ft^2/acre)
Group 1	113	35.7
Group 2	64	31.9
Group 3	3	1.0
Group 4	29	4.7
Group 5	21	1.9
All groups	230	75.2

[1] Group 1: White oak.
Group 2: Black oak, northern red oak, southern red oak.
Group 3: Ash, basswood, black cherry, black walnut, cucumbertree, shortleaf pine.
Group 4: Beech, blackgum, blackjack oak, black locust, chinkapin oak, elm, hackberry, hickory, post oak, red cedar, sugar maple.
Group 5: Blackhaw, buckeye, devils-walkingstick, dogwood, Indian-cherry, hophornbeam, mulberry, Ozark chinkapin, pawpaw, persimmon, redbud, red haw, sassafras, serviceberry, spicebush, tree-huckleberry, umbrella magnolia, wild plum, witch-hazel, miscellaneous understory shrubs.

Plots were selected so they could be paired according to similarities in age, site index, species composition, and stand structure. Individuals of each plot pair were usually contiguous (or located in the same stand) and received the same residual stocking treatment. One plot in each pair was randomly selected to receive a single fertilizer application of 300 lb of N per acre applied as ammonium nitrate (34-0-0) 1 year after the thinning treatment. Fertilizer was broadcast with hand cyclone seeders in late April or early May of 1977, 1978, and 1979 following full leaf-out on the selected plots. Even distribution was achieved by dividing each plot into four equal parts and applying a premeasured amount of fertilizer to each one-quarter plot.

Analysis

Seventy plots (35 fertilized and 35 nonfertilized) were used in this analysis; all plots had two 5-year growth periods for a total of 140 observations. Plot basal area per acre was calculated for all live trees 2.6 inches in d.b.h. and larger for each plot measurement.

Plot volumes were calculated by first constructing height-d.b.h. curves for each plot and each measurement to obtain heights for nonsample trees. All species were grouped because some species were not present in sufficient numbers to make up separate groups. Examination of scatter plots and preliminary regression analyses showed no gain by separating the height-d.b.h. measurements into species groups. Tree volumes were calculated using the equations from Clark and others (1986). All volumes are total cubic foot volume, inside bark, from ground level to tip, excluding branches, for all live stems 2.6 inches d.b.h. and larger.

Basal area and volume growth were the response variables that were measured. However, looking at net growth alone has limitations. First, fertilization can affect growth components differently. For example, fertilization may increase the growth of trees and simultaneously accelerate stand development, which may result in more mortality. These effects can cancel each other, and an analysis of net growth might show no fertilizer effect. Thus, no insight into how fertilization might be affecting stand development is gained. Therefore, the components of growth--survivor growth, mortality, and ingrowth--were observed as response variables rather than net growth.

Ingrowth basal area and volume are for trees that grew past the 2.6-inch d.b.h. threshold during the study measurement periods. Mortality equals the initial basal area or volume of trees that were alive at the initial measurement, but died during the growth period. Survivor growth equals the increase in volume or basal area of trees that were present at the beginning of the growth period and survived during the entire measurement period.

The variables stand age, basal area, and site index are important determinants of even-aged stand growth and development. Although the plots were carefully paired in this study, a mere paired comparison of growth affords little insight into how fertilizer response might vary with changes in these other variables, and it ignores the possible interaction of a fertilizer treatment with stand and site variables. This study also had two growth periods, and stand growth on both fertilized and nonfertilized plots might vary by growth period. Various authors (Auchmoody 1985, Farnum 1979, Lipas 1979, McWilliams 1990) have suggested the use of regression or analysis of covariance to incorporate stand or tree variables into

the analysis and as a means to test slope heterogeneity.

Nonlinear regression (SAS Institute 1988) was used to describe the effect of stand variables, fertilizer application, and measurement period on growth and to test slope heterogeneity. Dummy variables were used to represent the fertilized and nonfertilized plots and the growth periods. The initial full model was:

$$Y = \exp[b_0+b_1P+b_2F+b_3B+b_4A+b_5Q+b_6PB+ b_7PA+b_8PQ+b_9FB+b_{10}FA+b_{11}FQ] \quad (1)$$

where

Y = growth component of interest,
P = growth period (0 = period 1, 1 = period 2),
F = fertilizer treatment (0 = nonfertilized, 1 = fertilized),
B = initial basal area (ft^2/acre),
A = initial stand age (years),
Q = site index (ft, base age 50 years), and
b_i = coefficients to be determined.

A reduced model for each growth variable was then derived from the full model by inspecting the t-ratio of each parameter estimate and deleting those whose probability level was greater than 0.90. The reduced model was then fitted and examined carefully for logical relationships, patterns in the residuals, and correct model specification.

Results and Discussion

Table 2 gives the fit index and root-mean-square error for each equation. The trend was the same for both basal area and volume; survivor growth had the highest fit index, mortality was next, and ingrowth was last. With a fit index of less than 0.11 for both basal area and volume, the ability to explain ingrowth with the observed variables was quite poor.

The resulting equation for basal area survivor growth is:

$$Y1 = \exp[1.1573+0.18622F-0.0082256A+ 0.00082029PB] \quad (2)$$

where Y_1 is basal area survivor growth in square feet per acre. During the first growth period, only stand age and fertilizer treatment were significantly related to survivor basal area growth (fig. 2). The addition of fertilizer effectively increased growth 20 percent over the nonfertilized plots for each growth period. In the second period, initial basal area became an additional factor (fig. 2). Close examination of the growth data supported the trends indicated by equation (2).

Table 2. *Goodness-of-fit statistics for growth component equations.*

Growth Component	Fit index[1]	Root Mean Square Error
Basal area:		Ft^2/*acre*
Survivor growth	0.40	0.37
Mortality	0.36	0.61
Ingrowth	0.10	0.13
Volume:		Ft^3/ac
Survivor growth	0.68	10.1
Mortality	0.31	13.5
Ingrowth	0.11	1.4

[1] $\text{Fit index} = 1-\frac{\sum(y_i-\hat{y}_i)^2}{\sum(y_i-\bar{y})^2}$

Comparisons of growth responses in this study with other upland oak fertilization results are difficult because the present study is based on stand level growth, whereas previous studies have reported responses of individual dominant and codominant crop trees (Auchmoody 1986). However, the 20-percent increase in basal area growth observed here is comparable to responses reported for individual oak crop trees in the Boston Mountains (Graney 1983, 1987) and elsewhere (Auchmoody 1986). However, the continued response through the second growth period is unusual in that response to N fertilization is usually maximum for the first 2 years after treatment, then it declines rapidly and ends by the fourth or fifth year. But Graney (1987) reported that whereas responses of white oak crop trees to N fertilization ended after the fifth year, responses of northern red and black oak crop trees remained significant for 9 years. In this study, fertilizer was applied in the spring of the second growing season after plot establishment. Therefore, period one represented a 4-year response to fertilization, whereas period two represented a 5-year response. Younger stands produced the greatest growth responses to N fertilization in each growth period, but the percentage of increase was about 20 percent for all age classes (fig. 2).

Stand response to fertilization during the first growth period may have been significantly reduced by the severe 1980 drought. Although growth of all trees was affected, fertilized trees probably suffered the greatest reductions in growth. Graney (1987) reported

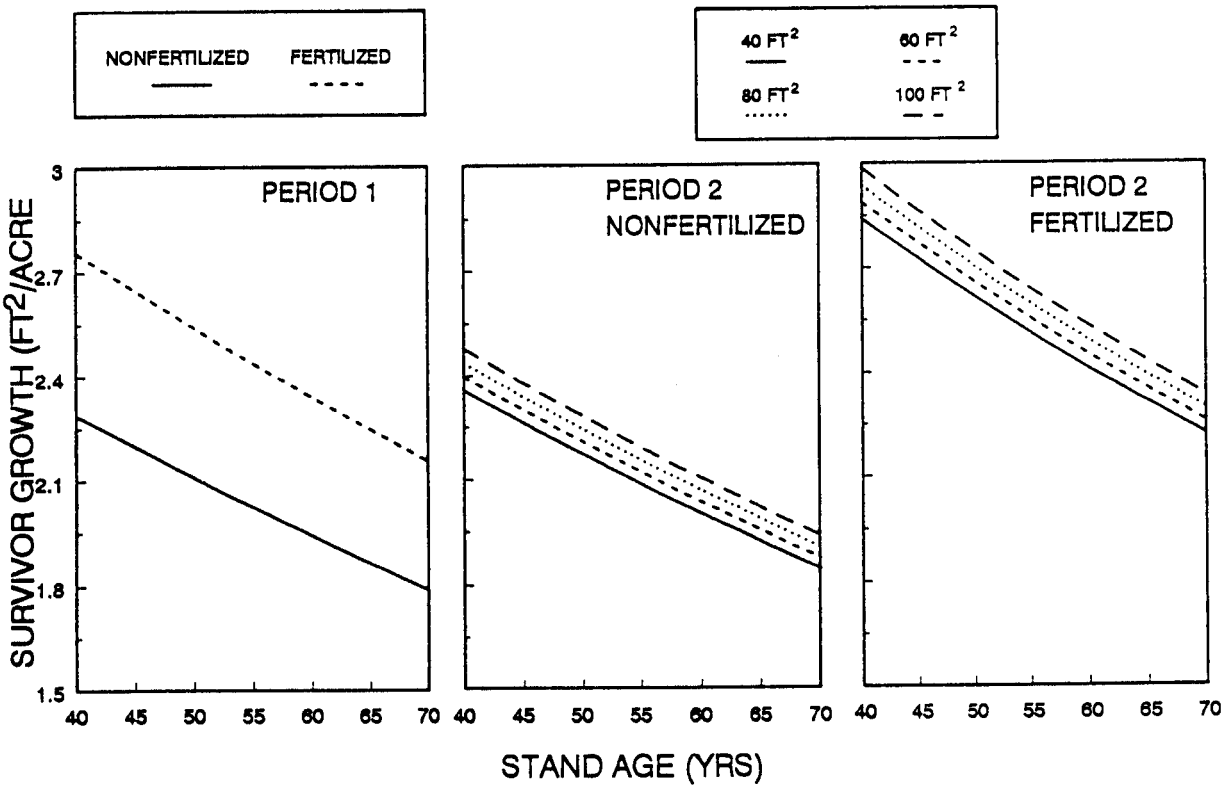

Figure 2. *Average annual basal area survivor growth for 10 years after treatment for upland oak stands in the Boston Mountains.*

that growth of fertilized red and white oak crop trees was 30 to 50 percent greater than nonfertilized trees through 1979, but was equal to or less than nonfertilized trees in 1980.

The delayed response to thinning (initial basal area) may be attributed to prethinning stocking levels, which ranged from 100 to 130 percent (Graney 1980). With the exception of a few dominant and codominant trees on each plot that were free to grow, most trees (especially white oaks) were tightly grown, small crowned individuals whose diameter growth averaged less than 1 inch in 10 years. Though all stands were thinned from below and lower vigor stems were prime targets for cutting, these smaller crowned trees still represented 40 to 80 percent of the residual stocking on most plots after treatment. When these smaller crowned lower vigor trees are released by thinning, growth response to increased growing space is slow to develop. Graney (1987) found that it took 3 to 5 years for tightly grown, small crowned, codominant red and white oak crop trees to produce a significant diameter growth response to thinning. But then, annual rates of diameter growth continued to increase through the 10th year.

Basal area growth during the first 5-year growth period could have also been reduced by the relatively dry growing seasons of 1976 and 1978 (when May through September rainfall was two-thirds of normal) and the severe drought of 1980 (when combined low rainfall and high temperatures resulted in significant and widespread mortality in forest stands throughout the Boston Mountain Area).

Basal area mortality is described by the equation:

$$Y_2 = \exp[-1.2503 + 0.030429B - 0.014572A - 0.014244Q] \quad (3)$$

where Y_2 is basal area mortality in square feet per acre per year. As would be expected, stands with more basal area will experience more mortality than those with less basal area because of the greater competition. Stand mortality also apparently declines with increases in age because younger stands are in a more dynamic phase of their life and they display intensified competition. Mortality is inversely related to site index, and this relationship might be the result of poorer sites being drier with the relatively shallow, sandy, and clayey soils that result in higher levels of moisture stress during the frequent summer droughts that affect this area (fig. 3). Nitrogen fertilization did not significantly affect mortality over the 10-year period.

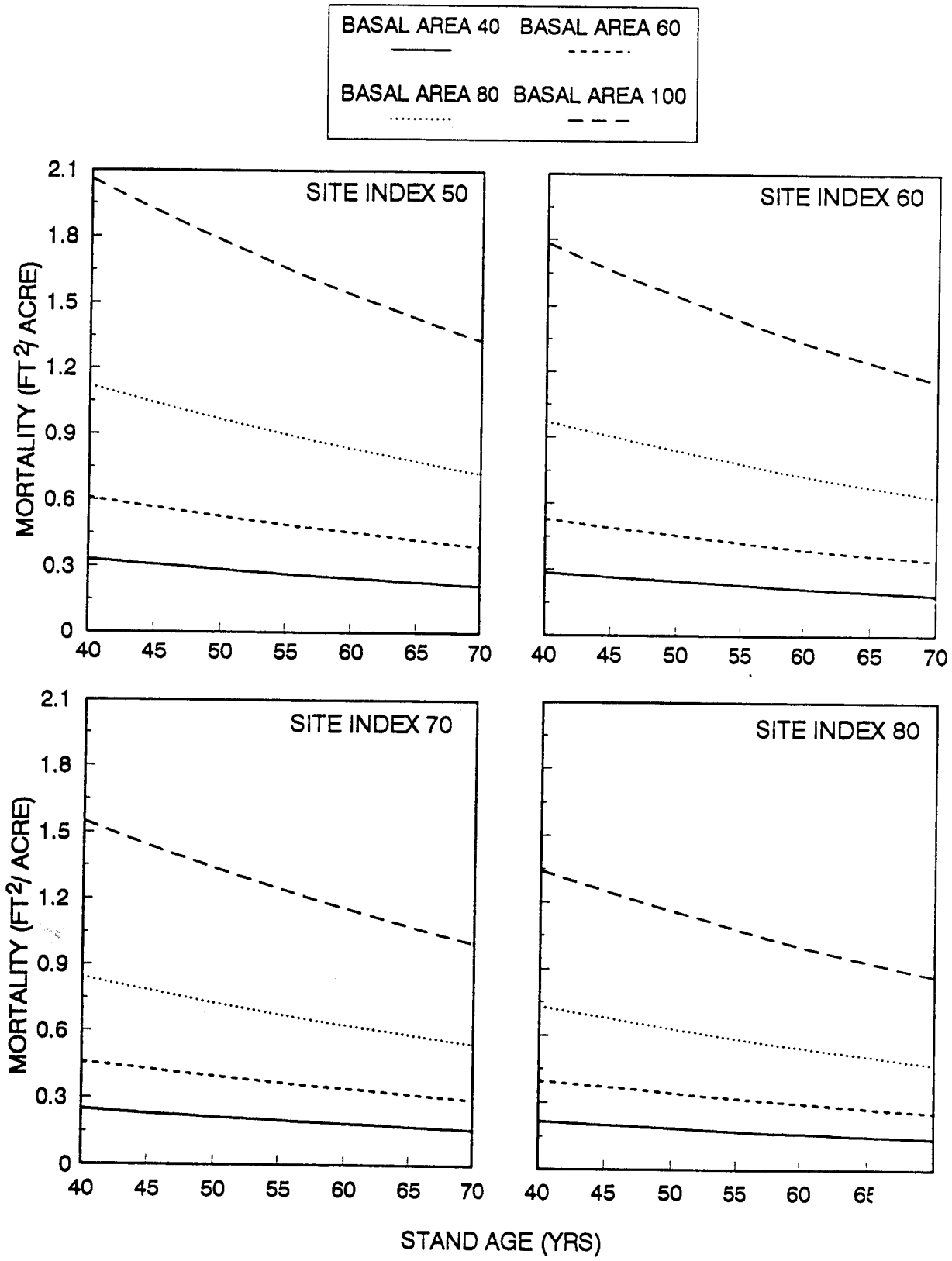

Figure 3. ***Average annual basal area mortality for 10 years after treatment for upland oak stands in the Boston Mountains.***

Whereas much of the mortality observed in higher density stands was associated with low vigor trees in the subdominant sapling and pole classes, mortality resulting from the 1980 drought occurred in all tree sizes and was most severe on poorer sites (site indexes of 50 and 60). Hickory and black oak were especially affected by the severe drought and represented most of the mortality observed for the dominant and codominant crown classes over all sites. Mortality for white oak, northern red oak, and other species was relatively light.

The equation for basal area ingrowth is:

$$Y_3 = \exp[-1.2793 - 0.12478B + 0.28146F] \quad (4)$$

where Y_3 is basal area ingrowth in square feet per acre per year. Stands with more basal area tend to have less ingrowth because the heavier shade of denser stands suppresses ingrowth. The addition of fertilizer stimulated basal area ingrowth, and fertilized stands had about 33 percent more ingrowth in basal area than nonfertilized stands (fig. 4). Site index apparently did not affect ingrowth in this study.

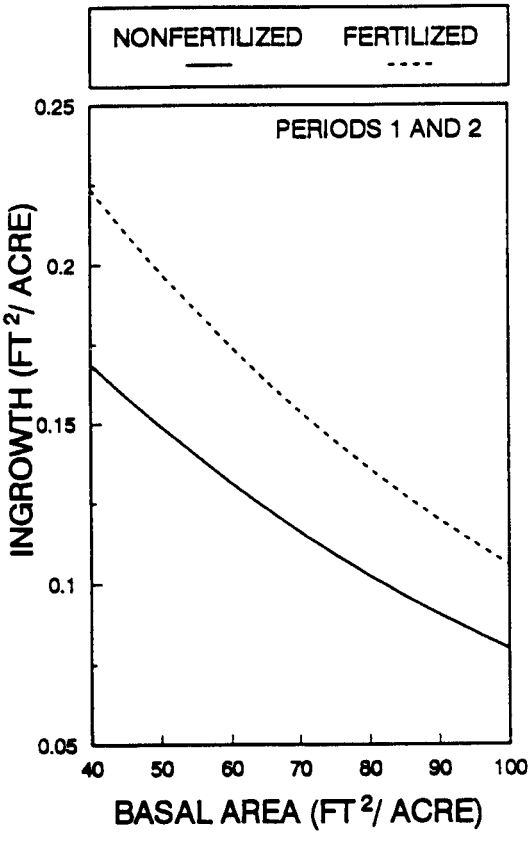

Figure 4. *Average annual basal area ingrowth for 10 years after treatment for upland oak stands in the Boston Mountains.*

All ingrowth on study plots developed from residual stems in the 1- and 2-inch d.b.h. classes, from large, advanced reproduction, and from sprouts on cut stems. Nearly all ingrowth was in noncommercial or nontree species listed in species group 5 (table 1). Some desirable species such as cherry, ash, and oaks (developed from stump sprouts) grew past the 2.6-inch d.b.h. threshold, but would probably never develop to merchantable size in intermediate-aged stands.

Survivor growth in terms of total cubic foot volume is represented by the following equation:

$$Y_4 = \exp[3.2434 + 0.14966F + 0.0025658B + 0.011453Q + 0.0010014BP] \quad (5)$$

where Y_4 is annual survivor growth in cubic feet per acre. Fertilizer application resulted in a 16 percent increase in growth. Site index and basal area also affected volume growth, and volume growth, as affected by basal area, had a somewhat different response between the two growth periods (fig. 5).

Response of stand volume growth to N fertilization is similar to the relationship observed for survivor basal area growth in each 5-year period--approximately a 20-percent increase in basal area growth, and a 16-percent increase in volume growth. Most of the observed response in survivor volume growth is probably due to the effect of fertilization on diameter growth rather than height growth. Whereas significant increases in height growth of fertilized reproduction and saplings have been reported for fast growing, intolerant species such as white ash, black cherry, and yellow poplar (Auchmoody 1982, 1986; Graney and Rogerson 1985), height growth of oaks has been less responsive to N fertilization (Graney and Rogerson 1985).

The increase in volume growth during the second 5-year growth period is consistent with the delayed response to thinning previously discussed for survivor basal area growth.

The following equation represents volume mortality:

$$Y_5 = \exp[0.028863B + 0.20564P] \quad (6)$$

where Y_5 represents annual mortality in cubic feet per acre. As with basal area, volume mortality was related to basal area and the time period. No relationship was observed with respect to fertilization. Mortality increases with an increase in basal area, and more mortality occurred in the second growth period (fig. 6).

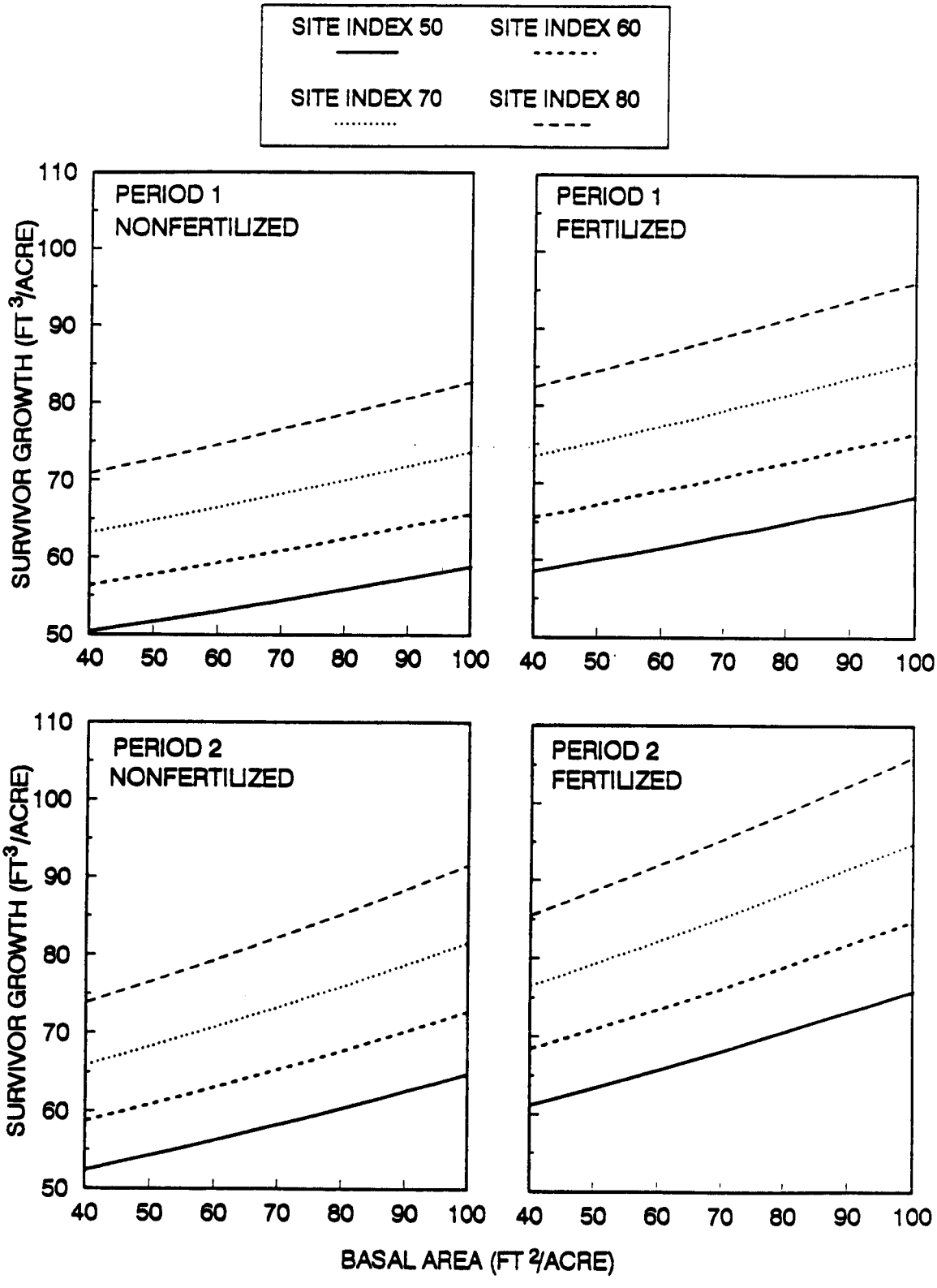

Figure 5. *Average annual volume survivor growth for 10 years after treatment for upland oak stands in the Boston Mountains.*

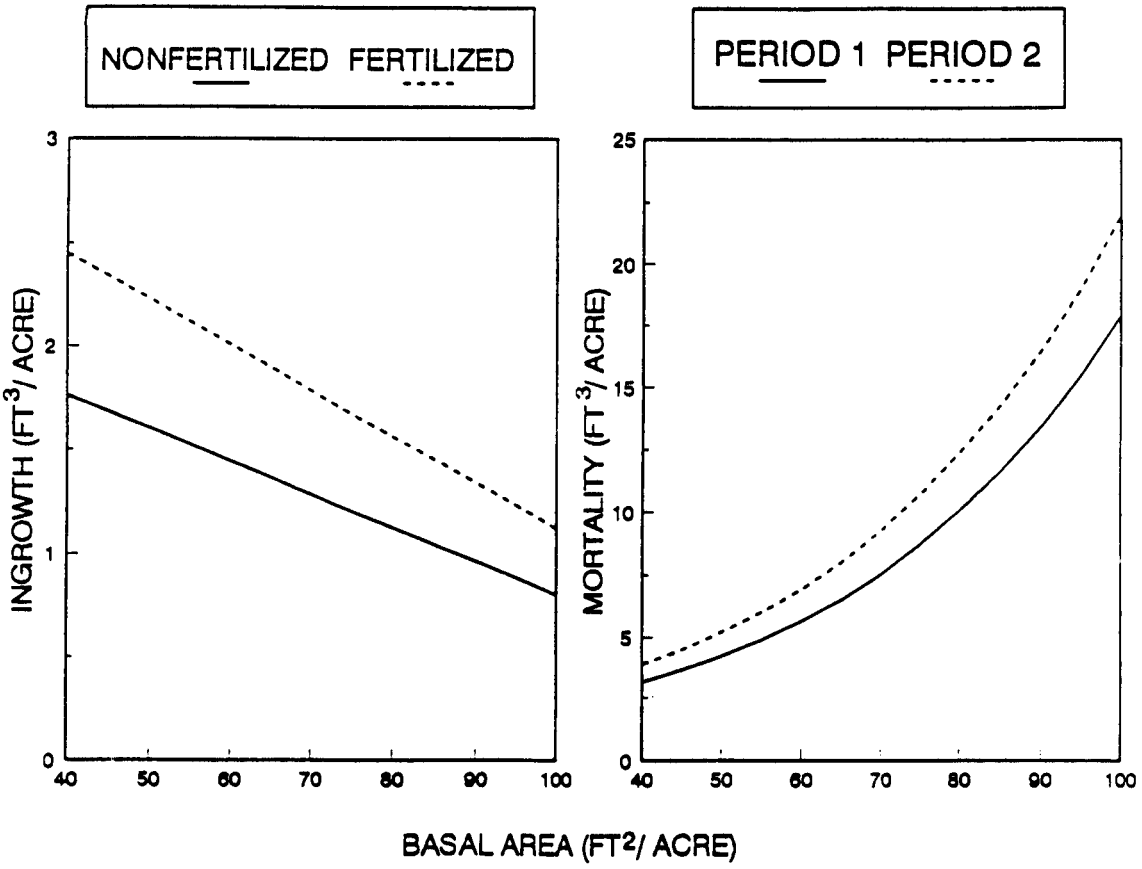

Figure 6. *Average annual volume mortality and ingrowth for 10 years after treatment for upland oak stands in the Boston Mountains.*

The increase in volume mortality in the second growth period is probably caused by the increase in stand density, but some mortality could also be attributed to a lingering effect of the severe 1980 drought. Although much of the 1980 drought mortality occurred during the first growth period, many trees that were severely stressed by the drought survived, but they grew poorly and eventually died during summer dry periods that occurred during the second growth period.

Finally, the equation for volume ingrowth is the following:

$$Y_6 = \exp[1.1035 - 0.012597B + 0.34000F] \quad (7)$$

where Y_6 is annual ingrowth in cubic feet per acre. The ingrowth pattern for volume is similar to that for basal area; it is related to both basal area and fertilization. Volume ingrowth is inversely related to basal area, and the fertilizer application increased ingrowth about 40 percent over nonfertilized plots (fig. 6). Volume ingrowth has the same set of independent variables as basal area ingrowth.

Conclusions

Regression analysis with dummy variables probably increased the sensitivity of the analysis by isolating the effects of stand age, site index, and stand density from that of fertilization. This analysis also facilitated the analysis of growth behavior by time period as the result of interactions between growth period and stand variables. Although requiring more complex interpretation, greater insight into stand behavior was achieved by using regression with dummy variables and looking at each growth component rather than using a simpler analysis technique.

Nitrogen fertilization will increase basal area and volume growth of upland oak stands in the Boston Mountains of Arkansas by about 16 to 20 percent, and the increased growth rate will persist for about 10 years on most upland sites. Fertilization can also have some benefits for wildlife by significantly increasing understory development and deer forage production in thinned upland oak stands (Snyder and

others 1982). Limited markets, plus the low value of small, hardwood roundwood, fluctuating oak sawtimber markets, and lack of premium prices for high quality, hardwood sawtimber in this area currently make stand level fertilization unprofitable. Fertilization of individual red and white oak crop trees will produce a significant growth response and has the advantage of concentrating the growth on selected higher quality and potentially higher value trees. However, labor costs for repeated hand applications to scattered individual stems is currently prohibitive.

Individual tree and stand level thinning studies in the Boston Mountains show that red and white oaks will maintain acceptable growth rates if thinnings are started at an early age and maintained throughout the rotation. In considering silvicultural investments in Boston Mountain oak stands on medium to good sites, density control in younger stands should have first priority.

Acknowledgments

Work was done in cooperation with the Department of Forest Resources and Arkansas Agricultural Experiment Station, University of Arkansas at Monticello.

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ARE OVERTOPPED WHITE OAK GOOD CANDIDATES FOR MANAGEMENT? [1]

Wayne K. Clatterbuck [2]

Abstract. Many mixed upland hardwood forests contain white oak (*Quercus alba* L.) trees that are overtopped. A key question in the management of these stands is whether overtopped white oaks have the potential to become crop trees. This paper reports 15-year results on diameter, height, and volume growth, and stem quality of released overtopped white oaks on the Cumberland Plateau in Tennessee. The 15-year performance of these released white oaks gives insight into the effects of repeated selective cutting and the development of low quality hardwoods. These data indicate that single tree selection is not a viable alternative for white oaks in upland hardwood forests.

Introduction

Overtopped white oaks in the upland hardwood forest have been a subject of controversy for many years. Do these trees have the potential to become crop trees? There is a difference of opinion among practitioners and researchers concerning the ability of overtopped white oaks to perform after release. Studies with pole-sized white oaks have indicated that released trees offer a good silvicultural opportunity and will respond with increased diameter growth rates (Minckler 1967; Schlesinger 1978; Dale and Sonderman 1984; Stringer et al. 1988). However, there is considerable uncertainty concerning diameter and height growth response and the development of high-quality butt logs with overtopped and suppressed white oaks (Roach and Gingrich 1968).

Billions of overtopped white oaks occur in the upland hardwood forests. Are these trees assets or liabilities? If overtopped white oaks respond favorably to release and become highly-valued trees, they are an asset. If not, these trees are a liability and should be controlled. McGee and Bivens (1984) initiated a study on the Cumberland Plateau in Tennessee in 1978 to determine how overtopped white oaks respond to complete overhead release and reported 4-year results. This paper extends that report with results after 15 years.

Study Area

The study was conducted on the Domain of the University of the South in Franklin County, TN, situated on the Cumberland Plateau. The study area is representative of the broadly distributed upland hardwood forests of the Plateau that have repeatedly been cut-over, burned and grazed for 100 years. No cutting occurred on the study area in the 20 years prior to 1978. Oak species comprise over 60 percent of the basal area. Site index (base age 50) for upland oaks ranged from 60 to 70 feet and stands were fully stocked. Agronomical, climatological, and geological characteristics of the area are described by Smalley (1982).

Methods

Procedures for determining whether tree age, diameter, height, and tree quality could be used to predict response to release were described in detail by McGee and Bivens (1984) and are briefly outlined below. One hundred and four overtopped white oaks which had been released and 40 unreleased trees were monitored. Sample trees were subjectively classified as low, medium, and high quality based on crown form, crown size, and straightness of stem (refer to McGee and Bivens for definitions). The 40 control trees were classified as high quality.

Initial means of age, diameter, and height of sample trees by quality class are shown in Table 1. Diameters ranged from 2 to 12 inches, although only 10 of the 144 trees had diameters greater than 10 inches. Height ranged from 20 to 70 feet. Age ranged from 20 to 120 years before release with only 2 trees greater than 100 years old.

Overtopped white oaks were released in 1978 by a commercial timber harvest that can best be described as a logger's choice harvest. Trees greater than 14 inches and many smaller trees were harvested. Any remaining overstory tree near an overtopped sample tree was cut. Based on prism counts, an

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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average of 30 square feet of basal area per acre was left.

Diameter, height, and volume of each sample tree were measured before release and 4 and 15 years after release. Epicormic branches greater than 6 inches long on the first 16-foot log were also counted as an indication of stem quality. Initial and 4-year height and volume measurements were taken from fixed relocatable ground points with a Barr and Stroud dendrometer. The 15-year measurements were taken from the same ground points with a Suunto clinometer. Tree volume (Y) in cubic feet was directly related to tree diameter (D) in inches and to a ratio of tree diameter over age (A) as shown in the following equation:

$$Y = b0 + b1\ (D) + b2\ (D/A).$$

Results

Diameter growth response of released overtopped white oaks showed little difference among the three quality classifications (Table 1). Generally, the larger trees with well-formed crowns had the greatest diameter growth. As expected, the unreleased trees had slower diameter growth rates than released trees. Diameter growth rates were steady at 2 inches per decade for released trees and 1 inch per decade for unreleased trees.

Volume growth patterns exhibited by the released and unreleased trees are similar to the previously discussed diameter growth patterns (Table 1). The larger trees produced more cubic foot volume growth than the smaller trees. While there are few examples of small trees increasing dramatically in volume, generally they performed poorly after release. Volume growth rate for high and medium quality released trees was about 5 cubic feet per decade, while the rate for low quality released trees and unreleased trees was 3 cubic feet per decade.

Most overtopped white oaks following release grew less than 6 inches in height per year (Table 1). There was tremendous height growth variability among released trees of all quality classes ranging from "negative" growth to 12 feet in 15 years. Negative growth was caused by decreases in total height due to dead tops and drooping tops. Four years after release, 20 out of the 104 released trees lost height (McGee and Bivens 1984). Most of these trees recouped those losses and had positive height growth after 15 years. The negative heights of released trees affected the mean values in Table 1. Unexpectedly, the unreleased trees had greater height growth than the released trees, partly because of the effect of negative values of some released trees after 4 years.

The number of epicormic branches increased initially following release, but then decreased between 4 and 15 years (Table 2). However, despite the decrease following the 4-year measurement, the number of branches today is greater than before release. The remaining persistent branches are larger in diameter and longer in length. The increase in epicormic branching following release further degrades log quality. The persistence of these branches over time suggests that log quality will remain poor.

Discussion

In summary, most released overtopped white oaks will increase in diameter and volume. However, height response is highly variable. Height growth is especially slow when crowns have been repressed (Oliver and Larson 1990). Trees with small, spindly crowns are susceptible to stem buckling and crown drooping. Larger and more epicormic branches can also be expected upon release of overtopped white oaks on upland sites.

Table 1. *Characteristics of white oak sample trees and their responses to release after 4 and 15 years.*

	Sample Trees	Avg. Age	Initial			4-Year growth			15-Year growth		
			Ht.	Dia.	Vol.	Ht.	Dia.	Vol.	Ht.	Dia.	Vol.
	No.	Yrs.	Ft.	In.	Cu. Ft.	Ft.	In.	Cu. Ft.	Ft.	In.	Cu. Ft.
High-quality	42	53	42	5.7	5.5	1.4	1.0	1.8	5.8	3.5	7.0
Medium quality	37	60	42	5.9	4.8	1.3	0.9	1.7	4.8	3.2	7.5
Low-quality	25	63	35	5.2	4.3	1.7	0.8	1.2	7.0	3.1	4.5
No Release, High-quality	40	50	45	6.2	6.2	2.4	0.4	1.1	7.2	2.0	4.4

Table 2. *Average number of epicormic branches greater than 6 inches in length on released white oak butt logs in relation to tree quality.*

	Initial	After 4 Years	After 15 Years
	---------- Number ----------		
High-quality	3.8	15.4	6.4
Medium quality	6.4	14.9	7.2
Low-quality	5.9	13.2	6.9
No Release, High-quality	4.8	7.2	7.0

Released trees, regardless of quality classification, exhibit a wide range of conditions, from trees that have crown dieback and drooping tops, to crooked stems, to stems with persistent epicormic branches, to high quality stems. Generally, the larger trees with well-formed crowns (high-quality) had the best response to release. However, after 15 years of release only 17 of the 104 released trees in this study have the potential to produce high-quality sawlogs.

In the upland hardwood forest, the logger's choice method of harvesting where the best trees are cut and the poor trees are left perpetuates low quality forests. Popular sentiment is that the small trees in the midstory, when released, will grow into the large trees of tomorrow. In this study, most of the small overtopped white oaks were 50 years or greater at time of release, not the younger trees that are associated with small size. The trees growing on the studied sites are not an indication of site potential. Site quality for these areas is 60 to 70 (base age 50) for upland oaks (Smalley 1982). Fifteen years following release sample trees average 45 to 50 feet tall and are 65 to 70 years old. The site potential is not being realized. These released trees are not expected to gain substantial height with age. A cycle of repeated, high-grade harvests resulted in the development and perpetuation of a low quality hardwood forest.

Fifteen year results suggest that uneven-aged methods (particularly single tree selection) do not appear feasible in promoting white oaks on these sites. Once white oaks become overtopped and crowns flattopped, the chance of them continuing height growth and becoming overstory trees is remote (Smith 1986). However, uneven-aged methods should not be completely dismissed in these areas. Uneven-aged management can be used, but it requires an intensive "hands-on" approach to make sure apical dominance of future crop trees is not lost.

Are overtopped white oaks good candidates for management? Data after 15 years on repeatedly cutover hardwood forests on the Cumberland Plateau indicate that overtopped white oaks are not good candidates for future crop trees. Although there are a few individual examples of high-quality released oaks present after 15 years, the performance of the majority of released trees is variable and difficult to predict.

Acknowledgements

Appreciation is expressed to Dr. C. E. McGee and especially Mr. Donald Bivens for initiating the study, allowing access to previous data, and locating the original study plots. The author is also grateful to Dr. Bill Davis for use of the Domain at the University of the South, Sewanee, TN.

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

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

Abstract. A 21-acre, 28-year-old water oak (*Quercus nigra* L.) plantation, located on an old-field loessial site near Winnsboro, Louisiana, was subjected to three thinning treatments during the winter of 1987-88: (1) no thinning, (2) light thinning (to 180 dominant and codominant trees/acre), and (3) heavy thinning (to 90 dominant and codominant trees/acre). Just prior to thinning, the plantation averaged 356 trees and 86 square feet of basal area per acre, with an average dbh of 6.6 inches. Thinning reduced stand basal areas to 52 and 34 square feet per acre for the light and heavy thinning treatments, respectively. Light thinning increased individual-tree diameter growth rate after four years, but not on the larger trees. Trees in heavily thinned stands exhibited substantially higher diameter growth rates than trees in lightly thinned or in unthinned stands.

Introduction

Very little information is available on growth and yield of southern oak plantations greater than 20 years of age. Much of the past research has emphasized establishment techniques for oak plantations and their subsequent growth during the early stages of stand development. However, very little research has been conducted on oak plantations in an intermediate stage of development. Consequently, little is known about growth and yield, about stand development, or about the response of these older plantations to intermediate silvicultural treatments, such as thinning.

With the advent of the Conservation Reserve Program (CRP) in 1985, and, more recently, the Wetland Reserve Program (WRP), many thousands of acres of marginal cropland have been reforested, principally to hard-mast-producing species such as oaks. There has been a great demand for information on the proper techniques to establish oak plantations on agricultural land. Much of the knowledge on planting and direct-seeding oaks and other species has been summarized by Allen and Kennedy (1989) and by Kennedy (1990).

As these new oak plantations, established under the CRP and the WRP, develop and mature, there will be an increasing demand for information on how to manage them. Landowners and other managers will need guidelines on thinning and other intermediate silvicultural operations. Unfortunately, tree and stand responses to thinning in oak plantations are unknown, and no guidelines currently exist for managing these older oak plantations.

For these reasons, a thinning study was established in 1987-88 in 28-year-old water oak plantations located on two fields in northern Louisiana. The primary objective of the study is to determine the diameter and height growth responses of water oak to three intensities of thinning. Stand parameters of the plantation one year prior to treatment were previously described by Krinard and Johnson (1988).

Methods

Study Area

The plantations were established in February 1960 on old agricultural fields of loessial soil on the Macon Ridge landform near Winnsboro, Louisiana. These fields had been under continuous cultivation for several decades prior to establishment of the plantations. The surrounding fields remain in cultivation, primarily for cotton and soybeans. The two plantations consist of a 14.5-acre tract on a larger field and a 6.5-acre tract on a smaller field, for a total of 21 acres. Both plantations are privately owned.

Both fields were planted in February 1960 at the rate of approximately 950 water oak seedlings per acre. Initial spacing was somewhat variable, but appears to have been approximately 9-10 feet between

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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rows and 5-6 feet within rows. No cultivation or weed control was performed after plantation establishment.

Soils at both plantations were described as a mixture of Calhoun, Calloway, and Loring series (Krinard and Johnson 1988), all of which developed from wind-blown silt, or loess. Calloway and Loring soils both contain fragipans at a depth of about 20-30 inches. Soil texture in the upper horizon of both fields was either silt loam or silty clay loam. Soil pH was very strongly acid, 4.5 to 5.0 (Krinard and Johnson 1988).

Broadfoot (1976) reported an average site index of 83 feet at 50 years for water oak on Calloway soils, but did not provide similar information for Calhoun or Loring soils. Using the method described by Baker and Broadfoot (1979), we estimated site index for water oak to average 86 feet at 50 years across the entire study area.

Treatments

In the fall of 1986, at age 27 years, the plantations were divided into 12 treatment plots, each of which was 150 feet wide by 45 rows long, covering an area of approximately 1.4 to 1.5 acres each. Three 0.1-acre square measurement plots were then systematically established within each of the 12 treatment plots, for a total of 36 measurement plots across both plantations. Diameter-breast-height was measured on all trees on each of the 0.1-acre measurement plots; total height was measured on a subsample of 8-10 trees on each of the measurement plots. Thinning treatments were originally planned to have been applied during the winter of 1986-87, but wet soil conditions prevented any harvesting activities. No re-measurements of dbh and height were made prior to thinning. Consequently, pre-treatment measurements were actually made one year prior to treatment.

In the winter of 1987-88, at age 28 years, four replications of three thinning treatments were applied in a randomized block design to the 12 treatment plots. The treatments used in this study were:

1. CONTROL -- no thinning.
2. LIGHT -- thin to 180 dominant and codominant trees per acre.
3. HEAVY -- thin to 90 dominant and codominant trees per acre.

Both thinning treatments consisted of low thinning to remove lower-crown-class trees. Logs were removed from the stand and were utilized as fuelwood. Post-harvest measurements were performed immediately after thinning treatments were completed.

Results and Discussion

Residual Stand Density and Structure

Stand conditions of the water oak plantation at age 27 years, one year prior to application of the thinning treatments, were previously reported by Krinard and Johnson (1988), and are summarized in table 1. Prior to thinning, the plantation averaged 356 trees and 86 square feet of basal area per acre, with an average total height of 56 feet and an average dbh of 6.6 inches. As previously stated, these are the only pre-treatment data available. No statistical differences were found among the three treatments in any of the stand parameters one year prior to thinning.

Table 1. *Stand conditions one year prior to thinning in a 27-year-old water oak plantation. Means followed by the same letter are not significantly different at the 0.05 level of probability.*

Treatment	Trees per Acre	Basal Area	Total Height	Dbh
		sq ft/ac	ft	in
Unthinned	336 a	90 a	59 a	7.0 a
Light Thin	392 a	85 a	56 a	6.2 a
Heavy Thin	340 a	83 a	54 a	6.5 a
Mean	356	86	56	6.6

Light thinning reduced stand density to 187 trees per acre with 52 square feet of basal area per acre (table 2). Heavy thinning reduced stand density to 103 trees per acre with 34 square feet of basal area per acre. These residual densities were slightly greater than the target densities of 180 and 90 dominant and codominant trees per acre for the light and heavy thinning treatments, respectively. Expressed as percentages, light thinning removed about 50 percent of the trees and 40 percent of the basal area from the stand. Heavy thinning removed about 70 percent of the trees and 60 percent of the basal area. Because thinning was "from below" and the smaller, less-vigorous, lower-crown-class trees were removed, both thinning treatments were effective in increasing average stand diameter in the residual stand (table 2). Average stand diameter on the lightly thinned plots increased from 6.2 inches one year prior to thinning to 7.0 inches immediately after thinning. Heavy thinning increased average stand diameter from 6.5 inches one year prior to thinning to 7.6 inches just after thinning. These average stand diameters in the

thinned plots were not significantly different from that in the unthinned plots.

Table 2. *Stand conditions, by treatment, immediately following thinning in a 28-year-old water oak plantation. Means followed by the same letter are not significantly different at the 0.05 level of probability.*

Treatment	Trees per Acre	Basal Area	Dbh
		sq ft/ac	in
Unthinned	319 a	92 a	7.2 a
Light Thin	187 b	52 b	7.0 a
Heavy Thin	103 c	34 c	7.6 a

Stand Development Following Thinning

Stand development in the thinned and unthinned plots during the four-year period after treatment is presented in table 3. The most striking development has been the steady decrease in the number of trees per acre in the unthinned plots, dropping from 319 per acre at the time of study installation to 270 per acre in four years. This decline represents a mortality rate of 15 percent over the four-year period. In contrast, mortality in the thinned plots has been considerably less, about 5 percent and 3 percent four years after light and heavy thinning, respectively. In fact, mortality in the thinned plots appears to have stabilized at a negligible rate over the past two years. Mortality in the unthinned plots has occurred primarily in the smaller, less-vigorous, lower-crown-class trees. Thinning essentially removed these same types of trees in one operation rather than allowing nature to remove them gradually over a long period of time. Thus, removal of anticipated mortality in a thinning provides the residual trees with the maximum benefit from this partial release from competition.

Table 3. *Changes in the number of trees per acre, by treatment, over a four-year period following thinning in a 28-year-old water oak plantation. Means followed by the same letter are not significantly different at the 0.05 level of probability.*

Treatment	Post-Harvest	One Year	Two Year	Three Year	Four Year
Unthinned	319 a	293 a	282 a	271 a	270 a
Light Thin	187 b	180 b	179 b	179 b	178 b
Heavy Thin	103 c	102 c	100 c	100 c	100 c

Both light and heavy thinning drastically reduced stand basal area, to 52 and 34 square feet per acre, respectively. During the four-year period following thinning, basal area has increased steadily to 67 and 46 square feet per acre in the lightly and heavily thinned stands, respectively (table 4). Stand basal area growth has thus averaged nearly 4 square feet per acre per year after light thinning and 3 square feet per acre per year after heavy thinning. Similarly, the unthinned stand has averaged 3 square feet of basal area growth per acre per year, increasing from 92 to 104 square feet per acre in four years.

Table 4. *Changes in stand basal area (in square feet per acre), by treatment, over a four-year period following thinning in a 28-year-old water oak plantation. Means followed by the same letter are not significantly different at the 0.05 level of probability.*

Treatment	Post-Harvest	One Year	Two Year	Three Year	Four Year
Unthinned	92 a	93 a	95 a	100 a	104 a
Light Thin	52 b	54 b	57 b	63 b	67 b
Heavy Thin	34 c	36 c	38 c	43 c	46 c

Although stand-level basal area growth rate has not been significantly affected by either thinning treatment, basal area increment of individual residual trees in the thinned stands has greatly increased during the four years following thinning. In fact, cumulative basal area increment of individual residual trees in the lightly thinned plots was more than double that of individual surviving trees in the unthinned stand. The effect of heavy thinning was even more dramatic, with cumulative basal area increment averaging more than three times as much as in the unthinned stand. Even though thinning resulted in such large increases in individual-tree basal area increment, these increases were spread across such fewer trees that stand-level basal area growth rates were not significantly increased by either thinning treatment.

Changes in average stand diameter during the four-year period following thinning are presented in table 5. We were unable to detect any statistical differences among the treatments in average stand diameter throughout the study period, even though average diameter of the heavily thinned stand appeared to be increasing at a more rapid pace than in either the lightly thinned or unthinned stands. Average stand diameter increased 1.2 inches during the four-year period in both the lightly thinned and the unthinned stands, but increased 1.5 inches during the same period in the heavily thinned stand. Even though not statistically significant, it is important to point out that the gap in average stand diameter between the heavily thinned stand and the unthinned stand has continued to widen over time. As illustrated in table 5, this gap was 0.4 inches after two years, 0.5

inches after three years, and 0.7 inches after four years. If this trend continues, we fully expect, at some point in the future, to see statistically significant differences between these two treatments in average stand diameter.

Table 5. *Changes in average stand diameter (in inches), by treatment, over a four-year period following thinning in a 28-year-old water oak plantation. Means followed by the same letter are not significantly different at the 0.05 level of probability.*

Treatment	Post-Harvest	One Year	Two Year	Three Year	Four Year
Unthinned	7.2 a	7.6 a	7.9 a	8.2 a	8.4 a
Light Thin	7.0 a	7.3 a	7.5 a	7.9 a	8.2 a
Heavy Thin	7.6 a	7.9 a	8.3 a	8.7 a	9.1 a

We believe that the lack of statistical significance among treatments in average stand diameter after four years is somewhat misleading. Average diameter of the unthinned stand increased from 7.2 inches to 8.4 inches in four years (table 5). However, we believe that this increase was only partially due to the diameter growth of the trees in that stand. Rather, the bulk of this increase was due to the death of numerous small trees over the four-year period, artificially inflating the average diameter of the surviving trees. Even with this confounding effect, we believe that significant differences will be detected in the near future.

Therefore, cumulative diameter growth of individual surviving trees provides a more accurate assessment of the effects of the thinning treatments (table 6). Neither thinning treatment had an effect on individual-tree diameter growth during the first year after treatment, with growth averaging about 0.20 inches. However, a response to thinning was detected during the second year, when cumulative diameter growth of residual trees in thinned plots was significantly greater than in unthinned plots. This trend continued through the third and fourth years, in which significant differences were found among all three treatments.

By the end of the fourth year after treatment, surviving trees in the unthinned stand had grown an average of 0.76 inches (table 6), or about 1.9 inches per decade. Such poor growth is indicative of a low-vigor stand, in which heavy mortality can be expected in the near future. On the other hand, residual trees in the lightly thinned stand grew an average of 1.12 inches in four years, or about 2.8 inches per decade, an acceptable growth rate for water oak on good sites. Residual trees in the heavily thinned stand grew an average of 1.36 inches in four years, or about 3.4 inches per decade, a growth rate classified as "good" for water oak by Putnam and others (1960). We believe that the residual water oak trees in the thinned stands have not yet expressed their full response to the thinning treatments, and that these diameter growth rates will continue to increase over the next few years.

Table 6. *Cumulative diameter growth (in inches) of residual trees, by treatment, over a four-year period following thinning in a 28-year-old water oak plantation. Means followed by the same letter are not significantly different at the 0.05 level of probability.*

Treatment	One Year	Two Year	Three Year	Four Year
Unthinned	0.19 a	0.32 b	0.58 c	0.76 c
Light Thin	0.21 a	0.45 a	0.83 b	1.12 b
Heavy Thin	0.20 a	0.55 a	1.01 a	1.36 a

Modeling of Individual-Tree Diameter Growth

Four-year diameter growth of individual trees was modeled as a quadratic function of initial diameter. Initial plot basal area and dummy variables for treatments and crown class were also used as predictor variables, and in interaction terms with diameter and diameter squared. The equation was weighted by initial diameter. After eliminating non-significant variables, the following terms were included in the final model:

- D_0 -- initial diameter
- D_0^2 -- initial diameter squared
- BA_0 -- initial plot basal area
- CC_1 -- dummy variable for trees in the dominant crown class
- T_1 -- dummy variable for trees subjected to heavy thinning
- BA_0*D_0 -- interaction term between initial basal area and initial diameter
- $BA_0*D_0^2$ -- interaction term between initial basal area and initial diameter squared
- CC_1*D_0 -- interaction term between dummy variable for trees in the dominant crown class and initial diameter
- $CC_1*D_0^2$ -- interaction term between dummy variable for trees in the dominant crown class and initial diameter squared
- T_1*D_0 -- interaction term between dummy variable for trees subjected to heavy thinning and initial diameter

CC_2*D_0 -- *interaction term between dummy variable for trees in the codominant crown class and initial diameter*

The fit index of the final model was calculated to be 0.42, while root mean squared error was 0.379.

After correcting for crown class and plot basal area, there was still a significant effect of the most severe thinning treatment. Thinning reduces stand density and also discriminates against lower vigor trees. The significance of the treatment may indicate that one can select higher vigor trees successfully.

The diameter growth curves for codominant trees for all three treatments and for dominant trees for the two thinned treatments are presented in figure 1. We used average basal area for each treatment. The following caveats may be applied to these curves. There were very few dominant trees less than 7 inches and there were very few trees greater than 10 inches in diameter. Although the curves do not exactly represent extrapolations over those ranges of diameter, the curve shape is based on very little data over those ranges.

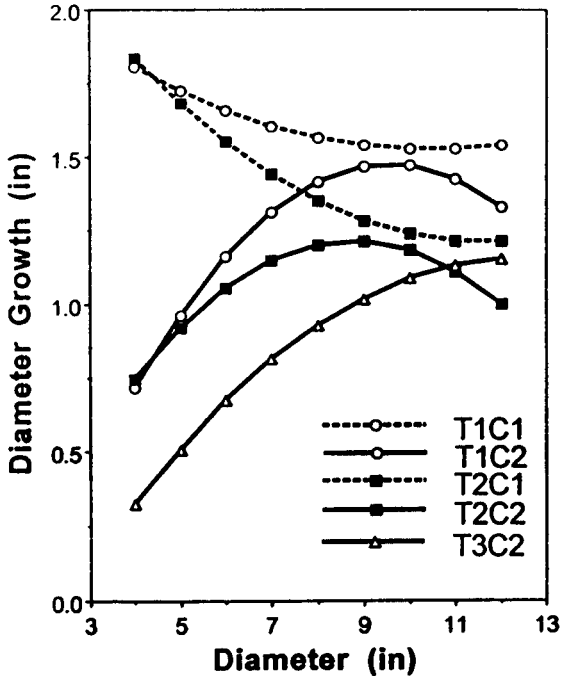

Figure 1. *Cumulative diameter growth curves, expressed as a function of initial diameter, for codominant trees in both thinned and unthinned plots and for dominant trees in thinned plots. Explanation of abbreviations: T1C1 – dominant trees in the heavily thinned plots T1C2 – codominant trees in the heavily thinned plots T2C1 – dominant trees in the lightly thinned plots T2C2 – codominant trees in the lightly thinned plots T3C2 – codominant trees in the unthinned plots*

The dominant trees grow faster than the codominant trees and the greater the intensity of thinning, the faster the trees grow. There was little difference between diameter growth of large trees on lightly thinned plots compared to large trees on unthinned plots.

Conclusions

Trees in the unthinned stand are not growing in diameter at an acceptable rate. These trees are not very vigorous and, if left unmanaged, will continue to decline in growth, vigor, and quality. Mortality is expected to be high in the next few years.

Light thinning has increased individual-tree diameter growth rate, but not on the larger trees. Even though residual trees are averaging about 2.8 inches in diameter growth per decade, the stand will probably need to be thinned again before the end of a sawtimber rotation.

Heavy thinning has substantially increased individual-tree diameter growth rate, to 3.4 inches per decade, nearly double the diameter growth rate of trees in the unthinned stand. Heavy thinning was even successful in increasing the diameter growth rate of the larger dominant trees in the stand.

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FIRE IN OAK ECOSYSTEMS [1]

Janet M. Watt, David H. Van Lear, and James G. Williams [2]

Abstract. Regeneration of oak stands on good sites is a silvicultural challenge in the Southeast. Suppression and reduction of burning in mature hardwood stands during this century has minimized an important environmental factor which once played a major role in regenerating oaks. Fire enhances oak regeneration by creating favorable seedbeds, encouraging the burial of acorns in burned areas by squirrels and bluejays, reducing populations of insect pests, and reducing competition from less fire resistant species in the understory and midstory. Adaptations of oaks, such as thick bark, resistance to rot, ability to persistently resprout following top-kill, and the ability to become established and survive on dry sites, indicate fire has played an important role in oak regeneration. Knowledge of the functions of fire in oak ecosystems is necessary to develop silvicultural prescriptions which mimic the natural disturbance regimes that favor maintenance of oak on better sites.

Introduction

Regenerating oaks (*Quercus* spp.) on better quality sites throughout the Southeast is a difficult task. High quality sites once dominated by oaks have converted to faster-growing, less fire resistant species. Advance oak reproduction is now unable to compete on better sites, and thrives only on drier, lower-quality sites where more tolerant species cannot survive (Sander 1988).

Disturbance regimes, including fire, are thought to have aided the establishment of many oak stands at the turn of the century (Crow 1988, Van Lear 1991, Van Lear and Watt 1993). However, research utilizing a regime of frequent fire to determine its effects on oak regeneration and ecosystem responses is limited. As foresters and ecologists recognize the need to mimic the natural disturbance regime to maintain biodiversity and other ecological values (Sharitz et al. 1992), the need for such research grows. The objectives of this paper are to 1) describe the current oak regeneration problem, and 2) discuss adaptations of oak to fire and the functions of fire in oak regeneration. We attempt to develop the hypothesis that fire suppression efforts in this century have created an environment that is unfavorable to maintenance of oak, especially on moderate to high quality sites.

The Oak Regeneration Problem

The problem in oak regeneration is one of achieving a satisfactory component of oak in stands established on moderate to high quality sites. When stands on these types of sites are harvested, new stands usually regenerate to shade- and fire-intolerant species--often much to the chagrin of the forester.

Today's mature oak stands, which were established near the turn of the century, resulted in large part from the burning practices of the era. Fires, both natural and man-caused, maintained the oaks then as they had for centuries. In addition, burning increased forage for grazing animals, which probably further encouraged oak domination over more palatable hardwood competitors.

Currently, adequate advanced oak regeneration in the Southeast is found more often on average to poor sites than on good sites (Sander 1988). Crow (1988) and Van Lear (1991) cited the lower frequency of fire in recent decades as a major factor in the failure of oak to regenerate on better sites. Fire exclusion has allowed faster-growing, more tolerant species to become established in the advanced regeneration pool on better sites (Abrams 1992). When the overstory is removed, oak regeneration is quickly overtopped by these species.

Competition from other hardwood species is only one of the suspected causes of decline in

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establishment of oak stands since the turn of the century. The predation of seedlings and acorns by wildlife and insects has also contributed to oak regeneration failures. Almost 200 different wildlife species utilize oak seedlings, sprouts, and/or acorns as a food source, including deer, some species of birds, and many rodents (Huntley and McGee 1981). Both Sork (1984) and Sander (1988) estimated that only 1% of acorn crops are available for regeneration following predation each year.

Germinating acorns, as well as young seedlings, can be adversely affected by insect pests. Several species of weevils, moths, wasps, and flies can destroy up to 50 percent of an acorn crop (Galford et al. 1988). Infestations, which can vary from year to year, and even from tree to tree in some areas, are a major contributor to the oak regeneration problem (Marquis et al. 1976). Since many of these insects spend all or part of their lives on the forest floor, populations could be reduced by prescribed burning which coincides with these portions of insect life cycles (Wright 1987).

Thus, the literature suggests that the oak regeneration problem has been exacerbated by cessation of burning, which has increased competition with oak regeneration, increased predation of acorns and oak seedlings, and reduced germination. When one considers the adaptations of oak to fire and the functions of fire in oak ecosystems, it is difficult to dismiss fire as an essential factor in the oak regeneration process.

Adaptations of Oaks to Fire

Oaks are well adapted to fire. They have thick bark and are resistant to rot. Bark thickness has been noted as one of the best attributes for characterizing a species' adaptation to fire (Martin 1989). Oak rootstocks also have a tenacious ability to resprout, and exhibit a tendency to become established and survive on dry sites, which typically have a frequent fire return interval.

The resprouting ability of oak regeneration is significant, especially when considered in terms of competition with other species. Oak advanced regeneration occurs as true seedlings or sprouts; the latter have root systems older than the stems and are often referred to as seedling-sprouts (Sander et al. 1976). Initial height growth in oak seedlings is slow, since most of the early growth is allocated to the root system (Kelty 1988). A large, well-developed, established root system provides for rapid shoot growth upon release, as well as enhanced ability to continually resprout. Repeated burning, followed by top-kill and resprouting, increases the root/shoot ratio of oak rootstocks, making them better able to compete following subsequent overstory disturbances.

Functions of Fire in Oak Ecosystems

Fire functions within oak ecosystems to increase the quantity and quality of advanced oak regeneration. Acorn germination may be enhanced by prescribed burning. The removal of deep litter layers by fire places acorns closer to mineral soil, providing favorable conditions for acorn germination. Also, removal of thick litter by fire encourages the caching of acorns by squirrels and bluejays in burned areas (Galford et al. 1988).

Squirrels and bluejays are acorn predators, but also act as dispersers and protectors through scatterhoarding, i.e., burial of the nuts in widely scattered locations. Many of the cached acorns are retrieved throughout the winter and early spring by squirrels and bluejays. However, since these species usually hoard sound nuts (Healy 1988), those acorns which are not retrieved have a greater chance of successful germination than those which remain lying on the forest floor. Not only does caching of acorns increase the probability of germination, it also protects acorns from predation by other animals (Barnett 1977).

Fire reduces populations of insect predators which attack acorns and young seedlings. Following a moderate to severe spring burn, Galford et al. (1988) found that populations of the acorn weevil (*Conotrachelus posticatus*) and the sap beetle (*Stelidota octomaculata*), which are primary pests of sprouting acorns, were reduced and remained low for several months. Fire reduced populations through direct kill and elimination of leaf litter habitat.

In a similar mark and release study, Wright (1987) observed that acorn weevils survived unharmed following a low severity burn. A prescribed burn conducted for the purpose of insect pest control must be of moderate to high severity to sufficiently destroy leaf litter used by insects for cover. A greater reduction in pest populations may also be obtained from a fall burn, which would coincide with the reproductive period of most insect pests.

Open stands, with increased light levels on the forest floor, would result from a regime of frequent fire in both pine and hardwood stands. A single prescribed burn has little effect on the understory

composition of a hardwood stand, other than a reduction in stem size of advanced regeneration (Van Lear and Waldrop 1989). Since most oak species have a low or intermediate tolerance to shade, they grow poorly in a closed understory (Abrams 1992). Repetitive fires, which result eventually in the elimination of less fire-resistant midstory and understory stems, create conditions suitable for the establishment of advanced oak regeneration. Crow (1988) noted the importance of increased light levels, which would occur through reduction of competition by fire, as an important factor in the development of greater root/shoot ratios in oaks.

Frequent fire would xerify the surface of the soil by consuming much of the forest floor and exposing the soil to greater solar radiation (Van Lear and Watt 1993). In addition, frequent burning would encourage development of a herbaceous understory, further xerifying the soil surface through increased evapotranspiration, thereby favoring oak advanced regeneration over more mesic species. A grass component in the herbaceous understory would enhance the flammability of understory fuels. The creation of more xeric conditions on mesic sites through burning would improve the capability of oaks to become established, as well as reduce the establishment rates of fast growing, fire-intolerant species which have been dominating the advanced regeneration pool on the better sites for decades.

In a long-term study of burning in pine stands, frequent fire functions to selectively favor oak advance regeneration over its competitors. Waldrop et al. (1987) noted that repetitive burning caused lower rates of mortality in oaks than in competing woody species. Oak advanced regeneration is less adversely affected by repeated fire than its competitors.

Germination of acorns after the removal of an oak overstory should not be relied upon for regenerating a stand to oak, since most new seedlings do not survive to maturity (Ross et al. 1986). The importance of establishing oak regeneration of sufficient size prior to the removal of the overstory was first stressed by Sander (1972). Acceptable growth and stocking of oak will result if there are at least 435 stems per acre > 4.5 feet tall at the time of release. Prescribed fire at frequent intervals during the last 10-20 years of the rotation theoretically would reduce competition from the regeneration of other species and improve light conditions by reducing midstory stems, thus providing adequate growing conditions for advanced oak regeneration to reach sufficient size to respond to release.

Although research utilizing a regime of frequent fire to promote oak advanced regeneration has not been completed, extended periods of frequent fire in mature stands have been suggested as a method for increasing the quality and quantity of oaks in the regeneration pool prior to harvest (Sander 1988, Van Lear 1991, Van Lear and Watt 1993). Effective hardwood competition control may require as many as three or more burns at 2- to 3-year intervals.

Summary and Conclusions

History indicates that frequent burning played a major role in favoring oak in southern ecosystems, on good sites as well as poor sites. The adaptations oaks have developed to frequent fire regimes, as well as the many functions played by fire in oak ecosystems, strongly suggest that oaks have been dependent on fire for their establishment, survival, and ability to dominate eastern forests. Research is needed to develop recommendations for the use of fire that mimics the disturbance regime which created today's mature oak stands, so that foresters may use fire as one tool to regenerate future forests dominated by oak.

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SEASON OF BURN AND HARDWOOD DEVELOPMENT IN YOUNG LONGLEAF PINE STANDS [1]

William D. Boyer [2]

Abstract. Four treatments--biennial burns in winter, spring, and summer, and a no-burn control--were applied in plots in naturally established stands of longleaf pine (*Pinus palustris* Mill.). Treatments commenced in 1974, when the pines were 15 years old, and the most recent observations were made in 1992. Midstory hardwood density increased in the absence of burning and with winter burning but decreased with spring and summer burning. The proportion of hardwood basal area to total stand basal area has remained relatively constant in both unburned and winter-burned stands. Hardwood regeneration was unaffected by burning.

Introduction

Control of understory hardwoods within young pine stands is expected to provide a number of benefits, including increased growth of overstory pine, reduced fuel loads, easier access, reduced cost of future site or seedbed preparation, and increased cover of grasses and other herbaceous vegetation.

A study to determine the long-term effects of several hardwood control treatments on understory succession and overstory growth was initiated in 1973. Combinations of fire, mechanical, and chemical treatments were applied. A major objective was to observe changes in the composition and structure of midstory and understory vegetation under the different treatment regimes.

Effects of treatments on growth of longleaf pine (*Pinus palustris* Mill.) over the first 10 years have been reported (Boyer 1987). The effect of the single chemical treatment on the regeneration and development of woody vegetation has been reported also (Boyer 1991). Responses of hardwood tree species to 18 years of biennial dormant-season and growing-season prescribed burns and to complete fire exclusion are described here.

Methods

The study was established on a sandy upland Coastal Plain site on the Escambia Experimental Forest[3] in southwest Alabama in 1973. At that time, study areas supported natural stands of longleaf pine. These stands were 14 years old from seed and 12 years from time of release from a seedtree overstory. Pine stocking averaged about 700 trees per acre. The last prestudy fire on all study areas was a prescribed burn in January 1962.

Three blocks were established, each in a different 40-acre compartment. Each block consisted of 12 0.4-acre square plots. Each plot was thinned to about 500 well-distributed dominant and codominant pines per acre. The residual pines in 0.1-acre subplots were marked and numbered, and their total height and d.b.h. were recorded. These pines averaged 22 ft. in height and 3.2 inches in d.b.h. and average basal area (BA) was 30 ft^2/acre. Average age-50 site indexes for longleaf pine on the study blocks, based on heights of dominant and codominant trees at age 33, ranged from 77 to 81 feet (Farrar 1981).

All woody stems were counted on nine systematically located 3.1-ft-square sub-subplots in each 0.1-acre subplot. A 10-factor wedge prism was used to estimate hardwood BA in each subplot. Hardwood BA averaged 3.6 ft^2/acre. There were approximately 5,300 small hardwood stems per acre with d.b.h. < 1.5 inches. Eighty-six percent of these were oaks (*Quercus* spp.), 11 percent, flowering dogwood (*Cornus florida* L.), and the remainder, common persimmon (*Diospyros virginiana* L.) and sassafras [*Sassafras albidum* (Nutt.) Nees]. Woody vegetation other than tree species averaged 102,000 stems/acre. Gallberry, [*Ilex glabra* (L.) Gray blueberries and huckleberries (*Vaccinium* spp. and *Gaylussacia* spp.), and blackberries (*Rubus* spp.) made up 91 percent of this total. Vines rooted in sample plots, averaged 14,400/acre. Seventy-two percent of these were honeysuckles (*Lonicera* spp.), and the balance greenbriars, (*Smilax* spp.).

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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[3] Maintained by Southern Forest Experiment Station, USDA Forest Service, in cooperation with the T. R. Miller Mill Company.

Twelve treatment combinations were randomly assigned to the 12 plots in each block. Each of four fire treatments--prescribed fire at 2-year intervals in winter (January or February), spring (April or May), and summer (July or August), plus an unburned check--was combined with three supplemental treatments. These were: (1) injection all woody stems down to about 1-inch groundline diameter with undiluted 2,4-D amine at time of study establishment in the spring of 1973, (2) handclearing, by cutting just above groundline, of all woody stems more than 4.5 feet in height at establishment and as needed thereafter, and (3) untreated check. All plots selected for fire treatments were initially burned in January 1974. Assigned season of burn treatments were begun after that time. Spring burns were always in odd-numbered years. Since 1979, winter burns have always been in even-numbered years, and summer burns, in odd-numbered years.

Plots were first reexamined in the winter of 1980, after 7 growing seasons. At that time, all subplot hardwoods in the 2-inch d.b.h. class and larger (>1.5 inches d.b.h.) were inventoried by species, and their d.b.h.'s were recorded. Smaller woody vegetation was again sampled on nine new systematically distributed 3.1-ft-square sub-subplot within each subplot in the fall of 1980. All subplot and sub-subplots measurements were repeated in the fall and winter of 1982-83, 1985-86, 1988-89, and 1991-92. In the last three periods, all hardwoods in the 1-inch d.b.h. class were measured as part of the subplot inventory and were dropped from the sub-subplot count, which then included only woody stems 0.5 inches in d.b.h. or smaller.

Because supplemental hardwood control treatments had significant effects on hardwoods in the 1-inch and larger d.b.h. classes, data for hardwoods in those size classes in the plots that received such treatments are not reported here. Supplemental treatments had little impact on hardwood regeneration on the forest floor, so this report deals with regeneration in all study plots.

By 1989, BA of the pine overstory on all individual plots ranged from 67 to 118 ft^2/acre and averaged 97 ft^2/acre. To promote optimum development of dominant residual pines and reduce natural mortality from competition, pine stands were commercially thinned in 1990 to a density of 70 ft^2/acre. The three plots in which pine density was less than 75 ft^2/acre were not thinned.

Results

Hardwood Midstory

The density of midstory hardwoods >1.5inches in d.b.h. increased on unburned and winter-burned plots and generally declined on spring- and summer-burned plots (fig. 1). From 1973 to 1992, hardwood BA increased from 2.9 ft^2 to 14.6 ft^2/acre on unburned plots. It increased from 3.7 ft^2 to 9.8 ft^2/acre on winter-burned plots during the same period. Hardwood BA declined from 4.1 ft^2/acre on spring-burned plots to 1.3 ft^2, and from 2.2 ft^2 to 2.1 ft^2/acre on summer-burned plots from 1973 to 1992.

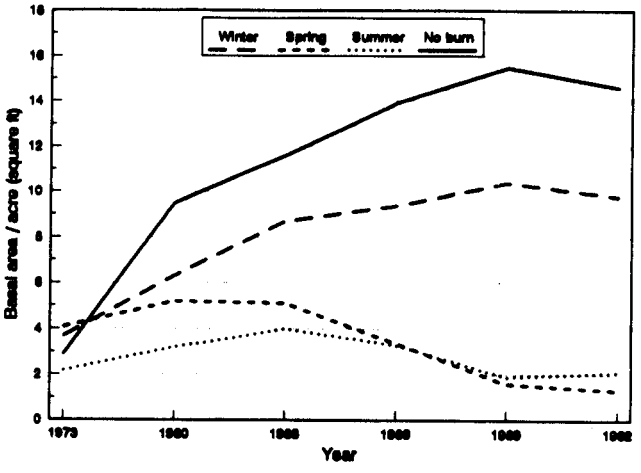

Figure 1. *Changes in midstory hardwood density with burning treatments.*

The number of midstory hardwood stems per acre increased from 1980 to 1989 on unburned and winter-burned plots and declined with growing season burns (table 1). Spring burns appear to be more effective than summer burns in reducing the number of midstory hardwood stems. Only one tree, an 8-inch d.b.h. oak, remains alive on the spring-burned plots.

The thinning operation in 1990 resulted in the loss of some hardwoods, especially where hardwood densities were relatively high on unburned and winter-burned plots. Only midstory hardwoods in the smallest (2-inch) d.b.h. class were lost.

The densities of midstory hardwoods on both unburned and winter-burned plots, while consistently increasing over time, have stabilized as percentages of total stand BA (fig. 2). Midstory hardwoods on unburned plots constituted 12 to 13 percent of total stand BA from 1980 to 1989, whereas those on winter-burned plots have constituted between 9 and 11 percent of total stand BA since 1973. Growing-season

burns reduced the relative density of hardwoods from 12 to 14 percent of total stand BA in 1973 to 1 to 3 percent by 1989. Thinning removed more pine BA from unburned plots (38 ft^2/acre) than from all burned plots (24 ft^2/acre). This resulted in the greater increase in relative hardwood BA on unburned plots even though absolute hardwood BA on unburned plots declined slightly. Future measurements will reveal whether the relative hardwood density on unburned plots remains at the higher 1992 level or returns to the 1980-1989 level.

Table 1. *Effect of fire on midstory hardwoods (> 1.5 inches in d.b.h.).*

Treatment	Year 1980	1983	1986	1989	1992
	stems/acre				
Winter burn	190	237	223	220	147
Spring burn	153	113	50	7	3
Summer burn	90	97	77	43	43
No burn	287	307	317	340	207

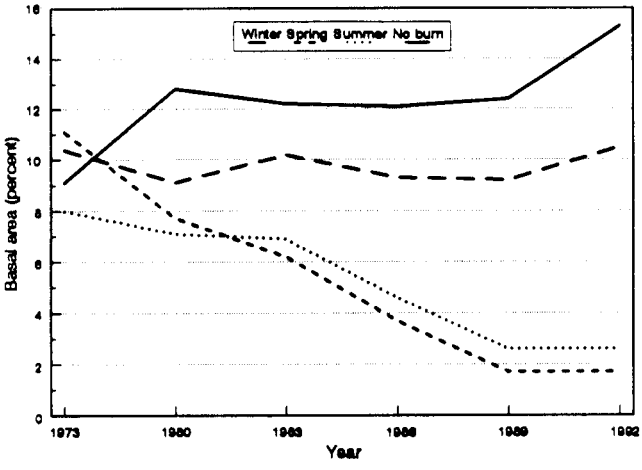

Figure 2. *Hardwood basal area as percent of total stand basal area, by burning treatment.*

Burning treatments have influenced the species composition of midstory hardwoods. Only dogwood (52 percent of surviving stems) and five oak species (48 percent of surviving stems) persisted on burned plots. Dogwoods made up 43 percent of the surviving stems on unburned plots and oaks 39 percent. Persimmon, sassafrass, and southern magnolia (*Magnolia grandiflora* L.) made up the remaining 18 percent of stems on unburned plots. Bluejack oak (Q. incana Bartr.) and water oak (Q. nigra L.) together accounted for 71 percent of all oak stems on both burned and unburned plots. However, 54 percent of all oaks on burned plots were bluejack, whereas water oaks made up 50 percent of all oaks on unburned plots.

Midstory Threshold

The immediate source for recruitment into the midstory is woody vegetation in the 1-inch d.b.h. class (0.6 to 1.5 inches in d.b.h.). This class was tallied on entire subplots beginning in 1986. There were no woody stems in this size class on spring-burned plots, and the number of stems in plots receiving the other 3 treatments has declined steadily since 1986 (table 2).

Table 2. *Effect of fire on woody stems in the 1-inch d.b.h. class.*

Treatment	Year 1986	1989	1992
	stems/acre		
Winter burn	140	63	13
Spring burn	0	0	0
Summer burn	60	10	3
No burn	317	270	123

In 1992, all woody stems in the 1-inch d.b.h. class on burned plots were oaks (80 percent) or dogwood (20 percent). On unburned plots, dogwoods made up 27 percent of all stems, four species of oak, 13 percent, six other tree species [sweetbay (*Magnolia virginiana* L.), sassafras, magnolia, persimmon, American holly (*Ilex opaca* Ait.), and black cherry (*Prunus serotina* Ehr.)], 49 percent, and arborescent shrubs, 11 percent. All oaks in this size class on burned plots were bluejack and post oaks (*Q. stellata* Wangenh.). On unburned plots, 60 percent of the oaks were water oak and southern red oak (*Q. falcata* Michx.), and only 40 percent were bluejack and post oaks.

Hardwood Regeneration

All woody stems with a d.b.h. of < 0.5 inches were tallied on sub-subplots to obtain estimates of numbers of stems by species and species groups. Tree species were only a small fraction of the total number of woody stems on the forest floor. Over the course of the six examinations, the average number of tree stems, over all four treatments, ranged from 5,300 to 13,200/acre. Numbers of shrubs and other woody plants (excluding vines) ranged from 58,000 to 208,000 stems/acre.

Hardwood tree regeneration on the ground grows into the midstory whenever an opportunity arises. Biennial prescribed fires over a period of 18 years have so far failed to significantly affect the amount of hardwood regeneration on the forest floor (fig. 3).

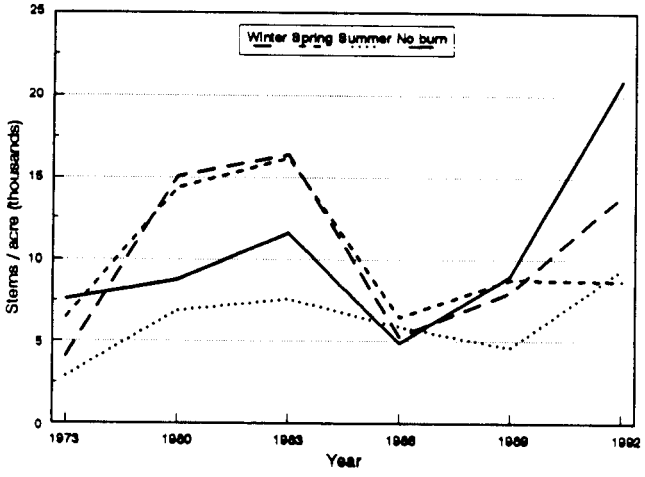

Figure 3. *Changes in hardwood regeneration with time and burning treatments.*

Examinations through 1983 treated as regeneration all stems 1.5 inches in d.b.h. or less, whereas 1986 and later examinations treated as regeneration only stems 0.5 inches in d.b.h. or smaller. However, numbers in the 1-inch d.b.h. class, as recorded beginning in 1986 (table 2), are too few to affect values recorded for all regeneration from 1973 to 1983.

Counts of hardwood regeneration (< 0.5 inch in d.b.h.) on all sub-subplots in the last three examinations were combined to show treatment effects on species composition. Burning tended to favor oak regeneration; 69 percent of all stems on burned plots were oaks, and 15 percent were dogwood. On unburned plots, 52 percent of the stems were oaks, and 40 percent were dogwood. The effect of fire on oak species composition was less pronounced in the case of regeneration than in the case of larger stems. Post and bluejack oaks made up 76 percent of oak regeneration on burned plots and 69 percent on unburned plots. Water and southern red oaks made up 20 percent of all oaks on burned plots and 31 percent on unburned plots. Season of burn did not appear to affect composition of the regeneration.

Discussion and Conclusions

Biennial prescribed fires over a period of 18 years have influenced hardwood development in young, naturally established, longleaf pine stands. Density of midstory hardwoods > 1.5 inches in d.b.h. increased steadily in the absence of fire and also with biennial winter fires while declining slowly with spring and summer burns.

The proportion of hardwood BA to total stand BA has remained relatively constant in both unburned and winter-burned stands over 19 years, averaging 12.3 percent without fire and 9.8 percent with winter fires. The proportion of hardwood BA to total stand BA in loblolly pine (P. taeda L.) plantations remained relatively constant from stand age 11 to stand age 24 (Burkhart and Sprinz 1984, Glover and Dickens 1985). Likewise, hardwood BA has remained at about 35 percent of total stand BA over 46 years in an unmanaged mixed pine-hardwood stand in Arkansas (Cain 1989). Other reports suggest that the proportion of hardwood BA in southern pine stands will reach a low point between stand ages 15 and 25 and then increase with time (Ruark and Bechtold 1989, Smith and others 1989). In the present study, no decline in percent hardwood BA was observed even though pine BA growth culminated between pine ages 21 and 27.

Biennial spring fires have virtually eliminated midstory hardwoods, and biennial summer fires have substantially reduced the number of stems. Hardwoods in the 1-inch d.b.h. class have been entirely eliminated on spring-burned plots, almost eliminated on summer-burned plots, and sharply reduced in number on winter-burned plots.

The burning treatments have not affected hardwood regeneration on the forest floor, which has increased from an average 5,300 stems/acre in 1973 to 13,200 stems/acre in 1992. Hardwood regeneration in 1992 ranged from a high of 20,900 stems/acre on unburned plots to 8,700 stems/acre on spring-burned plots, but the by-treatment differences were not significant at the 0.05 level.

Although periodic growing-season burns may eventually topkill hardwood stems up to about 4 inches in d.b.h., they apparently have little impact on rootstocks, which resprout after each fire. Biennial summer fires over a period of 26 years reduced numbers of hardwood rootstocks by less than 50 percent, although annual summer burning over a period of 20 years eliminated nearly all hardwood sprouts in a stand of loblolly pine on the Atlantic Coastal Plain stand (Waldrop and Lloyd 1991). Annual winter fires led to an increase in sprouts. Eleven annual summer fires were required to reduce the number of hardwood rootstocks by 85 percent in

an Arkansas loblolly-shortleaf pine stand (Grano 1970). Annual growing-season fires over a long period of time may be needed to eliminate most hardwood rootstocks within pine stands.

Differences between mixes of surviving hardwoods in burned and unburned stands were notable. Burning favored bluejack and post oaks at the expense of water and southern red oaks at all levels from midstory to regeneration. Dogwood remained a significant component of the midstory, including the 1 inch d.b.h. class in both the burned and unburned stands. Dogwood regeneration in burned stands, however, was only about one-third as numerous as that in unburned stands.

Future observations should reveal the compositions and structures of the plant communities that eventually stabilize under the three biennial burning regimes, and with fire exclusion, on this Coastal Plain site. Another long-term prescribed fire study in young longleaf pine stands was established to determine the effects of 3- and 5-year as well as 2-year burning cycles.

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SEASONAL AND CUMULATIVE LOBLOLLY PINE DEVELOPMENT UNDER TWO STAND DENSITY AND FERTILITY LEVELS [1]

James D. Haywood [2]

Abstract. An 8-year-old loblolly pine (*Pinus taeda* L.) stand was subjected to two cultural treatments for examination of seasonal and cumulative pine development. In the first treatment, pine density was either reduced by removal cutting to 296 trees per acre, at a 12- by 12-ft spacing, or left uncut with an original density of 1,210 trees per acre at a 6- by 6-ft spacing. In the second treatment, either no fertilizer was applied, or diammonium phosphate was broadcast at 134 lbs of P and 120 lbs of N per acre. Competing vegetation was controlled on all plots. Pine heights and diameters were measured in the spring, summer, fall, and winter of the 9th through 11th growing seasons. Plots that had undergone removal cutting had less spring height growth in the 9th and 10th growing seasons than the uncut plots, with no significant affect in the 11th season. Cutting increased diameter growth throughout each spring and summer, but basal area per acre increment failed to keep pace with the uncut plots. Fertilization increased height growth, beginning in the 10th growing season, and fertilization increased diameter and basal area per acre growth each year, especially on the cut plots. Fertilization of cut plots was more beneficial than cutting alone. Removal cutting alone resulted in less height and basal area growth than the other treatment combinations in the 9th through 11th growing seasons.

Introduction

The ability of fertilization to increase volume increment in pole- to sawlog-sized loblolly pine (*Pinus taeda* L.) stands is greatly dependent on the initial stand basal area per acre (Moehring 1966, Wells and others 1976, Windsor and Reines 1973). Therefore, the fertilization of stands that had undergone removal cutting (thinning) is often much more beneficial for increasing diameter and height increment than either fertilization or cutting alone (Jones and Broerman 1977). The cumulative effect is to increase net volume (and value) per tree left after removal cutting as fertilization acts to speed up site reoccupancy (Ballard 1981, Ballard and others 1981).

Clearly, the use of removal cutting and fertilization influences stand development as determined by yearly measurements. However, the question of when during the growing season does the effect of cultural treatments occur remained. In this study, loblolly pine height and diameter measurements were made periodically over several years to determine: (1) when growth responses to removal cutting and fertilization might occur during the growing season and (2) the cumulative growth responses to cultural practices over several growing seasons.

Methods

The Study Area

The 2.8-acre site, located in Rapides Parish, Louisiana, is a gently sloping Beauregard silt loam (Plinthaquic Paleudults, fine-silty, siliceous, thermic) soil. Soil drainage is adequate, and slope is sufficient that water does not pond. The site was planted with loblolly pine seedlings at a 6- by 6-ft (1.8- by 1.8-m) spacing in May 1981. The planting stock was containerized seedlings that had been grown in Styrofoam® blocks for 14 weeks. Over 97 percent of the planted trees survived through 1987, when this study was initiated. The 3 percent that did not survive did not create any openings in the stand canopy. Loblolly pine was the dominant vegetation as measured by basal area per acre, frequency of occurrence, and occupancy of the canopy. Diameters of all pine trees in the stand were measured in September 1987, and, based on these data, it was determined that diameter classes of pine trees were uniformily distributed across the site.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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Plot Establishment

In April 1988, the understory hardwood trees, shrubs, brush (including *Rubus* spp. and *Smilax* spp.), and herbaceous plants were cut with a tractor drawn, rotary mower. Twelve research plots were established with each plot containing 13 rows of 13 trees each (0.14 acre or 0.06 ha plots).

Treatments, Tree, and Plot Selection

Treatments were randomly assigned to the 12 plots in a 2 by 2 factorial arrangement with 3 replications as follows:

1. Removal cutting. Plot density was either reduced to 296 trees per acre or left uncut with an original density of 1,210 trees per acre.
2. Fertilization. No fertilizer was applied, or diammonium phosphate was broadcast at 667 lb/acre [134 lb/acre (150 kg/ha) of P and 120 lb/acre (134 kg/ha) of N]. This choice and rate of fertilizer was based on prior knowledge of loblolly pine responses to fertilization on a Beauregard silt loam soil (Tiarks 1982).

On the cut plots, the trees were removed to leave a 12- by 12-ft spacing by cutting every other row of trees and every other tree in the uncut rows. This left 12 pines on the interior measurement area of each cut plot. Cutting was not done selectively to avoid biasing the comparison of the cut and uncut plots. The purpose of removal cutting was not to improve the population of trees, but rather to compare growth between like populations of trees growing under different management practices. On the uncut plots, 12 trees were systematically selected for collecting height data, rather than measuring the height of every tree.

After tree selection, the plots were randomly assigned treatments. The cutting was done in November 1988, at the end of the eighth growing season. The fertilizer was broadcast in April 1989, at the beginning of the ninth growing season.

Plot Maintenance

The 12 selected trees on each plot were banded with red paint at about 5.5 ft to ensure relocation. All trees on the interior measurement areas were marked with a blue diameter point at d.b.h. for consistent resampling.

An ice storm occurred in February 1989. The ice bent about 28 trees and snapped 2 border trees on the cut plots. Most of the trees restraightened, however, several were no longer usable for height measurements although they were still used for collection of d.b.h. data.

Competition from other plant species is not a factor in this research. Therefore, all remaining large woody vegetation and vines were cut, and the herbaceous and small woody competitors were sprayed with glyphosate in April 1989. The plots were rotary mowed 3 weeks later and retreated with glyphosate later in the growing season to maintain weed control. In 1990, the plots were again sprayed and mowed. In 1991, the vines were again cut and the plots sprayed with glyphosate and a mixture of 2,4-D, dicamba, and dichloroprop and rotary mowed 3 weeks after spraying.

Measurements and Experimental Design

The interior measurement area was that portion of each plot originally occupied by the central 7 rows of 7 trees each (0.04 acre or 0.02 ha). On March 27, 1989, pine tree diameters (of all trees on the interior measurement area) were measured to the nearest 0.1 inch with a diameter tape, and total heights (of the 12 selected trees only) were measured with a clinometer to the nearest 0.5 ft. This measurement provided a baseline covariate for future analyses. The plots were again measured on July 5 and October 2, 1989; March 19, June 13, October 29, and December 14, 1990; and March 8, June 24, September 24, and December 4, 1991.

Data were analyzed by analyses of covariance with the covariate being the original height, diameter, or basal area per acre data (Probability > F-value = 0.05). The dependent variables were the periodic growth differences in the spring, summer, and fall of each year, as well as the cumulative growth differences for the 3-year period. The spring periods were March through July 1989 (100 days), March through June 1990 (86 days), and March through June 1991 (108 days). The summer periods were July through October 1989 (89 days), June through October 1990 (138 days), and June through September 1991 (92 days). The fall periods were October 1989 through March 1990 (168 days), October through December 1990 (46 days), and September through December 1991 (71 days).

Results and Discussion

Plots that had undergone removal cutting had less total height growth than the uncut plots for the 3-year period (fig. 1). However, the effect of cutting on height growth was most pronounced in the spring of the 9th and 10th growing seasons, with no significant influence on height growth in the 11th growing season (table 1). Ginn and others (1989) also reported an early suppression in loblolly pine height growth from reduction in stand density.

Fertilization increased total height growth for the 3-year period, but height growth was not significantly affected by fertilization until the 10th growing season, when height growth was increased on only the uncut plots in spring 1990 (see the removal cutting and fertilization interaction effect in table 1). However, height growth on both the cut and uncut plots was increased in summer 1990 (fig. 1, table 1). Thus, the effect of fertilization on height growth was delayed, whereas the effect of removal cutting on height growth was immediate. However, trees eventually returned to a normal growth pattern on the cut plots.

The cumulative influence of removal cutting and fertilization on pine height growth was additive for the 3-year period (fig. 2). Height growth averaged 8.8, 11.1, 6.1, and 8.5 ft from the 9th through 11th growing seasons on the uncut-unfertilized, uncut-fertilized, cut-unfertilized, and cut-fertilized treatments, respectively.

Removal cutting immediately increased diameter growth of the remaining trees for the 3-year period (fig. 1). This positive growth response to cutting was significant in every measurement season, except fall 1990 and 1991 [(Probability > F-value = 0.0708 and 0.1333, respectively (table 1)].

Fertilization significantly increased seasonal diameter growth in summer 1989 and 1990 and spring 1991 (fig. 1, table 1). Other studies have shown that initial stand basal area greatly influences pine tree responses to fertilization (Moehring 1966, Wells and others 1976, Windsor and Reines 1973) and fertilization of stands that had undergone removal cutting is often more beneficial than either fertilization or density reduction alone (Jones and Boerman 1977). This was demonstrated by a significant cutting and fertilizer interaction effect on diameter growth for the 3-year period (table 1), with fertilization having little cumulative effect on diameter growth on the uncut plots (figs. 1, 2). Diameter growth for the 3-year period averaged 0.5, 0.6, 1.4, and 2.1 inches on the uncut-unfertilized, uncut-fertilized, cut-unfertilized, and cut-fertilized treatments, respectively.

Plots that had undergone removal cutting had less cumulative basal area per acre growth than the uncut plots at a Probability > F-value = 0.0682 (table 1), and the uncut and cut treatments averaged a 36.5 and 29.5 ft^2 gain in basal area per acre for the 3-year period, respectively (fig. 1). Fertilization increased cumulative basal area growth, especially on the cut plots (fig. 2), but there was no significant cutting and fertilization interaction effect in the cumulative basal area per acre analysis [Probability > F-value = 0.1745 (table 1)]. The 3-year gain in basal area was 34, 39, 23, and 36 ft^2 per acre on the uncut-unfertilized, uncut-fertilized, cut-unfertilized, and cut-fertilized treatments, respectively.

To conclude, the negative effect of removal cutting on subsequent loblolly pine height growth was limited to the first 2 years after treatment. The positive response of removal cutting on diameter growth was immediate and continual through the 3-year period. Fertilization increased diameter growth only on the cut plots and had more influence on basal area per acre increment on the cut than uncut plots. Therefore, on infertile silt loam soils, fertilization of cut or thinned stands is the best management practice. Removal cutting alone is not recommended because of the effect on height and basal area per acre increment.

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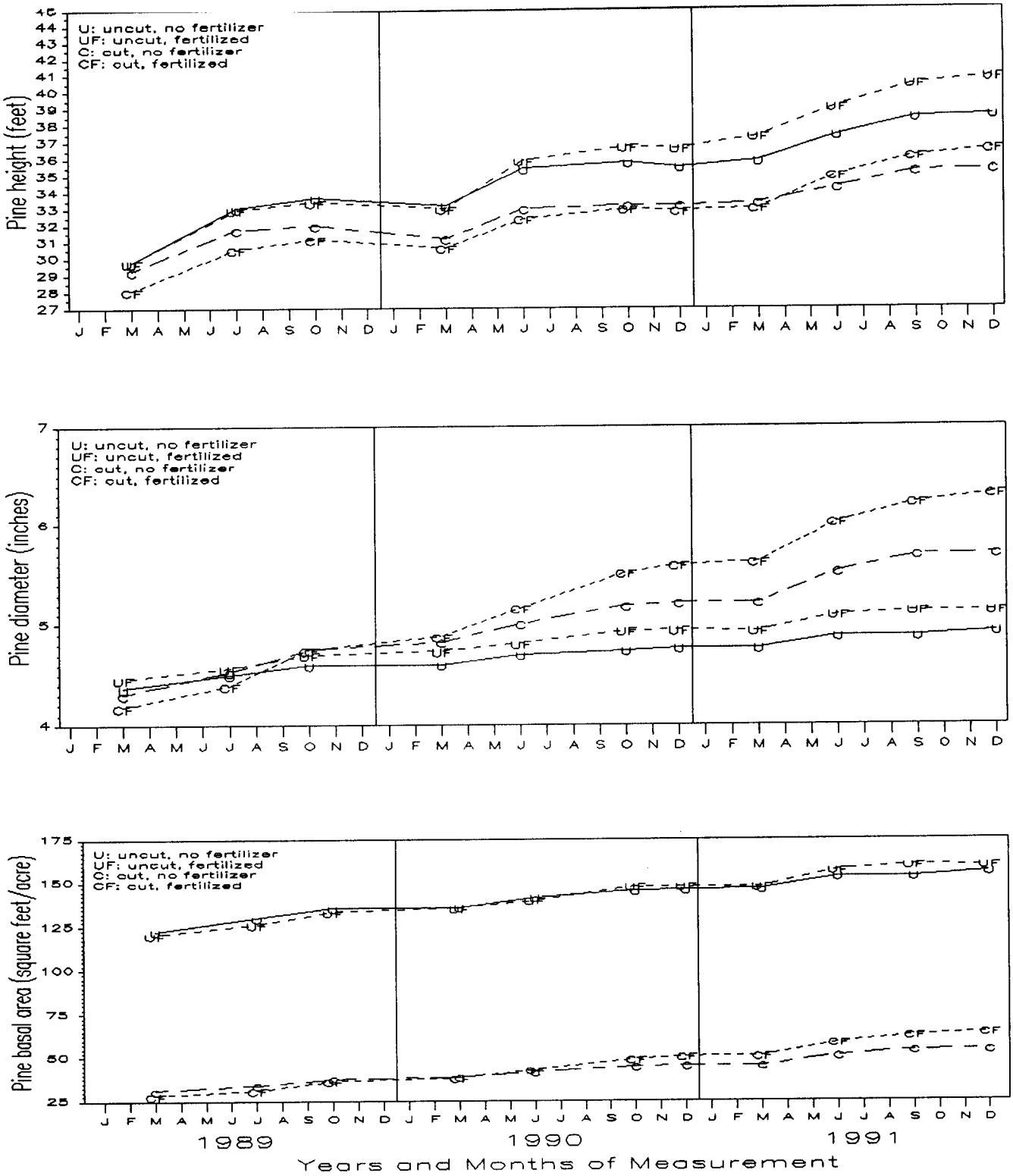

Figure 1. ***Total loblolly pine height (top), diameter (middle), and basal area per acre (bottom) in the 9th through 11th growing seasons.***

Table 1. *Probability of a greater F-value for the main effect treatments and interaction term when comparing seasonal and cumulative height, diameter, and basal area per acre growth of loblolly pine in the 9th through 11th growing seasons.* [1]

Variable Response	(Probability > F-value) 9th growing season Spring	Summer	Fall	10th growing season Spring	Summer	Fall	11th growing season Spring	Summer	Fall	Cumulative 3-year growth
Height growth										
Removal cut	.0042	.6832	----[2]	.0013	.2905	.4172	.5124	.5335	.9550	.0002
Fertilizer	.6114	.5813	----	.1421	.0055	.8574	.0120	.3737	.0256	.0007
Cut x fert.[3]	.8882	.1506	----	.0343	.9839	.9265	.0594	.6867	.7762	.8758
Diameter growth										
Removal cut	.0075	.0001	.0202	.0012	.0001	.0708	.0001	.0007	.1333	.0001
Fertilizer	.3643	.0046	.0627	.1653	.0002	.3964	.0145	.1381	.5226	.0051
Cut x fert.[3]	.7190	.0507	.9345	.0382	.0692	.0785	.3446	.9345	.0328	.0312
Basal area/acre growth										
Removal cut	.0376	.0908	.8027	.3736	.8376	.5710	.0098	.1410	.5073	.0682
Fertilizer	.0985	.0080	.0008	.9515	.0003	.7297	.0013	.0454	.2019	.0067
Cut x fert.[3]	.2558	.8308	.0660	.1554	.3328	.1691	.4618	.2643	.0018	.1745

[1] Probabilities are from analysis of covariance with the initial height, diameter, and basal area per acre data, taken in March 1989, as the covariate. The accepted level of significance was Probability > F-value = 0.05.

[2] Average pine heights were reduced on all treatments. No analysis was made.

[3] The removal cutting by fertilization interaction.

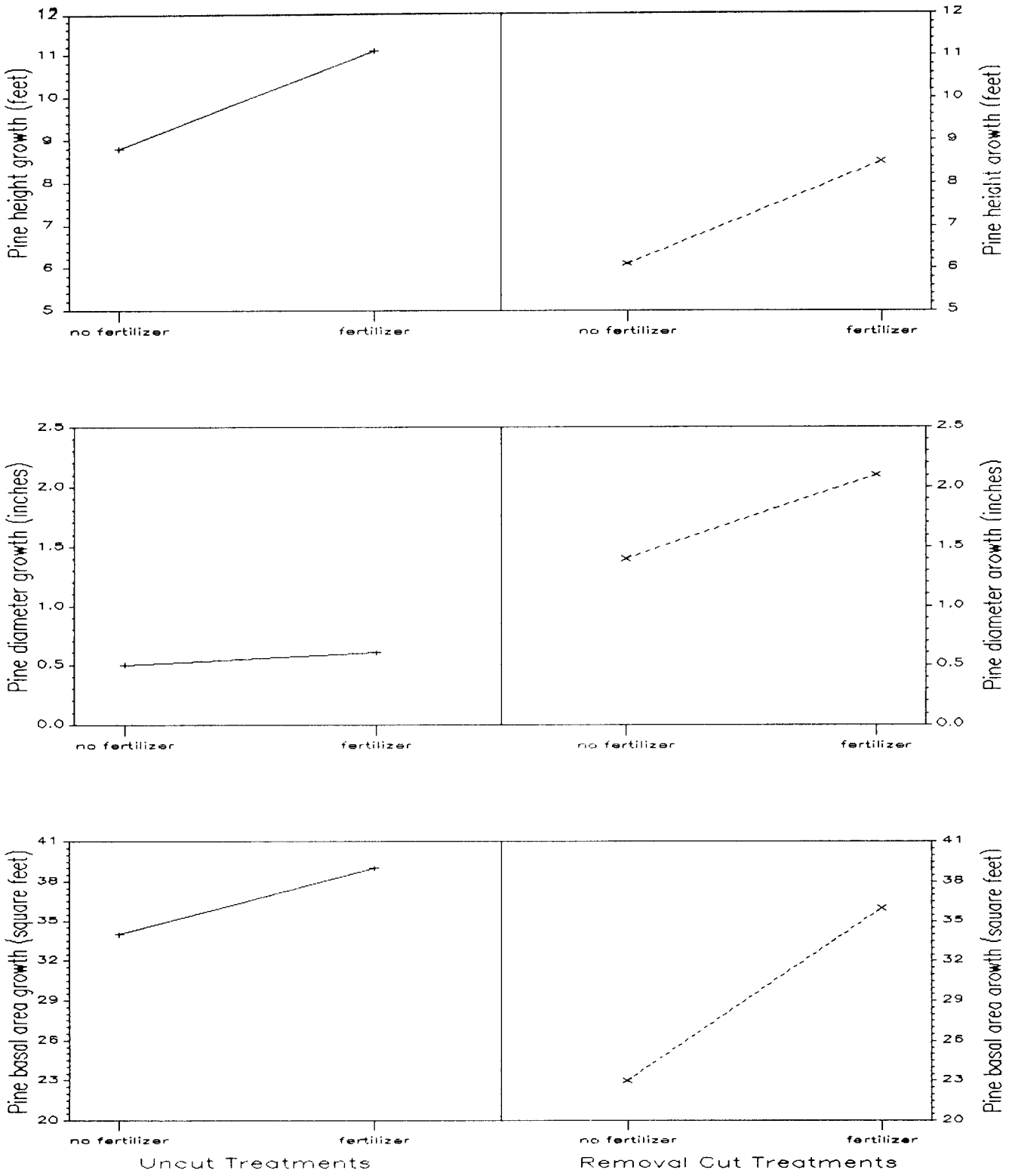

Figure 2. ***Three-year-growth response of loblolly pine height (top), diameter (middle), and basal area per acre (bottom) to removal cutting and fertilization.***

BARK YIELDS OF 11-YEAR-OLD LOBLOLLY PINE AS INFLUENCED BY COMPETITION CONTROL AND FERTILIZATION [1]

Allan E. Tiarks and James D. Haywood [2]

Abstract. Bolts cut from 11-year-old loblolly pines (*Pinus taeda* L.) were measured to determine the effects of applications of fertilizer and competition control treatments on the amount of pine bark produced. Bark thickness at breast height was not significantly affected by any of the treatments. Regression analysis showed that the dry weight of bark per unit surface area of the bolt increased as the volume of the bolt increased. The regressions for unfertilized and fertilized trees were significantly different: the fertilized trees had less bark. Because bark weight is correlated with bole diameter, bolts were placed in 20-mm-wide inside-bark diameter classes. Fertilizer and woody plant control treatments decreased mean bark weight from 71.6 to 59.7 kg m^{-3} of wood for bolts in the 120-mm class and from 72.9 to 62.0 kg m^{-3} for those in the 140-mm class.

Introduction

Weed control and fertilization treatments applied at time of establishment of new plantations increase the growth of southern pines substantially (Bacon and Zedaker 1987, Clason 1984, Schmidtling 1984, Tiarks and Haywood 1986, Zutter and others 1987). This reported growth increase is based on outside-bark diameter measurements and derived volumes and on the implicit assumption that the treatments do not affect the tree shapes or the proportions of bark and wood in the trees. However, cultural treatments do affect the taper of older trees (Shoulders and others 1989). Because bark has relatively little economic value, even small changes in bark-to-wood ratios could cause significant differences in the economics of a cultural treatment.

Because interest has usually centered on determining actual wood volume, most measurements of bark have been of thickness. These measurements have shown that bark thickness changes with d.b.h. (Burton 1962), height (Cochran 1982), and age (Koch 1972). Bark thickness is reduced by fire (MacKinney 1934) and varies with region and soils (Koch 1972). Bark thickness is also difficult to measure accurately (Mesavage 1969) and is highly variable (Judson 1964). Bark weights as a portion of wood volume or weight have been reported but have not been related to silvicultural treatments.

We harvested bolts from a stand of loblolly pine (*Pinus taeda* L.) that had received fertilizer and weed control treatments. We compared bark weights to bolt volumes and surface areas to determine the effects of the treatments on bark yields. We removed the effects of diameter on bark yields by including d.b.h. in regression models and by making comparisons within bolt diameter classes.

Methods

Bolts for taper and bark measurements were collected in an 11-year-old loblolly pine plantation established as part of a fertilizer and competition control experiment (Haywood and Tiarks 1990, Tiarks and Haywood 1986). The study site is in Winn Parish, LA, on moderately well-drained Malbis very fine sandy loam (fine-loamy, siliceous, thermic Plinthic Paleudults). A mature loblolly-shortleaf pine (*P. echinata* Mill.) stand was clearcut and the site intensively prepared by V-blading and root raking. In the winter of 1977-78, 64 loblolly seedlings were planted at a 2.4- by 2.4-m spacing on each of 32 19.5- by 19.5-m plots. The center 16 trees in each plot were designated as measurement subplot trees. To maintain uniform density, all dead seedlings were replaced in September 1978 with container-grown loblolly seedlings.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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Fertilizer, herbaceous plant control, and woody plant control treatments were applied in a 2 by 2 by 2 factorial experiment with a randomized complete block design. The four blocks served as replicates. Fertilizer was hand broadcast in April 1978 at the rate of 112 kg of nitrogen, 49 kg of phosphorus, and 93 kg of potassium per hectare. Woody plant control was accomplished by two herbicide applications. In 1978, low-volatile ester 2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid] was sprayed on all hardwoods after the pines had been covered. In 1979, the few remaining hardwoods were cut off near the ground and their stumps treated with a picloram (4-amino- 3,5,6-trichloro-2-pyridinecarboxylic acid) and 2,4-D [(2,4-dichlorophenoxy) acetic acid] mixture. Herbaceous plant control was achieved by hoeing a 1.14-m radius circle around each pine to remove grasses, grasslike plants, and forbs without damaging pine or hardwood roots. The hoeing was done three times yearly between April and September for the first four growing seasons.

Total height and diameter at breast height (d.b.h.) of the 16 loblolly pine trees in each plot center were measured for the first 10 years. When the pines were 11 years old, the heights and d.b.h. of all living pines on the plots, including those in the border rows, were measured. The measurement data were used to select trees for removal in a thinning operation that would leave 32 living pines per gross plot and 8 evenly spaced, well-formed, crop trees per measurement plot. In each plot, four of the pines identified for thinning and reflecting the diameter distribution of pines on the plot were selected. Whenever possible, trees within the measurement plots were selected, but only if they were from the original planting and not more than one standard deviation smaller in d.b.h. than the mean for the plot. Where this was not possible, trees from the inside border row and having d.b.h. within one standard deviation of the measurement plot d.b.h. mean were selected. Because we preferred to leave good trees in the measurement plots, we took about half of the sample trees from the border rows.

After the sample trees were felled, sample bolts were cut from their main stems at heights of 0 to 1, 1 to 2, and 3 to 4 m. These bolts were debarked by hand and the ovendry weight of the bark from each bolt was recorded. The top-end and bottom-end diameters of each debarked bolt were measured with a tape.

Single bark thickness was calculated by taking half of the difference between the d.b.h. of the standing tree and the d.b.h. calculated from the upper and lower diameters of the debarked bolt representing the 1-m to 2-m height. Because bark thickness varies around the circumference of the tree (Mesavage 1969), this method should give better results than does a bark gauge. The surface area and volume of each bolt were calculated from the upper and lower diameters of the bolt and assuming a truncated cone. These results were used to calculate the dry bark weight per unit volume of wood and dry bark weight per unit surface area of the debarked bole. The significance of effects of the treatments on bark thickness was tested by analysis of variance. Linear regression was used to describe the relationship between dry weight of bark per unit surface area and volume of wood. After the bolt data were separated by 20-mm bolt-diameter classes, general linear model regression was used to analyze the effects of the treatments on bark weight per unit of wood volume and bark weight per unit of surface area.

Results and Discussion

Heights and Diameters

Fertilization and herbaceous plant control significantly increased the height of the trees harvested (table 1). The two treatments increased height by 0.8 and 0.6 m, respectively. Only fertilization significantly affected d.b.h. The application of fertilizer at planting resulted in an increase of about 5 percent in d.b.h. at age 11.

Sample trees were selected to represent the diameter distribution of the stand, so it is not surprising that the treatments affected the d.b.h. of the sample trees as much as it affected d.b.h. for the stand (Haywood and Tiarks 1990). The average d.b.h. of the sample trees was about 10 mm larger than average d.b.h. for the stand, but the difference was uniform across all treatments. Average height of the sample trees was about 0.3 m greater than that of the stand (Haywood and Tiarks 1990). The height response to fertilizer application was slightly larger in the sample trees than in the stand, indicating that there was a small bias in sampling.

Table 1. *Effect of fertilization and vegetation control on the height, diameter, and single-bark thickness of loblolly pines harvested at age 11.*

Treatment Effect	Number of plots	Mean height	Mean d.b.h.	Single bark thickness
		(m)	(mm)	(mm)
Main effect treatment comparisons from the analysis of variance				
Fertilizer	16	13.2	165	12
		0.01 [1]	0.01	0.49
No fertilizer	16	12.4	157	12
Herbaceous plant control	16	13.1	163	12
		0.01	0.17	0.76
No herbaceous plant control	16	12.5	159	12
Woody plant control	16	12.9	163	12
		0.30	0.16	0.64
No woody plant control	16	12.7	159	12
	Treatment averages			
No fertilizer				
No plant control	4	12.5	154	13
Woody plant control	4	11.7	153	11
Herbaceous plant control	4	12.4	157	12
Woody + herbaceous control	4	13.0	163	12
Fertilizer				
No plant control	4	12.5	158	11
Woody plant control	4	13.1	170	13
Herbaceous plant control	4	13.3	165	13
Woody + herbaceous control	4	13.7	166	12

[1] *For each paired comparison, the probability of a greater F-value is given. Prob. of $F \leq 0.05$ is significant for this research.*

Bark Thickness

The average single-bark thickness was 12.1 mm and ranged from 3.3 to 22.5 mm with a standard deviation of 3.5 mm. While the observed range is large, Judson (1964) reported a range of about 5 to 30 mm for trees averaging 180 mm in d.b.h. The fertilization and weeding treatments did not significantly affect the bark thickness. Bark thickness increased with d.b.h. according to the relationship:

$$BT = 0.108 \times d.o.b. - 5.3$$

where d.o.b. is diameter outside bark at breast height in mm and BT is single-bark thickness in mm. The equation is highly significant (Probability $>F$ = 0.001), but the r^2 is only 0.29. The slope of the equation is higher than that reported by others (Koch 1972), but our data are based on a smaller range of d.b.h. Burton (1962) reported a slope of 0.078 based on 326 trees with d.b.h. ranging from about 40 to 250 mm.

Dry Bark Weights

Bark weight per unit surface area of bolts increased with the volume of the bolt (fig. 1). The larger bolts are on the older parts of the trees so the increased weight per unit surface area is caused by accumulation over time. Fertilization decreased the dry weight of bark per unit surface area from 15 percent for small bolts to 2 percent for the largest bolts measured.

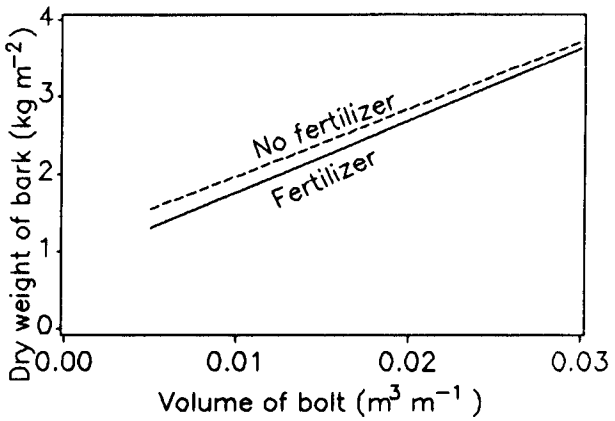

Figure 1. *Effect of fertilizer on the relationship between bolt volume and the weight of dry bark per unit surface area.*

Bolt data were separated by bolt diameter classes to eliminate the effect of diameter on bark weight. Only the 120 and 140 mm classes contained sufficient observations to draw conclusions. The other classes had either too few observations or too many empty cells. Fertilizer decreased the amount of bark on the bolts in both the 120 and 140 mm classes when quantity of bark was expressed either as dry weight of bark per unit of wood volume or as weight of bark per unit surface area (table 2). Woody plant control also decreased the bark yields, but the differences were significant only in the 140-mm bolt class. Volume of wood per unit length of bolt was not affected by the treatments.

Several factors may affect the weight of bark on trees when bark weight is expressed as a function of volume. These factors include the diameter and taper of the bole, bark density, and bark thickness. As the diameter of a bole increases, the ratio of its surface area to its volume decreases. A decrease in taper also decreases the surface area to volume ratio. In the analysis presented here, these effects have been removed by expressing the proportion of bark to wood as weight per unit surface area, and we feel that our data suggest that the treatments are decreasing bark thickness, bark density, or both.

We considered the possibility that because the treatments affect diameter growth, the classes could represent bolts from different heights. Within a given diameter class, the bolts from fertilized trees might be from higher, and thus younger, positions in the boles. However, the distribution of bolt heights within diameter classes was not affected by the fertilizer treatment, eliminating this possibility.

To relate change in bark weights to weight of wood delivered to the mill, we must calculate the change in bark weight of fresh bolts. The average water content of the bark was 124 percent (dry weight basis) and the average wet density of the wood was 1.02 Mg m^{-3}. Using figures for the 140-mm class from table 1, the wet bark weight for the no fertilizer, no woody plant control treatment is 16.0 percent of the total wet weight of the bolt, and the wet bark weight for the fertilized, woody plant control treatment is 13.6 percent of the total wet weight of the bolt.

This study demonstrates that fertilizer and woody plant control, in addition to increasing gross yield 27 percent by weight (Haywood and Tiarks 1990), increases the weight of wood per truck load by 2.8 percent. The waste bark pile would be 15 percent smaller. To verify these results, bark thickness, weight, and density should be measured intensively in other studies in which treatments such as fertilizer and competition control have been applied.

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Table 2. *Effect of fertilization and woody plant control on the weight of bark per unit volume of wood and per unit surface area of the bole. Effect of the treatments on volume of wood within diameter classes is shown for comparison.*

Treatment	n	Bark per unit bole volume ($kg\ m^{-3}$)	Bark per unit bole surface ($kg\ m^{-2}$)	Volume of wood per unit height ($m^3\ m^{-1}$)
		120-mm class		
No fertilizer No woody plant control	35	71.6a	2.14a	0.0112a
Fertilizer No woody plant control	24	63.9b	1.92b	0.0114a
No fertilizer Woody plant control	31	67.8a	2.03a	0.0113a
Fertilizer woody plant control	22	59.7b	1.82b	0.0117a
		140-mm class		
No fertilizer No woody plant control	37	72.9a	2.54a	0.0153a
Fertilizer No woody plant control	42	69.0b	2.39b	0.0151a
No fertilizer Woody plant control	31	69.2b	2.41b	0.0153a
Fertilizer woody plant control	38	62.0c	2.18c	0.0156a

Numbers in the same column and followed by the same letter are not significantly different ($p = 0.05$).

Pest Management and Growth and Yield

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POST-THINNING DISEASE AND GROWTH RESPONSES OF PITCH CANKER INFECTED SLASH PINES IN THE FLATWOODS OF FLORIDA [1]

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Abstract. Following thinning at age 12, the severity of pitch canker disease in infected slash pines (*Pinus elliottii* Engelm. var. *elliottii*) gradually decreased over time with the greatest reduction in severity occurring in those trees with the most severe initial damage. Trees that were disease-free at the beginning of the study generally remained healthy throughout the 5-year observation period. Susceptibility and hence disease occurrence, and/or severity were not enhanced by wounding, root damage, or other potentially deleterious influences associated with thinning-related stand disturbance. Although disease severity decreased following thinning, the impacts of initial crown loss were evident in the 5-year, post-thinning volume increment where trees with greater initial crown loss experienced greater growth loss. The absence of disease intensification following thinning, coupled with the recovery of even the most severely affected trees, suggests that operational thinning of young, pitch canker affected slash pine plantations on flatwoods spodosols may be a viable management option for retaining productivity following severe pitch canker outbreaks.

Introduction

Pitch canker, caused by the fungus *Fusarium subglutinans* (Wollenw. & Reinking) Nelson, Toussoun & Marasas comb. nov. (= *Fusarium moniliforme* Sheldon var. *subglutinans* Wollenw. and Reinking), can be a serious problem in southern pine plantations. The disease has been most damaging on slash pines (*Pinus elliottii* Engelm. var. *elliottii*) in the flatwoods regions of Florida and south Georgia (Dwinell and Phelps 1977, Oak et al. 1982, Phelps and Chellman 1976). In recent years, published reports (Kuhlman and Cade 1985) and our personal observations have noted the occurrence of the disease in young loblolly pine (*P. taeda* L.) plantations in several locations throughout the Southeast.

Reduced growth rate, stem deformity, and mortality are the primary impacts associated with pitch canker in slash pine plantations (Arvanitis et al. 1984, Blakeslee and Oak 1979, Oak et al. 1982, Schmidt and Underhill 1974). These impacts result from the occurrence of numerous resin-soaked cankers on the branches and upper portion of the main stem (Blakeslee et al. 1980, Dwinell and Phelps 1977, Dwinell et al. 1985). As cankers develop and girdle the shoots, all tissues distal to the infection are killed; foliage turns reddish-brown and exuded resin often causes dead foliage to be retained on the shoots for many months. Reduced stand growth diminishes productivity and may necessitate modifications of rotation length. Stem deformities in sapling and intermediate size trees may limit management options for sawtimber production. Yield losses from pitch canker are determined by the incidence, severity, distribution, and persistence of the disease.

During stand establishment, pitch canker resistant slash pine genotypes or less susceptible species may be used to limit losses (Barrows-Broaddus and Dwinell 1983, Dwinell 1978, Rockwood et al. 1988). Other approaches for disease management must be evaluated for use in existing stands where the genetic composition is fixed.

Salvage harvesting of severely affected stands can be used to curtail further losses from pitch canker. Thinning (precommercial or commercial) represents a cultural treatment that could offer useful therapeutic and preventative effects. Thinnings that remove declining trees could reduce the breeding habitat for insects such as the eastern pine (deodar) weevil (*Pissodes nemorensis* Germar), a wounding agent and vector associated with the disease (Blakeslee and Foltz 1981, Schmidt et al. 1976). Thinnings that remove all or some of the infected trees could reduce levels of on-site inoculum of the fungus (Blakeslee et al. 1978), thus reducing exposure to the pathogen.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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Also, reducing stand density could alleviate intra-specific competition and physiological stress, thus allowing the crop trees to more effectively express their natural defense mechanisms. Alternatively, thinning may foster increased disease if wounds associated with the thinning lead to new infections or root damage or post-thinning 'shock' interferes with the performance of natural defense mechanisms.

Despite the potential for positive effects of thinning on tree health and growth, we are aware of only one previous study on the relationship of thinning to the occurrence of pitch canker. In the late 1950's Bethune and Hepting (1963) assessed pitch canker damage in 14-to-21-year-old stands of the 'South Florida' variety of slash pine (*P. elliottii* var. *densa* Little and Dorman) growing in southern Florida. As part of this study, the authors installed a sanitation thinning treatment in three, one-quarter-acre study plots. Observations of disease incidence during the subsequent four years showed a disease increase of about 2 percent per year. Disease incidence at time of thinning was quite low; apparently seven percent or slightly less. Disease severity was not assessed and uneven disease distribution by crown class precluded reliable growth comparisons.

In this study, conducted on a typical flatwoods site in northern Florida, we provide the first report of post-thinning disease and growth responses of healthy and pitch canker-infected slash pines. Management guidelines are presented to reduce tree and stand losses caused by pitch canker.

Methods

This study was installed in a 12-year-old slash pine plantation established on a flatwoods spodosol (Newnan series) in northeastern Alachua County, Florida. The site had been chopped and bedded prior to planting at ca 700 trees per acre with an unimproved slash pine seed source. The plantation was thinned during the fall-winter of 1982-83. At time of thinning, stocking was ca 600 trees per acre with an understory composed primarily of gallberry (*Ilex glabra* L.) and saw palmetto (*Serenoa repens* Bartr.). During the year prior to thinning, the incidence and severity of pitch canker in the plantation increased sharply; the majority of trees developing typical pitch canker symptoms.

The plantation was thinned to approximately 250 stems per acre using a hydraulic shear harvester and the trees were chipped on site. Severe damage to residuals was minimal and on-site logging debris was limited. During thinning every fifth row was removed; thinning within the remaining rows was based on spacing with secondary consideration given to lower stem infection by fusiform rust (caused by *Cronartium quercuum* [Berk] Miyabe ex Shirai f. sp. *fusiforme*) and stem form. No selection pressure was directed against pitch canker infected trees. Consequently, the residual crop trees included a full spectrum of pitch canker infection levels (symptom-free trees to trees having more than 50 percent of their crown affected by the disease).

Fifty plots were installed at random locations throughout the stand. Each plot included four dominant or co-dominant trees, one from each of four classes of disease severity (percent of crown affected by pitch canker). The four pitch canker (PC) severity classes were 1) Class 1 -healthy (no symptoms evident), Class 2 - Light (trace-10%), Class 3 - Moderate (11-30%), and Class 4 - Severe (31-50%) of the crown affected by PC. Broad categories of PC infection were used to allow appropriate classification despite any observer dependent subjectivity in classification. The four trees in each plot were located in close proximity to minimize within-plot variation. The PC severity classes were based on crown loss categories originally developed in earlier work (Blakeslee and Arvanitis 1985) on pitch canker in slash pine and have been used with modifications by Kelly and Williams (1982) for loblolly pine.

Changes in crown loss due to pitch canker were monitored each spring (1985 - 1988) and the cause of any mortality was determined. The averaged evaluations of two independent observers were used to classify disease status. This information was used to follow disease progress over time.

Diameter at breast height and tree height were recorded for each tree in the summer of 1983 and again during the summer of 1988. Total tree volume (outside bark) at each measurement date was calculated using the equation of Bailey et al. (1982) for unthinned slash pine plantations on cutover, site prepared sites in the lower Coastal Plain of Florida, Georgia, and South Carolina:

$$TV_{ob} = 0.00616*D^{2.0578}*H^{0.7468}$$

where TV_{ob} = outside bark total stem volume in cubic feet, D = diameter at breast height in inches, and H = total stem height in feet. Individual tree diameter, height, and volume growth during the 5-year study period (1983-88) were also calculated. Finally, mean diameter, height, and volume growth during the study period were calculated for the four PC classes.

Analysis of covariance was used to evaluate differences in growth among PC classes. The data were analyzed using a randomized block design. The covariates, used to adjust for differences in initial size, were the initial 1983 diameter, total height, and total volume. Differences in adjusted mean growth among adjacent PC classes (1 vs 2, 2 vs 3, 3 vs 4) were tested using least-squares means t-tests ($p=0.05$) and the SAS General Linear Model Procedure (SAS Inst. 1985). Data are presented as adjusted means.

Results

Pitch Canker Incidence and Severity

Patterns of disease progress during the 5-year period following thinning differed according to the initial PC severity class (Figure 1.) Trees that were healthy (Class 1) at the beginning of the study generally remained disease-free throughout the observation period. Disease severity generally decreased in trees that were infected (Classes 2, 3, and 4) at the beginning of the study, the greatest reduction after five years being evident in Class 4 trees (most severe initial infection).

Examination of the number of trees in which disease severity was reduced, remained unchanged, or increased during the study period reveals the positive responses of the crop trees following thinning (Table 1). After five years, only 3% of the trees showed an increase in PC infection, while disease severity declined in 40% of the trees. The percentage of trees improving is actually greater because healthy trees (Class 1) were included in this calculation. The greatest improvement occurred in trees in the moderate (Class 3) and severe (Class 4) categories where disease severity declined in 52% and 82% of the trees, respectively. Pitch canker increased in only 2% of the trees that were in Class 4 at the beginning of the study. More than 90% of the trees that were initially disease-free (Class 1) remained so at the end of the study. One tree, initially in Class 4, died from PC during the 5-year period and one tree in Class 3 was lost due to lightning.

Pine Growth and Pitch Canker

Five-year diameter, height, and volume growth were strongly influenced by initial PC severity status (Figure 2). As the percentage of crown initially affected by PC increased from Class 1 (healthy) to Class 4 (trees with 31-50% crown loss), diameter and volume growth decreased significantly (P value <0.05). The mean tree volume increment of 4.0 cubic feet for Class 1 trees contrasts sharply with the 2.4 cubic feet growth for Class 4 trees. Volume growth loss of infected trees, relative to the growth of healthy trees, was ca 10% for Class 2 - (trace-10% crown loss) trees, 27% for Class 3 (11-30% crown loss) trees, and 40% for Class 4 trees (31-50% crown loss.

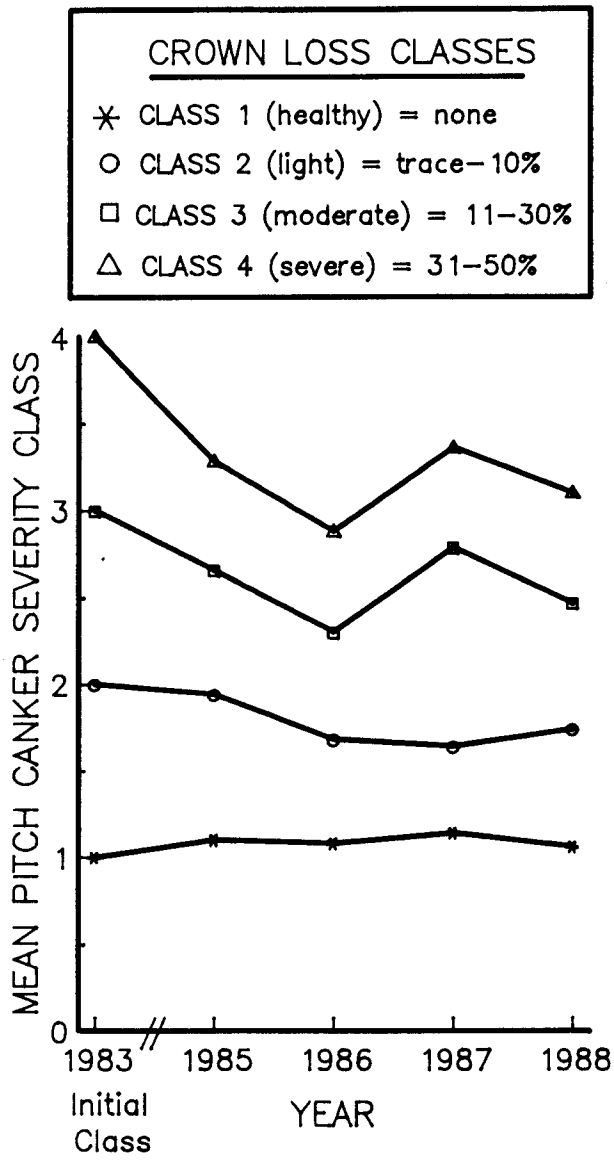

Figure 1. *Mean, post-thinning pitch canker severity class ratings from 1985-88 for slash pines of four different initial (1983) levels of crown loss due to shoot dieback caused by Fusarium subglutinans.*

Five-year height growth was also significantly reduced by the disease, although these differences were not as clearly expressed among PC classes as differences in diameter and volume. These findings are not unexpected since thinning young pine

Table 1. *Percentage of total slash pine trees in which the initial severity of pitch canker (PC) crown loss was reduced, remained the same, or increased during the 5-year period following thinning.*

Disease severity 1985-88	Initial PC Severity Class[1]				
	1 Healthy	2 Light	3 Moderate	4 Severe	Overall
	----------	----------	%----------	----------	----------
Reduced	---	28	52	82	40
Unchanged	94	70	46	16	57
Increased	6	2	2	2	3

[1] The initial (1983) PC severity classes were: 1 = healthy, 2 = trace - 10%, 3 = 11 - 30%, and 4 = 31 - 50% crown loss due to infections by *Fusarium subglutinans*. Percentages are based on 50 trees per PC class (49 trees in PC class 3).

plantations of average stocking is known to have greater impact on diameter and volume growth than on height growth (Smith 1962).

Discussion

Pitch canker is not an uncommon disease in intermediate age slash pine plantations; however, options other than salvage harvest have not been evaluated for disease management in such stands and the responses of pitch canker affected trees following thinning have not been studied. In this paper, we report the post-thinning response of healthy and pitch canker infected slash pines growing on a flatwoods spodosol in northern Florida.

In general, trees that were disease-free at the beginning of the study remained healthy throughout the 5-year study; 94% of the Class 1 trees were disease-free after the fifth year. This response may reflect the inherent genetic disease resistant nature of these Class 1 trees. At the least, the stability of Class 1 trees over time demonstrates that thinning, as utilized in this study, did not have a significant negative effect to increase disease frequency or severity in the most desirable crop trees.

Disease severity generally declined following thinning in all classes of trees having initial infection. During the 5-year observation period, the average Class 4 tree improved by nearly one disease severity class; over 80% of the Class 4 trees had reduced disease severity. Excluding healthy (Class 1) trees, over one-half of the trees responded positively following thinning by demonstrating reductions in disease severity. These positive responses following thinning are reinforced when contrasted with our observations of the substantial intensification of PC severity that occurred during the same period in a small area of the stand that remained unthinned. It is apparent that susceptibility and hence disease occurrence and/or severity were not enhanced by wounding, root damage, or other potentially deleterious influences related to operational thinning.

The brief reversal (1987) in the overall trend toward reduced disease severity in Class 3 and 4 trees may reflect the occurrence of environmental conditions favorable to disease development. The absence of similar intensification in Class 1 and 2 trees may reflect differences in genetic resistance sufficient for these trees to remain unaffected under the same circumstances.

While this study was not designed to evaluate mechanisms responsible for differential disease development and host responses, several important regulating factors are possible. The pitch canker pathogen produces reproductive fungal structures on infected slash pine shoots (Blakeslee et al. 1978), thereby providing an on-site source of fungal spores available for initiating new infections. The removal of infected trees during thinning would reduce the amount of on-site inoculum, subsequently reducing exposure of the crop trees to the pathogen. The eastern pine (deodar) weevil, a known wounding agent and vector of the pitch canker fungus (Blakeslee and Foltz 1981), uses declining, weakened trees as brood trees (Schmidt et al. 1976). The removal of such trees during thinning would reduce the amount of suitable reproductive habitat on the site, thus potentially limiting the subsequent population of weevils available for wounding the crop trees and transmitting the pathogen to them. Properly executed, thinning is thought to improve resistance to the southern pine beetle (*Dendroctonus frontalis* Zimmermann) by improving the vigor of the residual trees (Nebeker et al. 1985). To the extent that invasion of the host by the pitch canker fungus is also regulated by host vigor, reductions in stand density

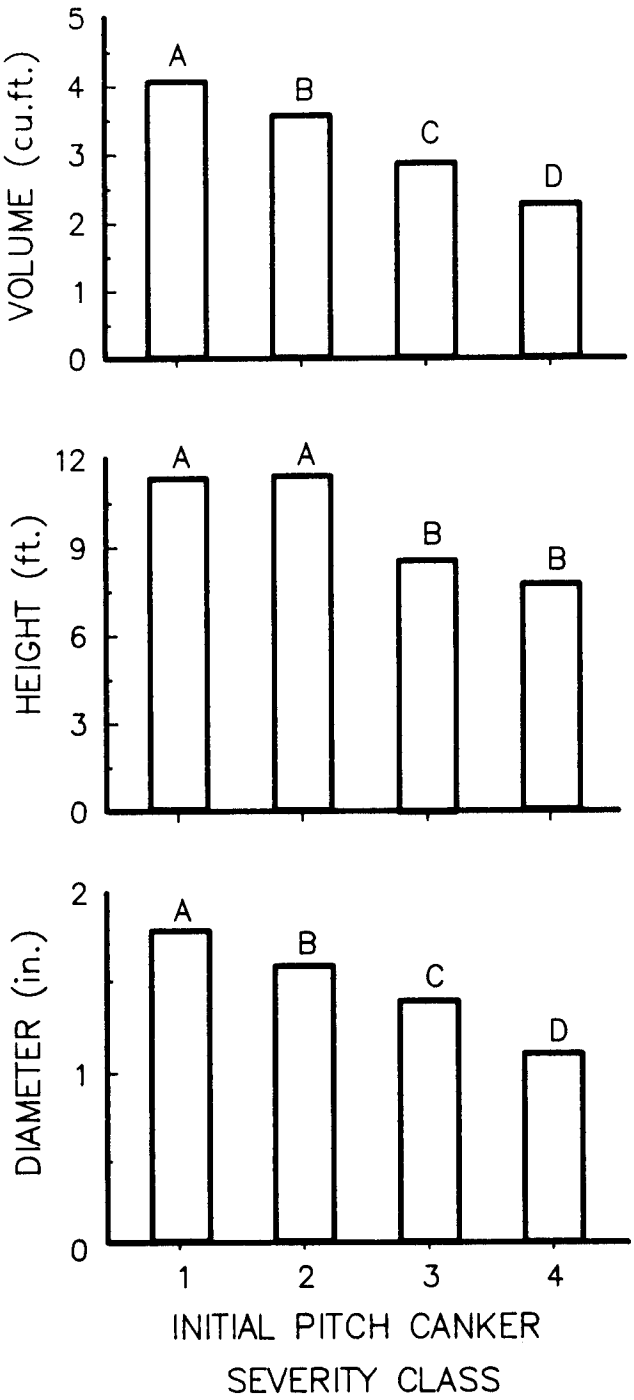

Figure 2. *Adjusted mean, post-thinning 5-year growth for slash pines of four different initial levels of pitch canker-induced crown loss severity. Pitch canker (PC) severity class 1 = no loss, healthy; 2 = Trace-10% crown loss; 3 = 11-30% crown loss; 4 = 31-50% crown loss. Within each graph, means from adjacent classes (1 vs 2, 2 vs 3, 3 vs 4) with a common letter do not differ significantly (p=0.05) according to least-squares means t-tests.*

may reduce damage from pitch canker by reducing competition-induced stress and enhancing physiologically active defense mechanisms. Reductions in moisture stress may be of greater importance than reductions in nutritional stress, given that nitrogen and/or phosphorus fertilization either has no effect on pitch canker or increases disease severity (Fisher et al. 1981). Recent research (Blakeslee et al. 1992) has shown that moisture stress fosters increased pitch canker development, however expression of genetic resistance is retained.

Tree growth progressively declined as disease severity increased. The adverse impact of increasing crown loss due to pitch canker may reflect the decreased photosynthetic capacity of affected trees as the disease effectively removes needle-bearing branches and/or the disease-induced reallocation of fixed carbon from normal growth functions to the intense resinosis response common to infected slash pines. The effects of PC on growth reported in this study are comparable to the lower range of losses reported by Arvanitis et al. (1984) where growth declined as the number of years of infection increased and the 5-year volume increment for severely affected slash pines in unthinned stands was between one-third and two-thirds of that accumulated by healthy trees.

If intra-specific competition is a minor factor affecting tree growth following thinning, the differential growth performance of trees among each of the four PC severity classes is a direct assessment of pitch canker's impact on growth. Using the volume growth of Class 1 (healthy) trees as the basis of comparison, volume loss of diseased trees during the 5-year period appears to reflect the amount of crown lost due to pitch canker; Class 2 trees (up to 10% crown loss) produced about 10 percent less volume; Class 3 trees (11-30% crown loss) produced about 27% less volume; Class 4 trees (31-50% crown loss) produced about 40% less volume. These results suggest that in thinned stands it may be possible, within the limits of the broad classifications of crown loss severity, to estimate volume loss from pitch canker by estimating disease severity.

Because this study used only dominant or co-dominant crown class trees, the observed differences reflect true post-thinning responses and do not reflect growth differentials between trees of lower and upper crown classes. Thinnings that favor dominants and co-dominants and bias against the more severely affected trees should favor the retention of crop trees with minimum potential for pitch canker induced growth loss and with maximum potential for recovery and growth.

Pitch canker can cause substantial losses in pulpwood size slash pine plantations. In many situations, forest managers have accepted these losses since therapeutic and preventative treatments were unknown. Although significant mortality can occur and substantial growth loss often occurs, affected stands normally survive and produce a merchantable crop. In some cases, the disease continues to progress, eventually forcing the manager or landowner to salvage harvest the stand. The favorable post-thinning responses reported in this paper suggest that operational thinning of young, pitch canker affected slash pine plantations on flatwoods spodosols may be a viable management option useful in retaining productivity following severe pitch canker outbreaks.

Acknowledgements

The authors thank the Integrated Forest Pest Management Cooperative for financial support and the research staff of Georgia Pacific Corporation for assistance with the collection of field data. Florida Agricultural Experiment Station Journal Series Paper No. R-01302.

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FOREST PEST MANAGEMENT ON TYPIC QUARTZIPSAMMENTS: A MANAGEMENT DILEMMA [1]

R.R. Cahal III, D.L. Kulhavy, W.G. Ross, W.D. Tracey and W.D. Hacker [2]

Abstract. Pine plantations on Typic Quartzipsamments in East Texas are difficult to establish. Forest management options following clearcutting are limited. A eight year regeneration study of the growth and survival of loblolly, *Pinus taeda*, L. shortleaf, *P. echinata* Mill., slash, *P. elliotii* Engelm and longleaf pines *P. palustris* Mill. was conducted to determine optimum tree species and treatments for reforestation; and to recommend practical alternative land uses and management strategies for Typic Quartzipsamments. With successful regeneration also comes insects and pathogens. Impacts of the Nantucket pine tip moth, *Rhyacionia frustrana*, (Comstock) the Deodar weevil, *Pissodes nemorensis*, Germar, *Annosus* root rot, *Heterobasidion annosusm* (Fr: Fr) Bref, fusiform rust, *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme* (Hedge and N. Hunt) Burdsall and G. Snow and the Texas leaf-cutting ant, *Atta texana*, (Buckley) will be discussed in the context of droughty site management.

Introduction

The sandhills are droughty, alluvial and marine deposits of relatively recent geological origin that are found from the barrens of New Jersey along the Atlantic Coastal Plain to Florida and then westward along the Gulf Coastal Plain to Texas (Burns and Hebb 1972). In the upper Gulf coastal plains of East Texas, Quartzipsamments occur on broad slightly convex interstream divides at elevations ranging from 300 to 700 feet above sea level and range in depths of 6 to 20 feet. In Nacogdoches and Rusk counties Quartzipsamments developed on outcrops of the Carrizo formation, continental stream deposits formed during the Eocene series of the Tertiary system. The Tonkawa soil series is classified as thermic coated Typic Quartzipsamments, and accounts for approximately 23,000 acres in Nacogdoches, Rusk, Panola, and San Augustine counties (Dolezel 1980). These soils are characterized by low fertility, rapid permeability and extreme acid reaction.

The original vegetation on the sandhills was an association of longleaf pine (*Pinus palustris* Mill.), turkey oak (*Quercus laevis* Walt.) and bluejack oak (*Quercus incana* Bartr.), commonly called scrub oaks and pineland three-awn (*Aristida stricta* Michx.), commonly known as wiregrass (Hebb 1957). The primary land use on Tonkawa soils today is woodlands (site index averages 55 for shortleaf pine *Pinus echinata* Mill.) althought the potential for pine is low due to droughty and infertile nature of the sand. Watermelons can be grown, but potential is low for any other cultivated crops. Sandhills are resistant to erosion and are considered important ground water recharge areas.

From 1973 to 1975 approximately 6,000 acres on Tonkawa were clearcut followed by extensive site preparation. Removal of all organic matter and surface litter from the site exposed the bare mineral soil to the sun and wind, which greatly decreased the moisture holding capacity of the soil and increased surface temperatures (Kroll et al. 1985). Repeated attempts were made to regenerate the area without success. Intensive management on this sensitive site provided incentive for a regeneration study.

From 1983 to 1990 a study was conducted by Tracey et al. (1991) on the site to determine the survival and growth of seven species/treatment combinations. Species/treatment combinations were: untreated loblolloy pine *Pinus taeda*, L., Terra-Sorb® treated loblolly, kaolin clay slurry treated loblolly, untreated slash pine *P. elliotii* Engelm, Terra-Sorb® treated slash, kaolin clay slurry treated slash, and containerized longleaf pine. The objectives of this study were to determine optimum tree species and treatments for reforestation; and to recommend practical alternative land uses and management strategies for Typic Quartzipsamments.

Containerized longleaf yielded the highest survival (> 50%) throughout the study followed by

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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loblolly Terra-Sorb® treated pine (38%) all other treatments were unacceptable (below 30% by the end of the eighth year). Tracey et al. (1991) recommended: 1) Encourage harvest systems that minimize site exposure and leave residual overstory; underplant pine; avoid clearcutting. 2) Site preparation on previously clearcut sites must be accomplished with minimal site disturbance and topsoil displacement. 3) Reforest droughty sites in East Texas with longleaf pine using container grown seedlings or loblolly pine treated with Terra-Sorb®. 4) Manage for non-timber resouces, including wildlife, limited recreation, and groundwater protection.

With successful regeneration also comes insects and pathogens. Artificial monocrop systems in forestry are of recent origin and their effects on the emergence of new pests and diseases are more likely to be the direct result of environmental change (Way 1981). Heavy winter and spring precipitation followed by periods of drought during the summer for the past two years and characteristics of the soil has caused undue stress to trees. Minor impact caused by insect and pathogens on the Tonkawa series include the Nantucket pine tip moth (NPTM), *Rhyacionia frustrana*, (Comstock), the deodar weevil, *Pissodes nemorensiss* Germar, annosus root rot *Heterobasidion annosus*m (Fr: Fr) Bref, and fusiform rust, *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme* (Hedge and N. Hunt) Burdsall and G. Snow.

Slash pine found scattered throughout the study area grows well on low lying soils with characteristics of Aquic Quartzipsamments. Moisture content of these soils insured excellent regeneration. Pathogens associated with slash pine, such as *Annosus* root rot and fusiform rust, are problematic.

The deodar weevil is a minor insect pest on the Tonkawa soil series. The weevil is found throughout the study area in low lying areas. The life cycle of this weevil differs from others in that the ovipostion occurs in the fall and the larvae feed on terminals during the winter. Adults emerge in the spring and remain inactive during the summer. Adults weevils feed on the inner bark often girdling a stem or twig. Weevil damage to terminals and the main stem of planted four to five year old loblolly pines was documented in areas of increased surface moisture due to record precipitation throughout the Tonkawa study site.

The Nantucket pine tip moth (NPTM) is widely distributed throughout the eastern and southern United States. NPTM are larval feeders of meristematic tissue of young pines causing significant damage, particularly in areas where forest regeneration practices favor its proliferation (Yates et al. 1981). Larval feeding severs the conductive tissue in the tip, causing it to turn brown and die. Infestations can result in growth loss, excessive branching, multiple terminals and deformed bushy trees and is of primary importance in even-age management of loblolly and shortleaf pines. While NPTM are a major forest insect pest in pine plantation management, on the Tonkawa study site they are secondary pests compared to the impacts caused by the Texas leaf-cutting ant, *Atta texana* (Buckley).

Atta texana confined to Texas and Louisiana, is the northernmost representative of this most specialized genus of Attini, a New World tribe of fungus-growing myrmicine ants. The range of the ant occupies much of the area of Texas and Louisiana lying between 92.5 and 101 degrees of longitude. In Texas, the range extends from near the Oklahoma border to the extreme southern border, with an extension into northeastern Mexico as far south as Vera Cruz.

Atta texana shows a decided preference for nesting in sandy or sandy loam soils, but is also capable of nesting in heavy soils and those of limestone origin (Smith 1963). These nesting areas (mounds) are most often found on the tops and sides of ridges where the water table is deep and nests can reach depths of 25 feet (ft) (Moser 1967,1984). *Atta texana* overturn the soil in excavating their tunnels and chambers. In building these tunnels and chambers, materials transported to the surface by ants are mixed with body fluids to form uniform pellets of soil (Weber 1966). The tunnels and chambers that *A. texana* construct in the soil are numerous and extend deeper than those of vertebrate animals. The nest area is usually marked by crescent shaped mounds about 6 to 12 inches in height and about 12 inches in diameter. Nests are conspicuous and abundant, reach sizes of 50 to 75 feet across, and have a decided impact on the forest landscape.

Atta texana shows a decided preference for grasses, weeds, and hardwood leaves. These leaf parts are gathered and used to cultivate their fungus. They prune the vegetation, stimulate new plant growth, break down vegetable material rapidly and in turn enrich the soil (Hölldobler and Wilson 1990). *Atta texana* is a forest pest because it cuts the needles from both natural and planted pine seedlings. The pines usually escape destruction as long as there is other green vegetation, but in the winter pine needles

satisfy the ants' need for green plant material (Moser 1967). Spatial distribution of *A. texana* is based on suitable habitat availability. The clearcutting disturbance of the study site quickly became a matrix (the most extensive and most connected landscape element type present, which plays the dominant role in landscape functioning (Forman and Gordon 1979)) of ideal ant habitat. Ant densities are normally higher in secondary than in primary vegetation (Haines 1978). Nest dimensions are significantly correlated with distances foraged by various species of leafcutters (Fowler and Robinson 1979). *Atta* foraging patterns are influenced by the availability and locations of preferred plant species in its territory (Waller 1982). Adaptations in their pattern of the nest distribution enables ants to use the food available in the habitat more effectively and to reduce the unfavorable results of competition among societies, which limit their reproduction and numbers (Cherrett 1968).

The objectives of the study were to: (1) determine the overall effects of *Atta texana* on soil texture, and organic matter within the mound and adjacent areas; (2) estimate the landscape area affected by *Atta texana* on different sites on an area on the Tonkawa soil series of thermic coated Typic Quartzipsamments; and (3) determine the distribution of *Atta texana* on a known area of Typic Quartzipsamments.

Methods

The study area is located along the FM 1078 road corridor (right of way) and an area of regeneration north of the Camp Tonkawa Boy Scout Camp, located in northern Nacogdoches and southern Rusk counties, 10 km west of Garrison, Nacogdoches Country, Texas. Distribution of the known nesting areas of *A. texana* were examined on these two different ecosystems. This study area encompasses many soil types that are capable of sustaining *A. texana*. These include Tonkawa, Darco, Tenaha and Briley soil series. *Atta texana* show a decided propensity for the Tonkawa soil series of thermic coated Typic Quartzipsamments for their mounds.

Soil samples were collected from 30 *A. texana* mounds found on the Tonkawa soil series. Samples were taken on the surface, and at depths of 6 inches (in.), and 50 in. on the *A. texana* mounds (an area currently being impacted by *A.texana*). This procedure was replicated on the inter-mound area (an area once effected by *A. texana*) and from a control area of similar physical characteristics away from the area of influence for a total of nine samples per mound. All soil samples were catalogued, oven dried, and sifted with a 10 gauge soil sieve. Loss on ignition methodology of each soil sample was processed in a Muffle furnace at a temperature of 500° C. This determines the percent of organic matter lost to the nearest 0.01%. Bouyoucos analyses (Bouyoucos 1962) was performed on 100 grams of each soil sample to determine the percent clay, percent silt and percent sand.

Using aerial photographs and ground truthing, all mounds and foraging openings were located in the regeneration study area. All nesting mounds and created forage openings were measured in the four cardinal directions (north, south, east, and west). This was done to measure the overall impacts of the nesting and foraging territories on the forest landscapes.

Results and Discussion

Atta texana in overturning the soil in excavating their tunnels and chambers have a profound effect upon organic matter and texture of the Tonkawa soil series. The tunnels and chambers that *A. texana* construct in the soil are numerous and extend deeper than those of any other vertebrate animals. In building these tunnels and chambers materials transported to the surface by ants are mixed with body fluids to form uniform pellets of soil.

Using Bouyoucos analysis to determine soil texture, it was found that *Atta texana* significantly increases the percent clay. In testing the percent clay by site it was found that percent clay at the mound surface was statistically more significant than at the intermound surface, which in turn was found to be statistically more significant than the control surface (Figure 1) at the a = .05 percent level. In comparing percent clay by depth (Figure 2) it was found that the mound surface was statistically more significant than than the 6 in. or 20 in. depths at the a = .05 level.

Soil brought to the mound surface by *Atta texana* is significantly lower in percent organic matter than the percent organic matter present in the soil at the intermound and control surfaces (Figure 3). Organic matter for the mound at 6 in. and 20in. is statistically higher than the same depths at the intermound and the control at a = .05 percent confidence interval. In testing the percent organic matter by site (Figure 4) it was found that percent organic matter for the mound at the 6 in. depth was

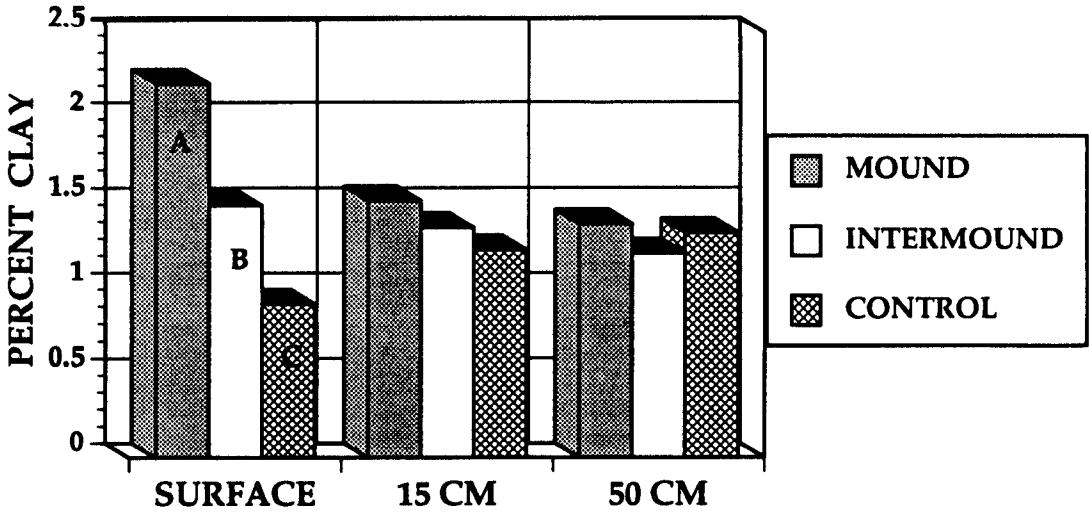

Figure 1. *Percent clay by site for Tonkawa soil series tested using Bouyoucos analysis method.*

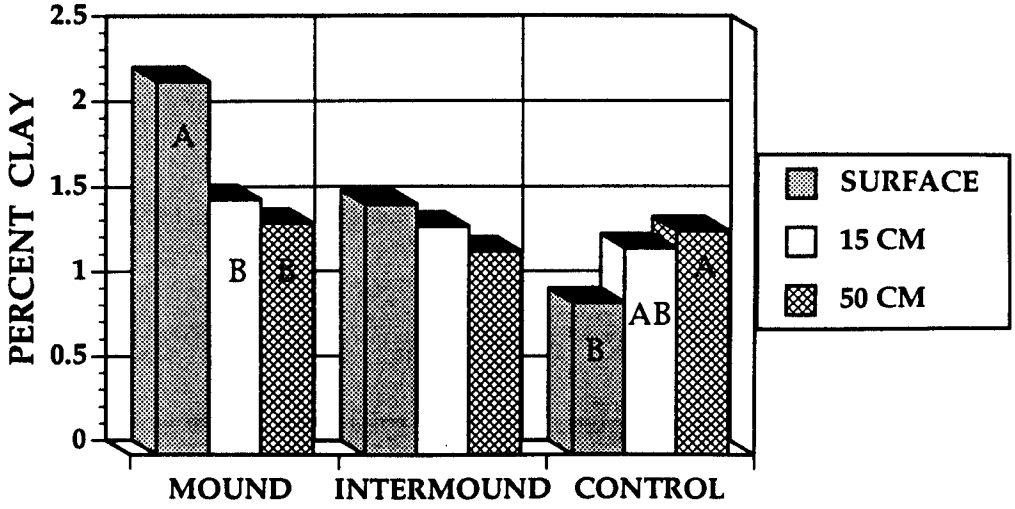

Figure 2. *Percent clay by depth for Tonkawa soil series tested using Bouyoucos analysis method.*

significantly higher than the surface and 20 in. at a = .05 percent confidence interval.

Atta texana intrinsically utilize created openings and disturbances (an event or events that causes a significant change from the normal pattern in an ecological system, Forman and Godon 1986) to create nesting areas and benefit from the use of corridors (a narrow strip of land that differs from the matrix on either side) in their expansion. *Atta texana* is found along the FM 1087 road corridor and along the edges of stream side corridors. In the regeneration areas *Atta texana* reacted to the monocultural habitat and dispersed in all directions causing massive destruction to the loblolly plantation in the area. Currently there are 52 openings found throughout the study area. The total area of the study is 320 acres or 13939200 sq. ft. Total defoliation attributed to *A. texana* accounts for 2970870 sq. ft or 21.5 % of the total landscape area. The immediate nesting areas or mounds account for 1.25% of the total area affected by *A. texana.* Not all disturbance areas contain mounds due to natural mound mortality or chemical treatment with methyl bromide.

Conclusions and Recommendations

While most consider *Atta texana* an economic pest, in nature they are of fundamental ecological importance. *Atta texana* serves an important ecological function of soil amelioration and increases biodiversity, especially on the very sensitive ecosystem of the Tonkawa study area. Its soil-enriching capabilities outway its pest status. *Atta texana* is unique in regards to soil preference, its nesting mounds, foraging areas and spatial distribution.

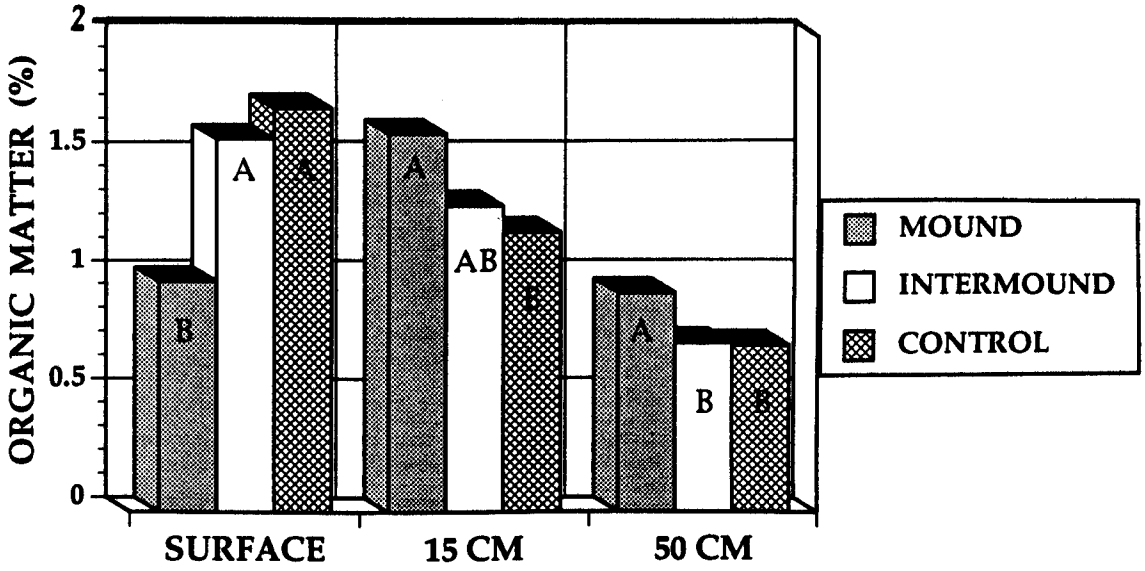

Figure 3. *Mean percent organic matter by depth for Tonkawa soil series tested.*

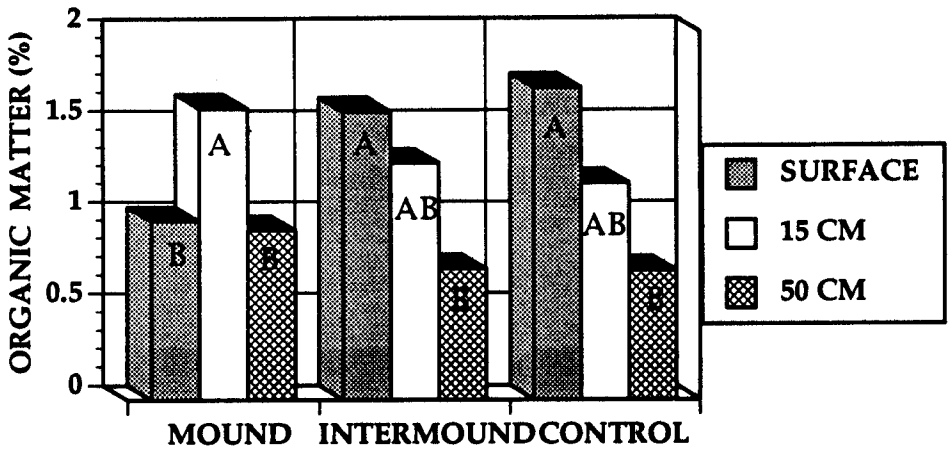

Figure 4. *Mean percent organic matter by site for Tonkawa soil series tested.*

Plantation forestry, particularly eucalyptus and pines, is adversely affected by *Atta* defoliation (Cherrett 1986). They are well-adapted for attacking monocultures (Vilela and Howse 1986) and the most disastrous outbreak of *Atta* can be attributed to the introduction of monoculture systems (Hölldobler and Wilson 1990). Repeated efforts at regeneration and control of *Atta texana* in certain areas of the study area has failed. Low site productivity makes intensive forest silvicultural practices unprofitable. Therefore it is our recommendations that 1) native vegetation be allowed to grow in the openings created by *Atta texana* 2) the area be managed for wildlife and limited recreation 3) *Atta texana* be allowed to continue their biological function of soil improvement and 4) the area be utilized as an important teaching aid for forest pest management and forest entomology labs because of the uniqueness of the area in regards to the pathogens and insects present.

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EVALUATING SUSCEPTIBILITY OF RED-COCKADED WOODPECKER CAVITY TREES TO SOUTHERN PINE BEETLE IN TEXAS [1]

William G. Ross, David L. Kulhavy and Richard N. Conner [2]

Abstract. Characteristics of loblolly (*Pinus taeda* L.) and shortleaf (*Pinus echinata* Mill.) pine trees favored by the endangered red-cockaded woodpecker, *Picoides borealis* (Vieillot) for nesting and roosting cavities over much of eastern Texas, tend to make these trees highly vulnerable to mortality from bark beetle attack. Resin flow and xylem moisture potential, often used as indicators of pine susceptibility to bark beetle mortality, were measured in several red-cockaded woodpecker cavity tree clusters in the Angelina and Davy Crockett National Forests. No differences in xylem moisture potential were found, while resin flow varied by site, tree species, and cavity tree type. With over half of cavity tree mortality in Texas caused by southern pine beetle, *Dendroctonus frontalis* Zimmerman, pro-active management to reduce bark beetle hazard in southern pine stands is imperative.

Introduction

The red-cockaded woodpecker, Picoides borealis (Vieillot) (RCW), has been federally listed as an endangered species since 1970. With populations occurring in a variety of pine and pine-hardwood ecosystems of the South and Southeastern U.S., the RCW is unique in that it excavates roosting and nesting cavities exclusively in living pine. Old-growth longleaf pine (*Pinus palustris* Mill.) appears to be favored when available (U.S. Fish and Wildlife Service, 1985), but shortleaf (*P. echinata* Mill.), loblolly (*P. taeda* L.) slash (*P. elliotii* Engelm.), Virginia (*P. virginiana* Mill.) and pitch (*P. rigida* Mill.) pines are readily utilized (Hooper et. al. 1980; Kalisz and Boettcher, 1991). RCW populations in Texas (Conner and Rudolph, 1989) and southwide (Costa and Escano, 1989) are generally declining due to loss and fragmentation of old-growth southern pine habitat (U.S. Fish and Wildlife Service, 1985; Conner and Rudolph, 1991a).

In addition to excavating its cavities in living pines, RCWs peck small holes, called resin wells, around cavity entrances that cause a copious flow of resin down and around the boles of their cavity trees. The resin serves as a barrier against rat snakes, *Elaphe obsoleta* (Say), a major RCW predator (Rudolph et al. 1990a), but has little effect on cavity competitors (Rudolph et al. 1990b). Attack by southern pine beetle (*Dendroctonus frontalis* Zimm.) is the major cause of RCW cavity tree loss in Texas loblolly and shortleaf pine stands in Texas (Conner et al. 1991a, Kulhavy et al. 1992). Trees favored by the RCW for nesting and roosting cavities tend to be old, ranging from approximately 60 to 130 years of age in loblolly and shortleaf pine, with slow radial growth, and infection with red-heart rot (*Phellinus pini*) (Conner and Locke 1982, Conner and O'Halloran 1987, Rudolph and Conner 1991). Such characteristics tend to place pine trees at high risk of attack by southern pine beetles and other phloem-boring beetles, even when bark beetle populations are generally at endemic levels.

A primary host defense against bark beetles is preformed resin flow (Hodges et al. 1979, Paine et al. 1985). Preformed resin is resin present in the resin ducts at the time of wounding or insect attack, rather than resin produced as a response to these stimuli. Bark beetles, particularly during endemic population levels, are often unable to colonize and kill pines with high resin flow. An important factor in predisposing trees to insect attack is moisture stress. Lorio and Hodges (1977) found that stressed pines were much less able to resist southern pine beetle attach than unstressed trees.

The purpose of this study is to examine the effects of RCW cavity tree excavation and resin-well pecking on preformed resin flow and tree moisture stress. Implications for management based on these and other characteristics of RCW cavity trees and cavity tree clusters will be explored.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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Methods and Materials

Data were collected in the Bannister Wildlife Management Area of the Angelina National Forest (ANF) of Texas periodically during the growing seasons of 1988 and 1989. Data were also collected in 1989 and 1990 from the Neches district in the Davy Crockett National Forest of Texas, approximately 100 km west of the ANF.

Red-cockaded woodpecker cavity trees evaluated in this study were either loblolly or shortleaf pines. Sample trees in the ANF were divided into four categories:

1. Trees currently used for RCW nesting and roosting that had been established prior to 1987 (old active),
2. Trees previously used for nesting and roosting, but currently not used by RCW (inactive),
3. Trees having external characteristics associated with RCW trees, such as age, evidence of heart-rot, etc., but no history of RCW utilization (potential) and
4. Cavity trees excavated after 1987 (new active).

In the DCNF, only the first three categories were sampled. Approximately 60 trees, divided into appropriate categories, were sampled in each forest. The same trees were used in each sampling interval.

Resin flow was measured by driving a 2.54 cm diameter circular arch punch to the interface of xylem and phloem at approximately 1.4 m (diameter at breast height) on the bole following the method of Lorio et al. 1990. All holes were punched between 0700 and 1000 hours to minimize effects of diurnal variation in resin flow (Nebeker at al. 1988). Triangular metal funnels were then placed under the wounds to divert exuded oleoresin into a clear plastic graduated tube. Resin flow was recorded at 8 and 24 hours after wounding. After recording twenty-four hour values, funnels and tubes were removed, and the bark plug replaced. To avoid placing undue additional stress on the trees, only one sample per tree was taken during any one sampling period.

Xylem moisture potential was evaluated using the pressure chamber technique (Scholander at al. 1965). Twig samples were taken from the upper crowns of cavity and non-cavity trees selected from among the tree samples for resin flow. Sampling took place during peak stress times of 1300 to 1500 hours at the same times as resin sampling. Only established active RCW trees, inactive trees, and potential trees were evaluated. Newly excavated cavity trees were too few in number to provide valid comparisons. Sample collection was accomplished with a shotgun, and moisture status evaluated within sixty seconds of removal.

Data were analyzed using the SPSS^X statistical software package (Norusis 1985). Resin flow at 8 and 24 hours was analyzed separately for each species and by each forest. Resin flow by species was analyzed using the Mann-Whitney U-Wilcoxon Rank Sum test (Norusis 1985). Kruskal-Wallis non-parametric rank analysis was used to evaluate resin flow by cavity tree type. When differences were significant at $P \leq 0.05$, ranked means were separated using the non-parametric multiple comparison procedure described by Danial (1990) using an experimentwise error rate of 0.20. The same procedures were used to analyze xylem moisture potential.

Results

Overall 8 and 24 hour resin flow, combining all cavity tree types, showed significant differences in resin flow by species (Figures 1 and 2), but with the species exhibiting highest resin flow differing by forest. In the Angelina National Forest, shortleaf pine had higher resin flow, while loblolly pine had the highest resin flow in the DCNF.

Analysis of sample trees by cavity tree type showed similar difference by species. In the ANF there were no significant differences in resin flow by cavity tree type in loblolly pine (Figures 3 and 4). In shortleaf pine however, newly activated cavity trees had much higher resin flow than old active, inactive or potential.

Results from the Davy Crockett National Forest were different (Figures 5 and 6). Active loblolly pine cavity-trees had significantly higher resin flow than the potential trees. For shortleaf cavity trees, resin flow was highest in the potential trees and lowest in inactive trees.

No significant differences were found in xylem moisture potential between cavity tree types in either forest. It should be emphasized, however, that these are results taken only during hours of peak stress and do not include newly excavated cavity trees.

Discussion

Cavity excavation and continual resin-well pecking by red-cockaded woodpeckers on old loblolly and shortleaf pine trees appears to affect preformed

resin flow. Direction and magnitude of these effects vary considerably with tree species and site conditions, however. Because of this variation it is difficult to generalize about effects of RCW activity on cavity tree vulnerability to bark beetles in terms of preformed resin flow. Given their general senescence, low vigor, and infection by pathogens, RCW cavity trees, especially shortleaf and loblolly, are naturally at a stage oaf life where vulnerability to mortality from all sorts of factors, including bark beetles, may be high.

Traditional approaches to bark beetle infestations include salvage cutting, cutting infested trees and applying insecticide, cutting infested trees plus a buffer zone and leaving these trees in the woods, and piling infested material and burning (Swain and Remion, 1981). All of these strategies except piling and burning may be appropriate under suitable conditions to prevent SPB infestations from reaching RCW cavity trees. Use of behavioral chemicals, such as the SPB anti-aggregation pheremone Verbenone, is currently being evaluated experimentally as a method of diverting attack away from high-value areas such as RCW colonies (Ron Billings pers. comm.). Artificial nest cavity construction, most commonly involving insertion of a prefabricated next box into a suitable living pine, is showing great promise in mitigating the impact of natural cavity tree loss. As important as these tactics are in the effort to prevent further decline in RCW populations and habitat, they are not substitutes for planning to reverse forest fragmentation and provide an adequate supply of natural habitat.

Long-term pro-active management strategies to favor the woodpeckers in loblolly-shortleaf stands must include reducing risk of bark beetle attack by increasing overall forest health. Thinnings to maintain low to moderate pine basal area, prescribed burning, and favoring longleaf pine in its native range are commonly suggested (Conner and Rudolph, 1989); Conner et al. 1991a; Conner at al 1991b). Prompt response to SPB outbreaks is critical to reducing impact, but is inadequate unless accompanied by pro-active management. Devising innovative approaches to managing forest ecosystems for optimum health of their native constituents in conjunction with providing society with the forest products and values it demands is the continuing challenge facing foresters and other resource management professionals.

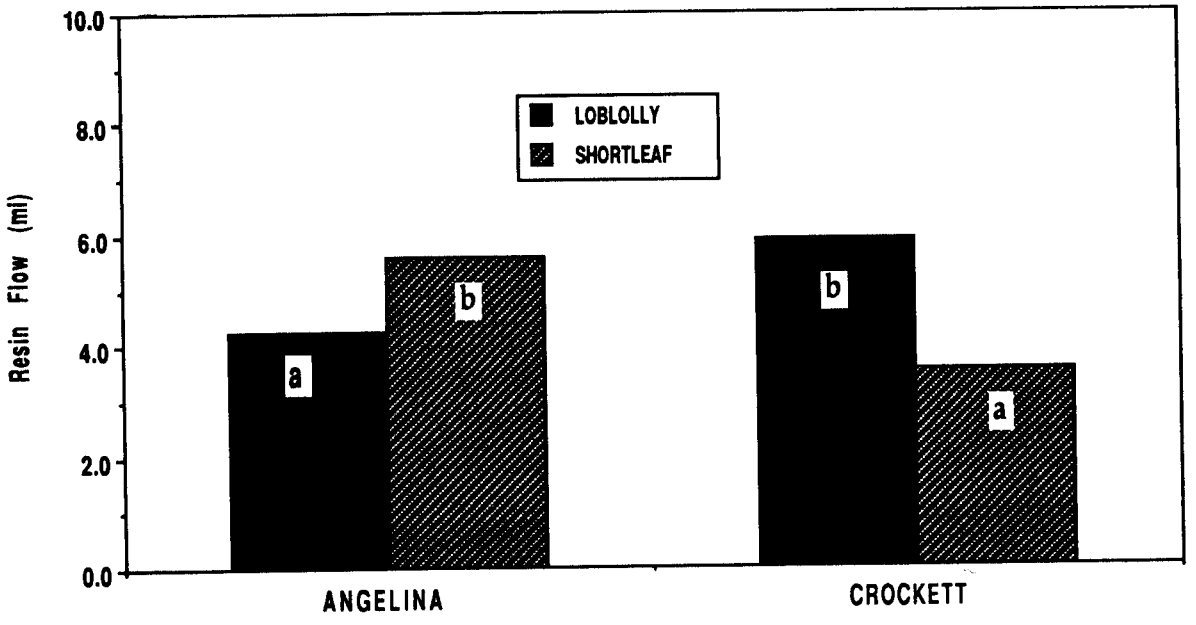

Figure 1. Eight-hour resin flow by species and forest.

Acknowledgements

This work was supported through a cooperative research grant with the Southern Forest Experiment Station, U.S.D.A. Forest Service and Stephen F. Austin State University (agreement no. 19-86-068) and McIntire-Stennis funds administered through the College of Forestry.

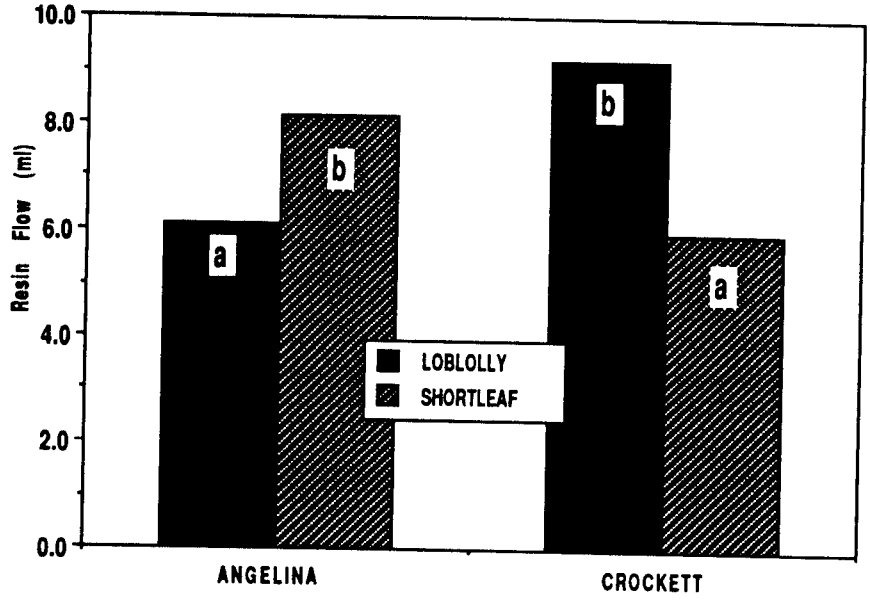

Figure 2. *Twenty-four-hour resin flow by species and forest.*

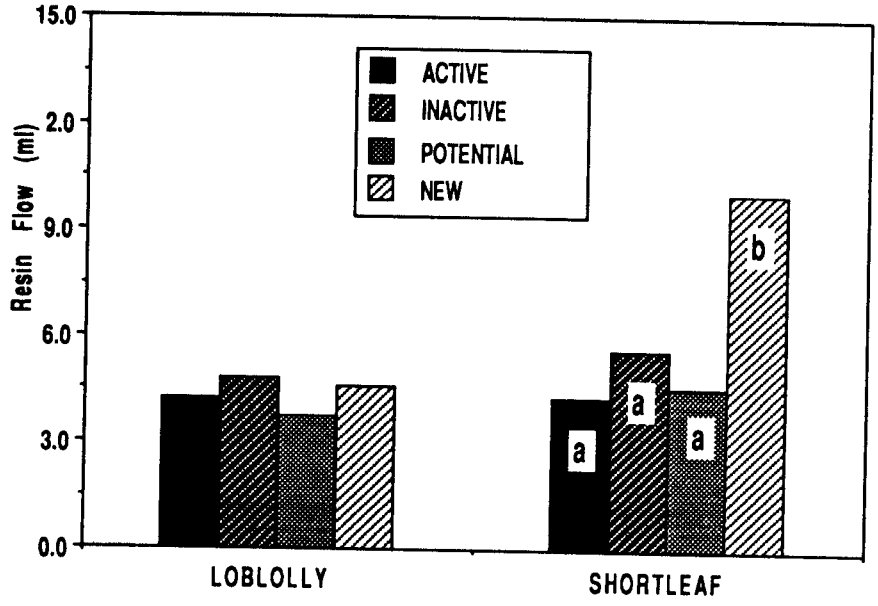

Figure 3. *Eight-hour resin flow by cavity tree type and species, Angelina National Forests.*

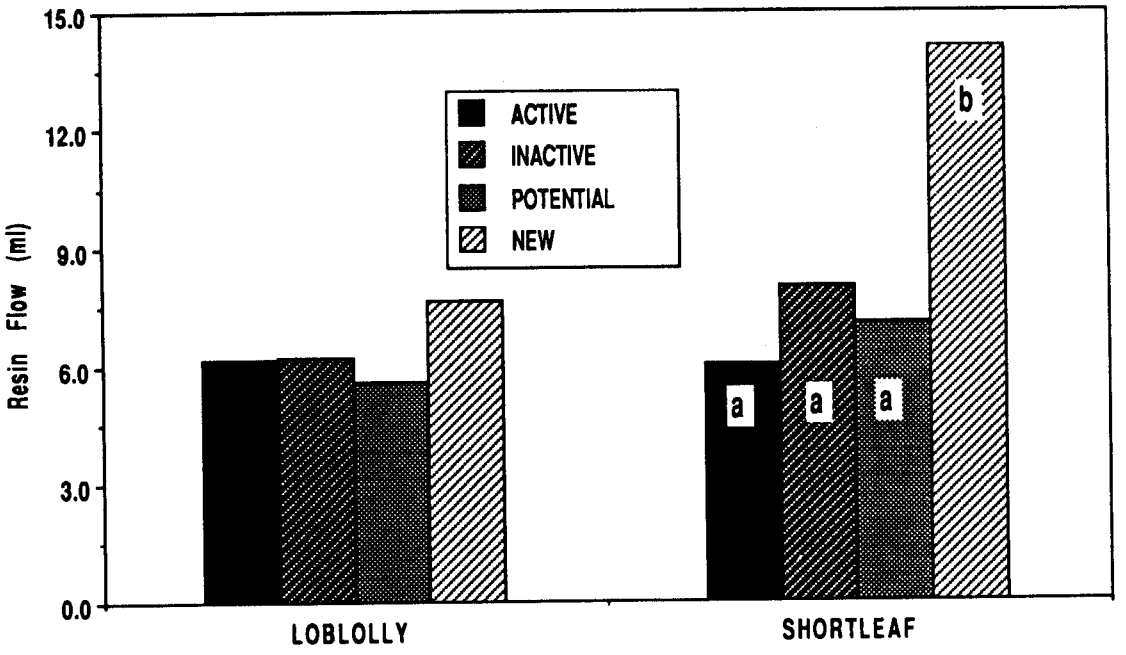

Figure 4. *Twenty-four-hour resin flow by cavity tree type and species, Angelina National Forest.*

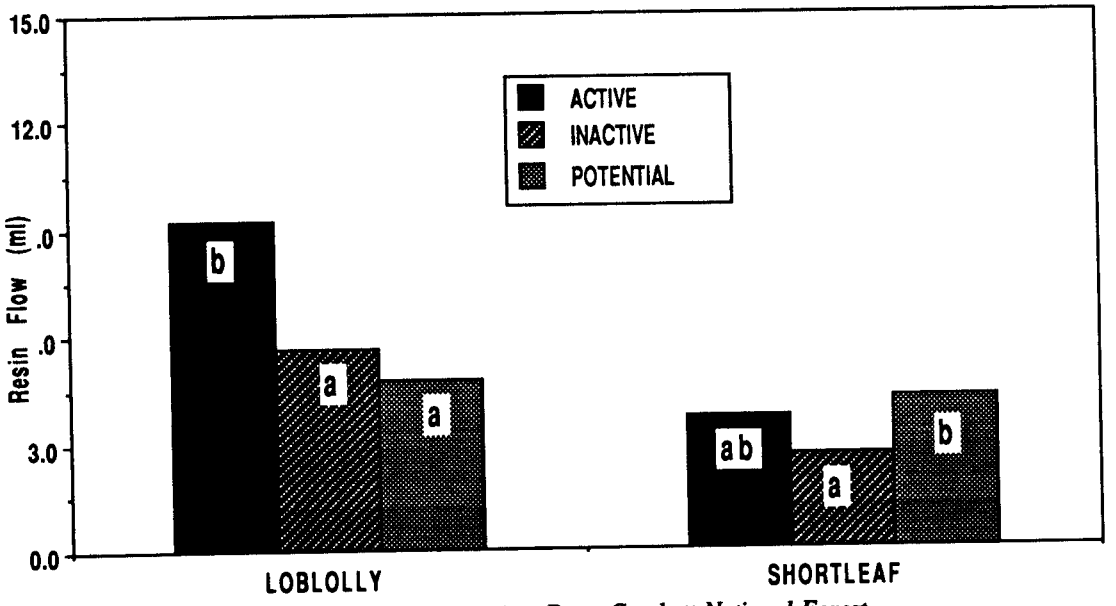

Figure 5. *Eight-hour resin flow by cavity tree type and species, Davy Crockett National Forest.*

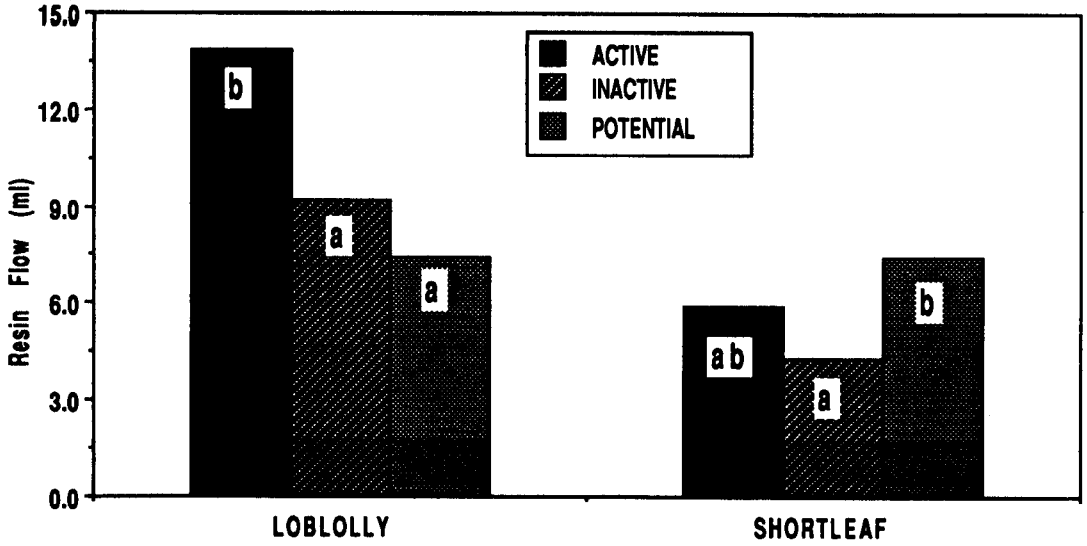

Figure 6. *Twenty-four-hour resin flow by cavity tree type and species, Davy Crockett National Forest.*

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EFFECTIVENESS OF SYNTHETIC BEHAVIORAL CHEMICALS FOR MANIPULATION AND CONTROL OF SOUTHERN PINE BEETLE INFESTATIONS IN EAST TEXAS [1]

Ronald F. Billings and William W. Upton [2]

Abstract. In an on-going effort to develop improved methods for controlling the southern pine beetle (SPB), synthetic formulations of the semiochemicals verbenone (SPB inhibitor) and frontalin (SPB aggregation pheromone) were applied to active infestations in East Texas from 1990-1992. The combination of felling all currently-infested trees and applying verbenone to adjacent standing trees successfully controlled 20% of 24 treated infestations (83%). Applications of verbenone without tree felling or felling all infested trees without verbenone slowed, but failed to consistently halt, infestation spread. In other tests, applications of verbenone to uninfested pines at the advancing front of single infestations and frontalin to uninfested pines in the opposite direction of the same infestations was successfully used to change the direction of infestation spread in eight of nine treated spots. The ability to manipulate SPB populations in this manner has utility for protecting high value resources, such as colony sites of the endangered red-cockaded woodpecker, that are located in the path of expanding infestations. Prospects for operational use of behavioral chemicals for SPB control are discussed.

Introduction

The southern pine beetle (SPB), *Dendroctonus frontalis* Zimm. (Coleoptera: Scolytidae), is the most destructive insect pest of southern pine forests. From 1960 to 1990, losses attributed to this insect throughout the southeastern United Stated amounted to more than $900 million (Price et al. 1992). During this thirty-year period, foresters and land managers have utilized a variety of direct control strategies and tactics to reduce resource losses, including chemical and mechanical methods (Billings 1980, Price et al. 1992). Since 1970, the most commonly-applied methods to halt the characteristic expansion of multiple-tree infestations have been cut-and-remove (salvage) and cut-and-leave (Billings 1980). Since 1985, the Texas Forest Service, among others, has been exploring the use of synthetic behavioral chemicals in an effort to develop additional options to suppress SPB infestations.

Several beetle- and host-produced volatiles play a role in the host selection and mass attack behavior of the SPB (Vité and Renwick 1968; Payne 1980). The female-produced compound known as frontalin is the primary aggregation pheromone of SPB (Kinzer et al. 1969). Synthetic frontalin has proven useful for inducing SPB attacks on standing pines (Vité and Francke 1976) or as a means to disrupt small infestations (Richerson et al. 1980). Verbenone, an inhibitory compound produced by male SPB (Renwick 1967; Payne 1980), shows promise as a potential SPB control tactic. In earlier field tests, Payne and Billings (1989) demonstrated that (S)-verbenone applied to uninfested pines around the leading edge of small expanding infestations (spots) effectively slowed rates of spot growth. A more effective treatment for completely disrupting the growth of SPB infestations consisted of felling all infested trees in combination with verbenone applied to nearby uninfested (buffer) trees. Although these tactics showed promise, the authors recognized the need for additional replications and modifications in the deployment of verbenone before the methods could become operational.

In the present study, field trials were conducted from 1990 to 1992 in East Texas to evaluate the effectiveness of improved formulations of synthetic behavioral chemicals (Salom et al. 1992) for suppressing expanding SPB infestations. These investigations represent a continuation of earlier studies by Payne and Billings (1989). In additional field tests, the potential use of behavioral chemicals to change the direction of SPB infestation spread was assessed.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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Materials and Methods

Behavioral Chemicals and Elution Devices

A series of field bioassays with attractant-baited traps (Salom et al. 1992) demonstrated that an enantiomeric ratio of 34%(+):66%(−) verbenone was more inhibitory to adult SPB than the 17%(+):83%(−) verbenone used in previous treatments to suppress infestations (Payne and Billings 1989). The former was therefore used as the inhibitory component for both suppression and manipulation treatments described herein. The verbenone elution device was a white, 5 x 10 cm polyethylene bag (0.75 or 0.85 mil thick) containing a 4.5 x 7 cm cellulose sponge. Each bag was filled with 5 ml verbenone, heat sealed, and stored refrigerated until deployment. This sealed bag eluted verbenone at rates averaging 9.4 mg/hour for 20 - 30 days during summer months (Salom et al. 1992). The 34%(+):66(−) verbenone was formulated by mixing two parts 17%(+):83%(−) verbenone (Bedukian Research, Danbury, CN) with one part 69%(+):31%(−) verbenone (Phero Tech Inc., Delta, British Columbia).

In conjunction with the SPB inhibitor verbenone, the manipulation of infestations to change the direction of spread employed the SPB attractant frontalin. To induce attacks on uninfested pines, one Eppendorf capsule in a brown polyethylene pouch was attached to each tree; the capsule contained 400 micrograms of 99% pure frontalin, provided by Phero-Tech Inc.

Infestations

Field tests were conducted during the late spring and summer of 1990, 1991, and 1992 in loblolly pine *(Pinus taeda* L.) and shortleaf pine (*Pinus echinata* Mill.) forests of East Texas. Candidate infestations were evaluated for probability of continued expansion, based on density of uninfested host type (Hedden and Billings 1979) and apparent intensity of beetle activity (e.g. total number of currently-infested trees and the presence of fresh-attacked trees as defined by Billings and Pase 1979). Only those infestations in the process of expanding were selected for treatment. Infestations in plantations and natural stands of various ages (10-60 years) were used for each treatment. Of the 42 infestations treated with verbenone to evaluate control tactics (suppression), 33 were monitored for at least one week prior to treatment to confirm infestation expansion and to determine expansion rate. The other nine infestations were treated upon initial visit. The infestations ranged in size from 5 to 184 currently-infested trees (mean = 69) at time of treatment (Table 1).

Infestations in which behavioral chemicals were applied in order to change direction of spread (manipulation) ranged from 25 to 85 active trees at time of treatment, with a mean of 61 trees. Seven of nine infestations were in sawtimber stands with mean diameters ranging from 10-14 inches; the remaining two were in pulpwood-sized plantations (Table 3). Each spot was monitored for one week prior to manipulation with behavioral chemicals to document occurrence, direction and rate of spot spread.

Pre-treatment Methods

The same pretreatment methods were used for both suppression and manipulation treatments. Upon initial visit to each beetle spot, the following data were recorded: total number and diameter at breast height (DBH) of infested trees, SPB brood stage at breast height, tree species composition (% loblolly), stand density (pine and hardwood basal area measured with a 10 BAF prism), stand type, and location.

Immediately prior to treatment, each spot was remeasured and the number, DBH, and brood stage of each tree attacked during the pretreatment monitoring interval were recorded. For the pretreatment interval, the actual number of additional trees attacked per day in each spot was computed and compared to rates of spread as predicted by a spot growth model (Stephen and Lih 1985).

Three suppression tactics and one manipulation tactic were evaluated on active infestations located primarily on the Angelina and Davy Crockett National Forests and Huntsville State Park in East Texas.

Suppression treatments consisted of (1) verbenone only, (2) felling all currently-infested trees only, and (3) felling all currently-infested trees plus verbenone. In treatment 1, the verbenone elution devices (bags) were applied to standing, fresh-attacked trees (stage 1 trees as defined by Billings and Pase 1979) and to unattacked pines in a horseshoe-shaped buffer zone, about 40 - 60 feet wide, at the expanding front of the spot. In treatment 2, all currently-infested trees were felled toward the spot origin; uninfested buffer trees, those typically felled in the cut-and-leave method, were left standing with no application of verbenone. In treatment 3, the same uninfested buffer

trees were treated with verbenone as in treatment 1 and, in addition, all currently-infested trees and those under SPB attack were felled toward the spot origin and left on site. The bags were attached to target trees with a staple gun at a height of 2 m. The number of bags varied from 1-3 per tree depending upon the proximity to fresh-attacked trees and tree diameter. As a general rule, in each spot as many trees were treated with verbenone in treatments 1 and 3 as there were currently-infested trees in the spot.

To change the direction of infestation spread, a verbenone buffer was established around the advancing front of designated infestations, as per suppression treatment 1. Simultaneously, uninfested trees in the opposite direction of the front were baited with SPB attractant. The number of trees baited with attractant was equal to the number of fresh-attacked trees at the time of treatment. The attractant lures were attached with a staple gun, one per tree, at a height of 2 m. In addition, two uninfested pines, situated one chain in advance of the most recently attacked trees in the original direction of spot growth, were flagged as "simulated RCW cavity trees." The ultimate goal of the manipulation study was to protect these target trees from eventual SPB attack by reversing the direction of infestation spread.

Post-treatment Methods

Infestations were revisited at weekly intervals for four to six weeks following treatment. The number and DBH of trees attacked during the post-treatment interval were recorded. Only trees that were successfully colonized were included in the final analysis. To measure treatment efficacy, actual numbers of additional trees killed per day following treatment were compared to pretreatment growth rates. In addition, actual post-treatment growth rates were compared to mean growth rates predicted to occur in the absence of treatment, using the spot growth model (Stephen and Lih 1985).

To evaluate the effectiveness of the manipulation tactic, the number and DBH of trees attacked by SPB following the treatment date, together with their location within the treated spot (original head or baited head), were recorded. The manipulation was considered successful if beetle attacks in the treated infestation shifted from the original head to the baited head during the 4-week post-treatment interval. Also, whether the designated "RCW cavity trees" become infested at the original head of each spot was noted as an additional measure of treatment efficacy.

Results

Model Validation

For the 33 spots monitored prior to treatment, mean rate of spot growth was 2.39 trees attacked per day, compared to model predictions of 2.61, based on input data collected at time of first visit. On the average, the model over predicted spot growth by only 9%, although considerable variation occurred between actual and predicted spot growth rates for individual infestations (Table 1). As in a previous study (Payne and Billings 1989), the model provided a practical means of confirming the efficacy of different treatment tactics by predicting tree losses that would have occurred in the absence of control treatments.

Treatment 1

Of the eight infestations treated solely with verbenone, only two (25%) were successfully controlled (Table 1A). Compared to pre-treatment rates of spot growth, post-treatment growth rates were slowed in four of the spots, although attacking beetles eventually breached the verbenone buffer. Overall, this treatment reduced rates of spot growth by 70% (compared to pre-treatment growth rates) and 66% (compared to post-treatment model predictions) during the 6-8 week post-treatment interval (Table 3). Only one spot (3) showed no apparent treatment effect.

Treatment 2

Felling all beetle-infested trees only, with no verbenone buffer, stopped spot growth in four of ten treated spots (40%) (Table 1B). Among all spots combined, treatment 2 reduced spot growth by 57% (pretreatment) and 72% (post-treatment model predictions) (Table 3). Only one infestation (14) showed no apparent treatment effect.

Treatment 3

The felling of all infested trees in combination with a verbenone buffer was effective in completely suppressing all but 4 of 24 spots (83%) (Table 2). The spot growth model predicted no spot growth in the absence of treatment for only one spot (3). Overall, this treatment reduced initial rate of spot

Table 1. *Growth rate of southern pine beetle infestations before and after treatment with 34%(+):66%(-) verbenone (Treatment 1) and felling currently-infested trees without application of verbenone (Treatment 2), East Texas, 1990-1992.*

A. Treatment 1 - Verbenone only

			Pre-treatment					Post-treatment					
Year	Spot no.	Mean DBH (in)	Initial # of infested trees	Growth interval (days)	New trees attacked	New trees/ day	Predicted trees/ day[a]	Infested trees at treatment	Total verbenone applied (ml)	Growth interval (days)	New trees attacked	New trees/ day	Predicted trees/ day[a]
1990	1	10.0	35	8	4	0.5	1.4	35	200	56	16[d]	0.3	1.3
	2	8.6	43	7	6	0.9	0.7	47	175	59	12[d]	0.2	0.9
1991	3	17.1	5	0	0	0.2[b]	—	5	150	41	10[f]	0.2	0.0
	4	9.3	32	4	2	0.5	0.5	34	350	42	2[c]	0.1	0.6
	5	6.9	61	9	25	2.8	0.6	77	780	41	28[d]	0.7	0.6
	6	9.1	78	9	21	2.3	2.3	74	700	42	23[d]	0.6	1.9
	7	6.6	101	6	22	3.7	5.3	105	830	48	20[c]	0.4	1.6
1992	8	14.0	55	0	0	1.8[b]	—	55	375	42	59[d]	1.4	4.2
	Mean	10.2	51			1.58	1.80	54	445			0.47	1.39

B. Treatment 2 - Fell all currently-infested trees only

1990	9	8.3	61	0	0	1.0[b]	—	61	—	45	6[c]	0.1	0.9
	10	12.4	39	7	10	1.4	2.7	39	—	45	16[d]	0.4	3.9
1991	11	8.0	112	9	19	2.1	2.9	124	—	36	91[d]	2.5	4.4
	12	12.2	27	10	5	0.5	1.0	28	—	42	19[c]	0.5	1.7
	13	9.2	69	14	8	0.6	3.4	45	—	42	2[c]	0.1	1.7
	14	8.8	117	7	16	2.3	6.6	113	—	37	69[e]	1.9	2.9
	15	6.3	111	7	12	1.7	2.3	111	—	48	25[c]	0.5	1.6
1992	16	9.5	154	7	51	7.3	5.6	184	—	42	93[d]	2.2	9.4
	17	16.8	110	9	50	5.6	4.8	150	—	34	43[d]	1.3	6.9
	18	14.5	82	7	4	0.6	2.4	74	—	21	11[d]	0.5	1.8
	Mean	10.6	88			2.30	3.52	93	—			0.99	3.52

[a] According to southern pine beetle infestation growth model of Stephen and Lih (1985).

[b] Estimated, based on number of fresh-attacked trees at time of treatment.

[c] Spot growth halted during posttreatment period, treatment considered successful.

[d] Trees attacked beyond buffer, but treatment slowed spot growth.

[e] Treatment did not appear to slow spot growth.

[f] Treatment success questionable, model predicted spot would not have grown in absence of treatment.

Table 2. *Growth rate of southern pine beetle infestations before and after treatment with 34%(+):66%(-) verbenone in combination with felling all currently-infested trees (Treatment 3), East Texas, 1990-1992.*

			Pre-treatment					Post-treatment					
Year	Spot no.	Mean DBH (in)	Initial # of infested trees	Growth interval (days)	New trees attacked	New trees/ day	Predicted trees/ day [a]	Infested trees at treatment	Total verbenone applied (ml)	Growth interval (days)	New trees attacked	New trees/ day	Predicted trees/ day [a]
1990	19	15.6	35	0	0	0.9 [b]	—	35	120	68	0 [c]	0.0	0.9
	20	10.6	29	7	8	1.1	1.6	34	175	35	4 [c]	0.1	1.3
	21	12.8	115	7	5	0.7	5.6	97	375	40	1 [c]	0.0	4.4
	22	13.2	80	6	24	4.0	5.3	94	500	40	2 [c]	0.1	9.1
	23	11.2	55	6	8	1.3	4.8	51	290	43	2 [c]	0.1	3.2
	24	10.1	28	29	57	2.0	0.5	68	175	63	65 [d]	1.0	1.6
	25	8.0	66	8	10	1.3	1.0	69	250	30	2 [c]	0.1	1.0
	26	7.3	27	17	14	0.8	0.2	35	260	32	0 [c]	0.0	0.1
1991	27	11.3	92	7	27	3.9	3.0	117	750	38	56 [d]	1.5	4.4
	28	12.7	33	3	16	5.3	0.7	49	600	68	18 [c]	0.3	2.2
	29	7.0	88	8	40	5.0	2.8	127	1,000	41	14 [c]	0.3	5.0
	30	8.3	96	2	20	10.0	4.5	116	750	53	1 [c]	0.0	4.1
	31	12.7	56	0	—	1.8 [b]	—	56	500	41	11 [c]	0.3	5.4
	32	8.5	87	36	90	2.5	—	87	840	39	0 [c]	0.0	4.1
	33	11.0	22	7	3	0.4	0.9	25	250	31	0 [c]	0.0	0.5
	34	7.8	61	7	6	0.9	1.0	62	370	31	1 [c]	0.0	0.7
1992	35	7.9	54	6	2	0.3	0.3	56	400	42	0 [f]	0.0	0.0
	36	13.1	98	6	17	2.8	4.3	102	1,000	42	30 [d]	0.7	3.9
	37	16.2	53	9	8	0.9	1.3	52	540	42	2 [e]	0.1	2.0
	38	8.5	104	26	46	1.8	2.3	82	820	42	0 [e]	0.0	2.4
	39	13.9	141	8	30	3.8	4.2	171	1,500	42	39 [d]	0.9	8.2
	40	7.8	54	42	45	1.1	—	54	710	42	1 [e]	0.0	1.5
	41	17.2	40	34	42	1.2	—	40	400	42	5 [e]	0.1	1.4
	42	9.7	95	42	104	2.5	—	95	950	42	8 [e]	0.2	2.8
	Mean	11.8	67			2.34	2.5	74	563			0.24	2.92

[a] According to southern pine beetle infestation growth model of Stephen and Lih (1985).

[b] Estimated, based on number of fresh-attacked trees at time of treatment.

[c] Spot growth halted during posttreatment period, treatment considered successful.

[d] Trees attacked beyond buffer, but treatment slowed spot growth.

[e] Treatment did not appear to slow spot growth.

[f] Treatment success questionable, model predicted spot would not have grown in absence of treatment.

growth by 90%; post-treatment rates of spot growth were 92% less than model predictions for the same spots in the absence of treatment (Table 3).

Changing Direction of Spread

In eight of the nine infestations treated with a combination of verbenone and frontalin, attacking SPB populations were redirected from the original head to the baited head within 2 to 3 weeks (Table 4). Once the directional change had occurred, all additional spot growth occurred exclusively in the vicinity of the baited head during the 4-6 week post-treatment monitoring interval. Not a single simulated "RCW cavity tree" was infested due to continued advancement of the original infestation head in any of the manipulated spots. Even in spot B, the only spot which failed to completely reverse direction, the designated "RCW cavity trees" remained uninfested. In this case, all spot growth halted before the infestation spread to the designated target trees, even though additional tree mortality occurred at both the original and the baited head.

Discussion and Conclusions

These field tests confirm findings of Payne and Billings (1989) that the combination of felling all currently-infested trees and applying verbenone to uninfested buffer trees is the most successful method yet developed to suppress SPB infestations with behavioral chemicals in East Texas. The verbenone dispersers (polyethylene bags) used in the present study provide a more practical and less costly means to deploy verbenone than the polymer spray previously used. Additional studies are underway to evaluate the efficacy of these methods in other southern states (C. W. Berisford, T. L. Payne, personal communication).

Verbenone alone may be useful as a means to slow infestation growth, particularly in small infestations (< 50 trees) in small-diameter stands. To suppress SPB infestations, synthetic verbenone can be applied in combination with felling previously-infested trees without need to fell uninfested trees, thus overcoming a major disadvantage of cut-and-leave. Forest managers, however, must await further testing of verbenone in other regions of the South, commercial production of verbenone dispensers, and registration of verbenone by the Environmental Protection Agency (EPA) before the proposed suppression tactics become operational.

The field trials reported herein provide the first documented evidence that medium-sized SPB infestations (< 85 trees) can be manipulated with behavioral chemicals to successfully change their direction of spread. Such capabilities may be useful to protect high value resources in the path of expanding infestations. Examples include colony sites or specific cavity trees of the red-cockaded woodpecker or habitat of other endangered species, private forest lands adjourning wilderness, recreation areas, etc. The operational use of this tactic, however, also requires registration of the required behavioral chemicals (verbenone and frontalin) by EPA for this specific purpose.

Acknowledgements

The authors thank Donna Work, Kevin Coffman and Cathy Wallace of the Texas Forest Service for their assistance with various aspects of this study. We also express appreciation to the National Forests in Texas, particularly personnel of the Davy Crockett and Angelina National Forests (USDA Forest Service) for providing support and access to infestations used in this study. For their continued cooperation in this and other behavioral chemical studies with the southern pine beetle, we thank Tom Payne, Scott Salom and Don Grosman of VPI & SU, Blacksburg, VA and Wayne Berisford and Mark Dalusky, University of Georgia, Athens, GA. Financial support for this study was provided by the Texas Forest Service and USDA Forest Service, Forest Pest Management, Atlanta, Ga.

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Table 3. *Change in mean spot growth rates (new trees attacked per day) following application of verbenone only, felling all infested trees only, verbenone plus felling all infested trees or no treatment (e.g. pre-treatment monitoring interval), East Texas, 1990-1992.*

Treatment	No. of infestations	Actual			Model Prediction[a]		Infestations Controlled
		Pre-treatment new trees/day (A)	Post-treatment new trees/day (B)	Growth rate change[b]	Post-treatment new trees/day (C)	Growth rate change[c]	
1. Verbenone	8	1.58	0.47	− 70%	1.39	− 66%	25%
2. Fell all infested trees	10	2.30	0.99	− 57%	3.53	− 72%	40%
3. Verbenone and tree felling	24	2.34	0.24	− 90%	2.92	− 92%	83%
4. Pre-treatment monitoring	33	2.39[d]	—	—	2.61[e]	+ 9%	—

[a] According to southern pine beetle infestation growth model of Stephen & Lih (1985).
[b] Computed as [(A-B)/A]x100%
[c] Computed as [(C-B)/C]x100%
[d] Value = actual mean growth rate for 33 spots monitored prior to application of treatments 1-3.
[e] Value = mean growth rate predicted by the spot growth model for 33 spots monitored prior to application of treatments 1-3, based on input data collected at first visit.

Table 4. *Summary of numbers of additional trees attacked per week at the original and baited heads within SPB infestations manipulated with behavioral chemicals East Texas, 1990-1992.*

Year	Spot	Treatment date	No. of infested trees	Mean DBH(in)		Week with respect to treatment date −1	+1	+2	+3	+4
1990	A	08/17	41	12	Original head	10 [a]	5	1	0	0
					Baited head	0	16	9	4	12
	B	08/24	54	13	Original head	9	19	2	9	5
					Baited head	0	14	8	3	9
1991	C	07/30	62	12	Original head	20	2	6	0	0
					Baited head	0	10	4	1	6
	D	09/04	25	14	Original head	10	0	2	0	0
					Baited head	0	3	8	4	1
	E	09/05	81	10	Original head	14	7	1	0	0
					Baited head	0	28	10	25	5
1992	F	07/23	73	11	Original head	20	6	1	0	0
					Baited head	0	9	4	6	1
	G	09/14	85	8	Original head	20	23	10	3	0
					Baited head	0	14	18	2	1
	H	09/28	55	8	Original head	16	1	1	0	0
					Baited head	0	15	5	8	2
	I	09/28	77	13	Original head	18	2	0	0	0
					Baited head	0	11	5	8	7

[a] Number of additional trees attacked per week.

FACTORS INFLUENCING OPTIMUM PLANTING DENSITY OF NONTHINNED LOBLOLLY PINE ON CUTOVER SITES [1]

J.A. Gent, Jr., L. Davis, M. Davison, and T. Fethe [2]

Abstract. For profit-oriented organizations, optimum planting density is defined as the planting density at which land expectation value is maximized. Using this criterion, optimum planting density of nonthinned loblolly pine (Pinus taeda L.) on cutover sites was found to be most sensitive to growth and yield model selection, site index, wood pricing, and discount rate. Optimum planting densities based on growth projections from four growth and yield models ranged from 450-900 stems per acre (SPA) at low site index and from 850-900 SPA at high site index. After model validation, the "best" model indicated optimum planting densities of 450 and 850 SPA for site index 45 and 75, respectively. On site index 45 land, optimum planting density was 300 SPA at low pricing levels and 850 SPA at high pricing levels. At average pricing levels, optimum planting density for site 60 land at discount rates of 4% and 7% were 650 and 450 SPA, respectively. These findings indicate that there is no single optimum planting density for all sites.

Introduction

The influence of initial density on tree growth and yield has been studied for many years, with studies being established as far back as 1937 (Pienaar et al. 1985). Even though our knowledge of how initial density influences stem size and volume production has increased greatly since then, there is still much disagreement on optimum planting density. Disagreements exist because optimum planting density is as much a question of economics as it is stand growth dynamics.

For profit-oriented organizations, optimum planting density is defined as the planting density at which land expectation value (LEV) is maximized. LEV represents the present value of the net returns of a continuing series of rotations. The return on investment is analyzed over a continuing series of rotations because the time value of money must be considered when comparing investments with different rotation ages or planning horizons. Discounting in perpetuity puts investment options with different rotation lengths on the same planning horizon. This is important because rotation age must also be considered when making planting density decisions.

Borders and others (1991) have argued that "planting, bedding, harvesting, and transportation costs vary by stand density and should therefore be incorporated into the decision-making process as variable costs on industrial lands". They demonstrated that ignoring these variable costs may lead to less than optimal decisions concerning planting density and rotation age.

The original objectives of this study were to: (1) determine which factors need to be considered in making site-specific planting density decisions for nonthinned loblolly pine (Pinus taeda L.) on cutover sites; and (2) develop a tool to assist foresters in making site-specific planting density decisions. For the purposes of this paper, we will only address the first objective.

Methods

Growth & Yield Models

Since a planting density analysis requires the use of a growth & yield model to predict the future volumes associated with various planting densities, it was obvious that we first needed to determine if growth & yield model selection influenced the optimum planting density decision. There were four models to work with: (1) the Virginia Polytechnic Institute and State University (VPI) TruLob model (Amateis et al., 1984); (2) the North Carolina State University (NCSU) model (Hafley and Buford, 1985); (3) the old University of Georgia (UGA) model (Bailey et al., 1985); and (4) the new UGA model (Borders et al, 1990). To facilitate examination of these models the computer code for each model was

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converted to a common language. The models were set up with the same input/output and volume equations so they could be called from the same main program.

Harvesting and Transportation Costs

Harvesting and transportation costs were calculated with the Auburn Harvesting Analyzer (Tufts et al., 1985). This Lotus® spreadsheet was converted to the same language as the main computer program and the growth & yield models so they could be linked together. The Analyzer's default cost and production assumptions for a single HydroAx 511 feller-buncher, two Timberjack 380 grapple skidders, one loader, and three haul trucks were used for all analyses.

Variable Establishment Costs

As suggested by Borders and others (1991), we considered variable site preparation, seedling, and planting costs. The second column in Table 1 shows the spacings that might be used for densities ranging from 300 to 900 stems per acre (SPA). In formulating these spacings, the number of planting rows/acre were kept to a minimum because it is assumed that machine planting cost is a function of number of passes/acre. Rows were maintained at a spacing of 10 feet until the intra-row spacing dropped below one-half the row spacing (5 feet).

Assuming that machine planting 726 SPA at a 6 x 10 foot spacing costs $35/acre, each pass of the planting machine costs $1.67. At $1.67/row, 12, 10, and 8 foot row spacings cost $28, $35, and $43/acre, respectively. In contrast to machine planting, hand planting cost is related to the number of seedlings planted rather than number of passes per acre. Assuming that planting 726 SPA costs $35/acre, hand planting costs $0.048/seedling. Assuming a seedlings cost of $32/thousand, each seedling costs $0.032.

Similar to machine planting, the number of passes/acre of certain treatments such as bedding and ripping, will vary by planting density. For the purposes of this discussion, it is assumed that bedding costs $50/acre at a 10 foot spacing. The costs at 12 and 8 foot row spacings are $40 and $62/acre, respectively (Table 1).

In performing this analysis, we only considered planting densities in the range of 300-900 SPA. Densities below 300 SPA were not considered because it takes so long to obtain crown closure we do not think site resources are being used efficiently. Densities above 900 SPA were not considered because experience has shown that at higher densities there may be a problem in terms of reaching a merchantable stem size.

Calculation of LEV

The following equation was used to calculate after-tax LEVs:

$$LEV = [GI * (1-TAX) - (H+T) - (R * (1+i)^{age})] / [(1+i)^{age} - 1]$$

where: GI = gross income
TAX = corporate income tax rate
H = harvesting cost
T = transportation cost
R = regeneration cost
i = real discount rate
age = rotation age

Per acre tax and administrative costs are not included in this calculation because they are considered to be sunk costs; that is, they remain constant regardless of planting density. Capital gain is not considered in this equation since capital gains and ordinary income are currently taxed at the same rate.

Basic Assumptions

The basic set of assumptions used for the following analyses include:

- Site preparation cost = $100/acre
- Initial survival = 85%
- Distance to pulpwood receiving mill = 40 miles
- Distance to chip-n-saw (C-N-S) mill = 40 miles
- Variable hand planting and seedling costs
- 50% of the volume greater than 9 inches DBH is C-N-S
- No thinning or fertilization
- Site index = 60 feet
- Corporate income tax rate = 40%
- Discount rate = 4% real
- Initial densities restricted to 300-900 SPA range
- Average southeast delivered pulpwood and C-N-S prices
- Stands are harvested at optimum rotation age

Table 1. *Variable planting, seedling, and bedding costs for various planting densities.*

SPA	Spacing	Number Row/Acre	Machine Planting	Hand Planting	Seedlings	Bedding
			$/ac	$/ac	$/ac	$/ac
300	12 x 12	17	28	14	10	40
400	10 x 10	21	35	19	13	50
500	8.7 x 10	21	35	24	16	50
600	7.3 x 10	21	35	29	19	50
700	6 x 10	21	35	34	22	50
800	5.5 x 10	21	35	38	26	50
900	6 x 8	26	43	43	29	62

Assumptions: $35/acre planting cost @ 726 stems/acre
$32/thousand seedlings

Pricing Assumptions

In performing these analyses, we used a range of pulpwood pricing levels (Table 2). The low pricing level is represented by North Carolina which had a delivered price of $59/ccf for pulpwood and $92/ccf for C-N-S. The high pricing level is represented by Louisiana where pulpwood and C-N-S were both approximately $95/ccf. The average SE delivered price was $67/ccf for pulpwood and $95/ccf for C-N-S. All prices were taken from Timber Mart-South for the 2nd Quarter of 1992.

Table 2. *Delivered prices used for sensitivity analyses.*

PRICING	DELIVERED PRICES PULP	C-N-S
Low (NC)	59	92
Average (SE)	67	95
High (LA)	96	95

Timber Mart-South, 2nd Quarter 1992

Results and Discussion

Growth & Yield Model Selection

As noted earlier, since a growth & yield model is required to predict yields, we first needed to determine if growth & yield model selection influenced the optimum planting density decision. Using the basic set of assumptions presented earlier, the VPI model indicated optimum planting densities of 900 SPA for site indices 50 and 70 (see Figure 1). The NCSU model showed an optimum planting density of 650 SPA for both site indices. Similar to the VPI model, the old UGA model showed optimum planting densities of 900 SPA for both site index 50 and 70. The new UGA model indicated an optimum planting density of 450 SPA for site index 50 and 900 SPA for site index 70. Growth & yield model selection obviously has a significant effect on the planting density decision.

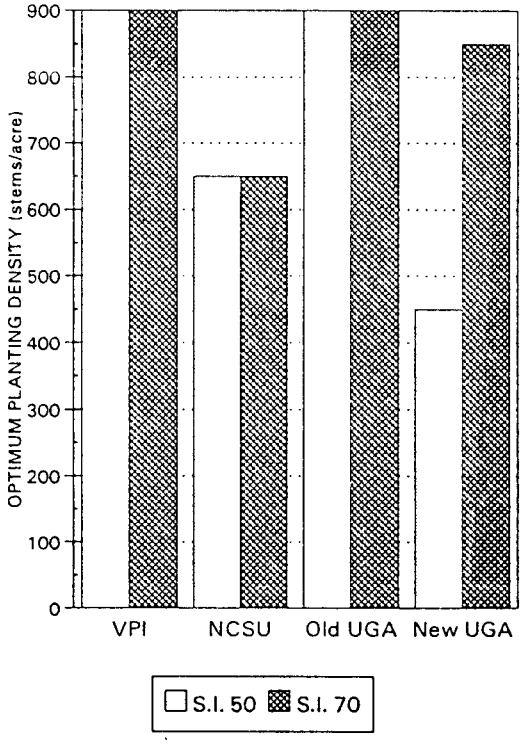

Figure 1. *Optimum planting density for four growth & yield models.*

To determine which of these models suited our needs the best, the models were validated with a large spacing study data set composed of studies established on Union Camp and Champion International lands (see Clutter and Gent in these same proceedings). The new UGA model provided the best yield estimates so it was used for this analysis.

Site Index

Figure 2 shows the planting density curves for site indices 45, 55, 65, and 75 for the high and low pricing levels. At high pricing levels optimum planting density is not very sensitive to site index; the optimum was 850-900 SPA for all site indices. However, at low pricing levels optimum planting density increases as site index increases. On site index 45 land the optimum is 300 SPA while the optimum for site index 75 is 850 SPA. In general, optimum rotation age decreases as site index increases.

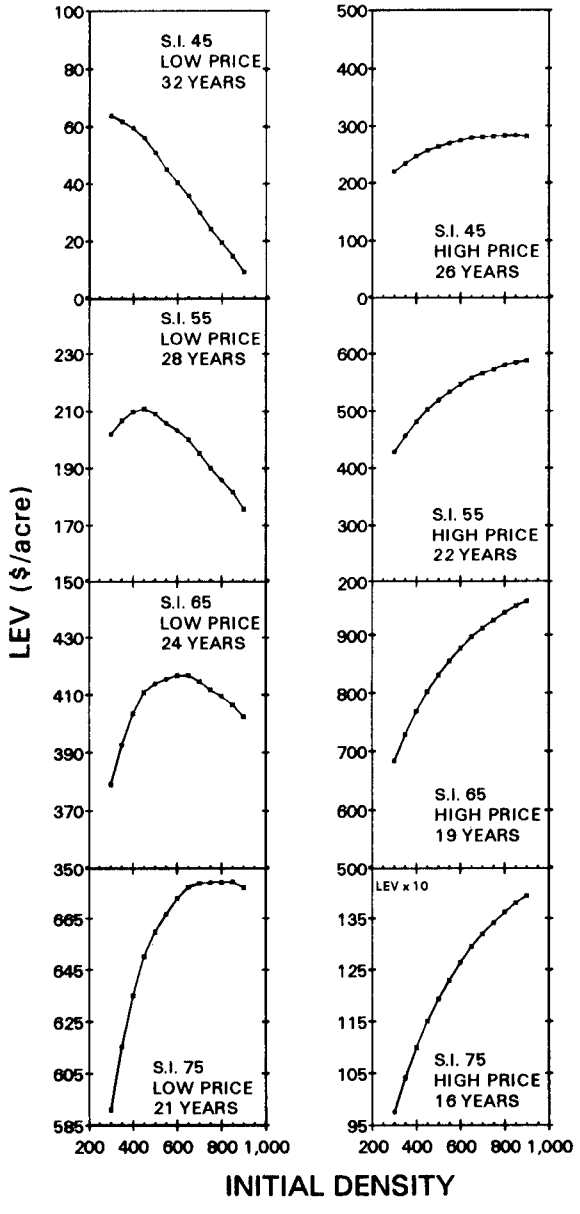

Figure 2. *Planting density curves by site index for low and high pricing levels. YEARS refers to optimum rotation age.*

The reason the optimum planting density is so low on site index 45 land at low pricing levels is that the volume increase across the range of densities considered is only 5 cunits (Table 3). The relatively small increases in volume or value associated with increasing planting density is not enough to off-set the increase in planting and seedling costs. On high sites, the volume gain from one density to the next is large enough to pay for the variable planting and seedling costs.

Table 3. *Merchantable volume yield at age 25 for various planting densities on site index 45 and 75 land.*

PLANTING DENSITY	S.I. 45	S.I. 75
	- ccf/acre -	- ccf/acre -
300	17	46
400	18	50
500	19	52
600	20	54
700	21	56
800	22	57
900	22	58

Haul Distance

The planting density curves for pulpwood haul distances of 25, 50, 75, and 100 miles are shown in Figure 3. At high pricing levels optimum planting density is fairly insensitive to haul distance. However, at low pricing levels optimum planting density decreases as haul distance increases. This relationship results from the fact that the implied stumpage price (delivered price - cut & haul) decreases as haul distance increases. As illustrated in the site index analysis, lower pricing tends to reduce optimum planting density.

Spread In Product Price

In this analysis, the delivered pulpwood price was set at \$75/ccf while the delivered C-N-S price ranged from \$75/ccf to \$200/ccf. Figure 4 shows the planting density curves for C-N-S prices of \$75, \$100, \$150, and \$200/ccf. These curves indicate that as the spread in product price increases, optimum planting density decreases and rotation age increases. This reduction in planting density and increase in rotation age increases the amount of C-N-S.

Planting Method

Figure 5 shows the planting density curves for variable machine and hand planting costs and fixed planting costs by site index. When fixed planting

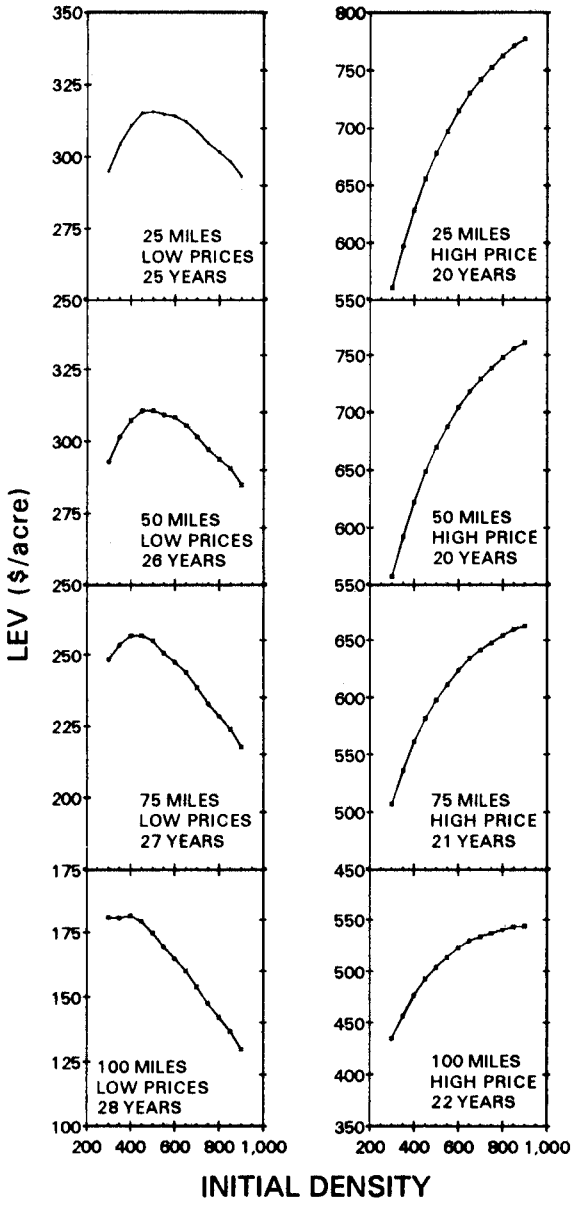

Figure 3. *Planting density curves by haul distance for low and high pricing levels. YEARS refers to optimum rotation age.*

costs are used, the optimum planting density is 900 SPA for all site indices since the per unit cost of planting decreases as planting density increases. On site index 45 land, the optimum planting density for variable hand and machine planting are similar. The LEV for hand planting is higher because the variable cost is lower. On site indices 55 and 65, the optimum planting density for machine planting is higher than that for hand planting because between 400 and 800 SPA machine planting costs are constant ($35 @ 10 foot row spacing). On site index 75 land, optimum planting density for hand and machine planting are 900 and 850 SPA, respectively. The optimum planting density for machine planting drops off slightly because the planting cost increases at 900 SPA.

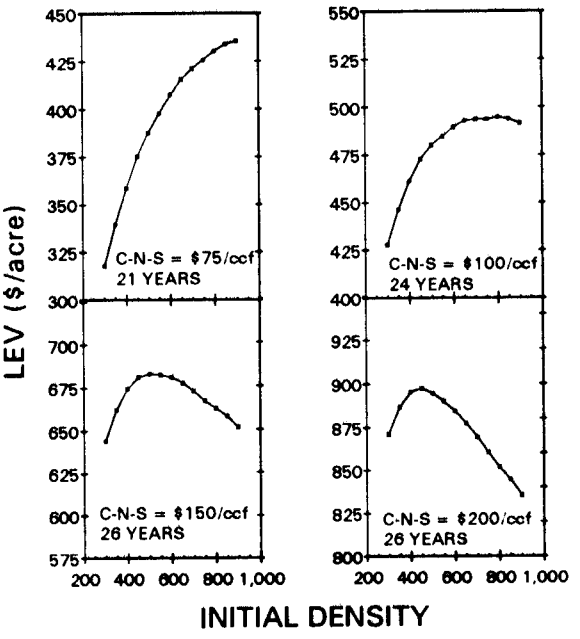

Figure 4. *Planting density curves for C-N-S delivered prices of $75, $100, $150, and $200/ccf. Pulpwood price set at $75/ccf. YEARS refers to optimum rotation age.*

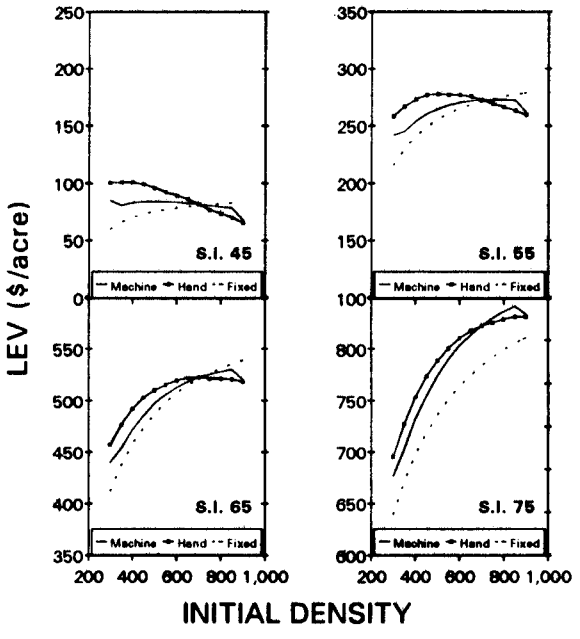

Figure 5. *Planting density curves by site index for fixed and variable hand and machine planting costs.*

Variable Site Preparation Cost

Variable site preparation costs for treatments such as bedding and ripping influence the optimum planting density decision in a fashion similar to variable machine planting costs. On high site index

land and/or high pricing levels, inclusion of variable site preparation costs may decrease optimum planting density from 900 SPA to 850 SPA. On low to medium site index land and low pricing levels, inclusion of variable site preparation costs may decrease optimum planting density from the 350-400 SPA range to 300 SPA.

Anticipated Initial Survival

Figure 6 shows the planting density curves for initial survival rates ranging from 40% to 100% for the low and high pricing levels on site index 60 land. At high pricing levels optimum planting density is insensitive to initial survival. At low pricing levels optimum planting density is fairly sensitive to initial survival. Optimum planting density for anticipated initial survival rates of 40% and 100% are 850 and 450 SPA, respectively.

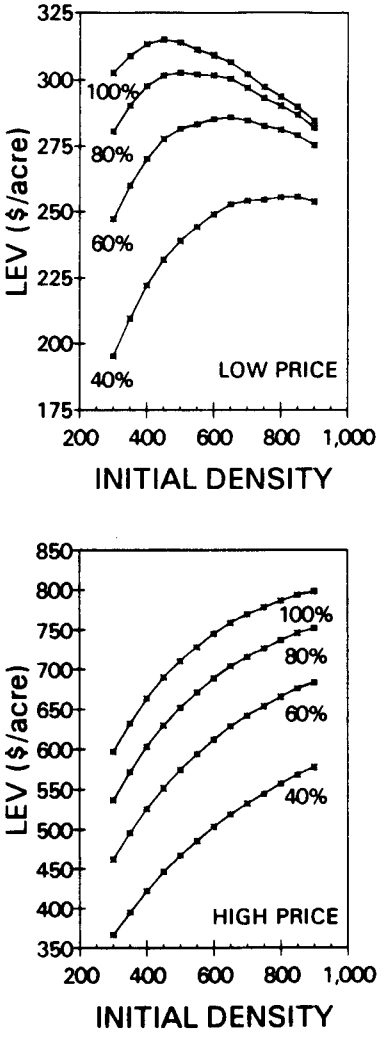

Figure 6. Planting density curves by initial survival for low and high pricing levels.

Discount Rate

Figure 7 indicates that optimum planting density is sensitive to discount rate selection. Optimum planting density and optimum rotation age at a discount rate of 4% are 650 SPA and 24 years, respectively. At a discount rate of 7%, optimum planting density and optimum rotation age are 450 SPA and 21 years, respectively. It appears that higher discount rates tend to reduce both the length of time the investment is carried and the magnitude of the investment; in this case the variable planting and seedling costs.

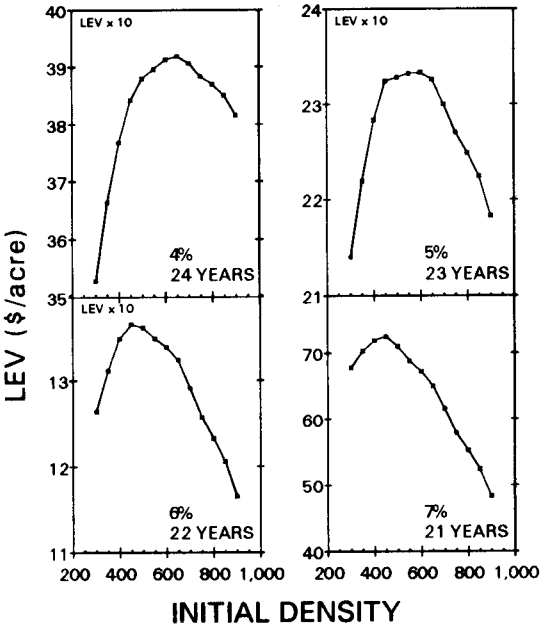

Figure 7. *Planting density curves for discount rates of 4, 5, 6, and 7 percent. YEARS refers to optimum 1 rotation age.*

Conclusions

Results of this study indicate that there is no single optimum planting density for all sites or economic conditions and constraints. Optimum planting density appears to most sensitive to growth & yield model selection and pricing level. Under certain conditions it is also influenced by site index, spread in product pricing, haul distance, planting method, anticipated initial survival, and discount rate selection.

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A COMPARISON OF PREDICTED MENSURATIONAL AND ECONOMIC PERFORMANCE OF THINNED LOUISIANA LOBLOLLY AND SLASH PINE PLANTATIONS [1]

V. Clark Baldwin, Jr. and Rodney L. Busby [2]

Abstract. Loblolly (*Pinus taeda* L.) and slash pine (*P. Elliottii* Engelm.) are both planted extensively in Louisiana, although slash pine is outside its natural range west of the Mississippi River. Growth and yield performance of the two species in the Southern United States is documented for young, unthinned plantations, but little has been published about the comparative performance of these species in older, thinned plantations. Stand and stock tables for similar plantations of loblolly and slash pine managed under several alternative thinning schemes were predicted with the COMPUTE series growth and yield models. Then land expectation values were calculated for three discount rates using the sawtimber and pulpwood volume revenue predictions for intermediate and final harvests and reasonable seedling, planting, and stand management costs. The mensurational and economic results were compared. It was assumed that each species was planted on the same site; an equation is presented that makes the necessary species site index adjustments to meet that assumption. Results showed that, mensurationally and economically, for the management scenarios considered, loblolly pine outperformed slash pine on the better sites, slash pine generally did better on average sites, and slash pine did better on poor sites.

Introduction

Loblolly pine is the most commonly planted pine in Louisiana. However, non-native slash pine has also been planted extensively within the State. Loblolly appears to perform as well or better than slash pine in areas of the Southern United States where both species grow naturally (e.g., Borders and Harrison 1989, Cole 1975, VanLear and others 1977), but overall comparitive performance between the two species in Louisiana has not been well documented in older stands or in thinned stands. A performance comparison of unthinned plantations through age 20 in Louisiana and southern Mississippi showed that both species grew about equally well on intermediate and dry sites, but slash was a better choice than loblolly for planting on flat, wet sites having less well drained soils (Shoulders 1983). Furthermore, in most cases slash pine grew better in height. Thirty-one-year results of a side-by-side loblolly-slash pine comparative growth study in northwest Louisiana, in which the stands had been thinned to 300 stems per acre at age 15, showed growth of the two species was comparable (Clason and Cao 1983). The researchers also noted that early growth of slash pine was better than that of loblolly when individual tree competition was less of a factor, but slash yields were noticeably less as competition intensified between ages 24 and 31.

Data were not available to make a Statewide thinned-stand direct-species comparison, so we chose to compare loblolly and slash pine performance mensurationally and economically by comparing output results of two growth and yield prediction models: COMPUTE_P-LOB (Baldwin and Feduccia 1987, Ferguson and Baldwin 1987) and COMPUTE_P-SLASH (produced from Zarnoch and others 1991). These prediction systems were developed from data collected from multiple measurements of research plots in thinned and unthinned plantations in the West Gulf region. Details concerning the data are in the publications cited, but for both species, the prediction equations are based on growth and yield observations for a range of sites, planting spacings, residual thinning densities, and stand ages through 40 years for slash pine and through about 45 years for loblolly pine. For both species, most of the research plots were in Louisiana.

We present and compare results of growth and yield predictions for both species under three possible management scenarios using zero, one, or two thinnings. In addition to the growth and yield results,

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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we present economic results for two stumpage price scenarios based on land expectation values calculated from the stand and stock table predictions and on consideration of reasonable revenues, costs, and three alternative interest discount rates.

Methods

Site Quality

In order to evaluate species performance fairly on a given site using the COMPUTE models, growth expectation caused by site factors estimated by site index had to be equalized. To accomplish this we selected 258 growth and yield plots from 44 locations in Louisiana where loblolly and slash pine studies were established side by side (fig. 1). All but 24 of the plots were unthinned; those 24 had been thinned twice. The unthinned plots were most of the Louisiana plots used by Shoulders (1983), from which measurement data through age 25 were made available to us.[3] The relationship between the mean stand dominant/codominant height for each species at each measurement age is shown in Figure 2. From at least age 15, slash pine dominant height was greater than loblolly pine dominant height, and the difference increased with age.

The plots at these locations were then paired according to age and treatment and a regression equation fitted to predict the dominant height of slash pine as a function of age and the dominant height of loblolly pine. The equation is:

$$\text{HTDOMSLASH} = 1.2621\ \text{AGE} + 0.5873\ \text{HTDOMLOB} \quad (1)$$
$$(N = 366,\ SE = 3.7\ \text{ft}),$$

where:

N = the number of height-age observations, and
SE = standard error of the estimate.

Low, medium, and high site indices for loblolly pine at base age 25 were defined as 50, 60, and 70 feet, respectively. Substituting these values into equation 1 at age 25 gave the corresponding dominant heights and base age 25 site indices for slash pine of 61, 67, and 73 feet. These were the "site equalization" values input into the growth and yield models for the comparisons. Since we did not alter the different site index functions in the growth and yield prediction systems, this procedure ensured only magnitudes of dominant height differences at age 25. However, it did provide a workable procedure to compare the species as if they were grown on the same site.

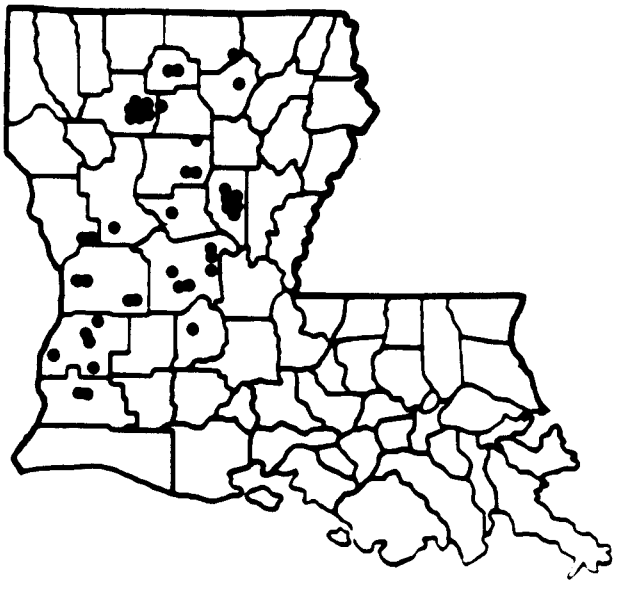

Figure 1. *Within-parish locations of side-by-side loblolly and slash pine growth and yield research installations in Louisiana.*

Management Options

Case 1 was a medium low thinning either once, twice, or not at all during the rotation; case 2 was a heavy thinning either once, twice, or not at all. Those two cases were based on commonly held assumptions concerning the timing of thinnings and the need for each intermediate harvest at least to pay for itself (Feduccia 1983). Case 3 involved thinning timing and intensity decisions based on maintenance of continual optimum stocking largely estimated from stand density management diagrams (Dean and Jokela 1992[4]). In cases 1 and 2, low thinning to the target residual basal area (80 or 60 ft^2, respectively) first

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[3] We gratefully acknowledge Dr. Calvin E. Meier of the USDA, Forest Service, Southern Forest Experiment Station, supplier of these data, who is performing a detailed new analysis of this classic site-species study.

[4] Dean, Thomas J.; Baldwin, V. Clark, Jr. Using a density management diagram to develop thinning shcedules for loblolly pine plantations. Research Paper SO-XXX. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. (Paper in editorial review)

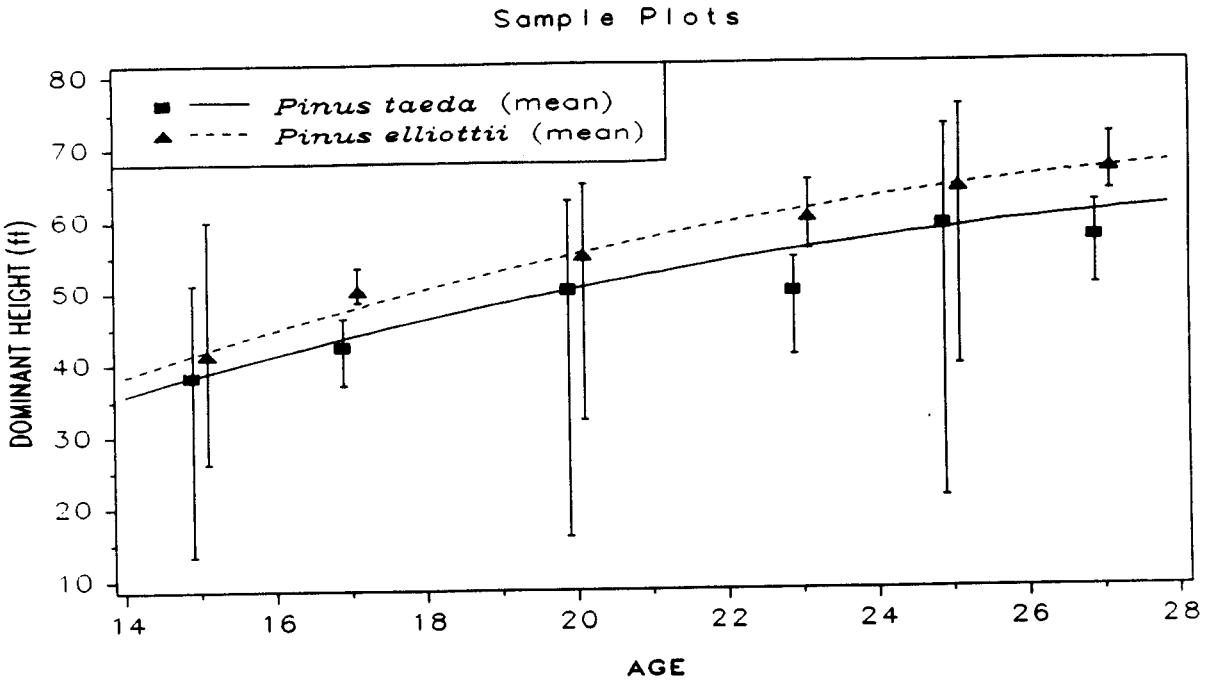

Figure 2. *Relationship between the mean and range of dominant height and age of loblolly and slash pines in side-by-side plots from two Louisiana growth and yield studies.*

occurred when the stand reached at least 110 ft^2 of basal area per acre, so at least four cords per acre of pulpwood could be realized from the thinning. The same criteria were used to determine the timing of the second thinning, except the target basal area to signal thinning was 90 ft^2 per acre for case 2. The stands were then thinned at the appropriate time(s) and grown to age 35. For both slash and loblolly pine, two thinnings were never formed on the low sites because insufficient basal area growth accumulated after the first thinning. For all the comparisons in those two cases, a planting density of 681 trees per acre (8- by 8-ft spacing) was assumed.

For case 3, we assumed that the primary management objective was to obtain final harvest plantations with an average quadratic mean d.b.h. of 12 inches. Using the density managment diagrams referenced above as guides, we obtained estimates of the planting densities and basal area removal amounts to accomplish that target for each species. Again the number and timing of thinnings was constrained by the goal of making each thinning profitable. Then one-thin, two-thin, or no-thin management options for medium and high sites were only simulated and the resulting mensurational data predicted. Thus not only were the timing and level of the thinnings variable, so were the planting density and the time of the final harvest.

Economic Evaluation Criterion

The criterion used to compare the returns from investing in loblolly or slash pine reforestation was the land expectation value (LEV). LEV is calculated by finding the discounted present value of all future costs and revenues from managing a stand in pine production over an infinite time horizon. It is the value of bare land used for growing perpetual rotations of even-aged stands of timber. Revenues are earned when products are harvested from the stand either in a final harvest or as the forested track is thinned. Costs are incurred when the site is brought into production, and there are annual costs to pay property taxes, fire protection, and miscellaneous costs of keeping the land in forestry production. The formula for LEV is:

$$LEV = \sum_{t=0}^{\infty} \frac{R_t - C_t}{(1+i)^t}, \qquad (2)$$

where:

LEV = land expectation value,
R_t = revenue occurring at year t,
C_t = cost occurring at year t, and
i = discount rate per year expressed as a decimal.

Two methods can be used to calculate LEV: (1) express all costs and returns at their expected inflated dollar values and use a nominal discount rate that incorporates the inflation rate and the required real return on the investment; or (2) express all costs and return at their expected real purchasing power and use a discount rate that is the required real return on the investment. The difference is how inflation is handled in the analysis. Inflation causes erosion of purchasing power, so it must be factored out of the analysis. For example, if LEV is calculated using a real discount rate of 7 percent and if expected future inflation is 4 percent per year, the nominal discount rate would be 11 percent. Use of either discount rate will lead to the same answer; however, the expected future cash flows must reflect the discount rate used. If the nominal discount rate is used, future values must be expressed in inflated values; if the real discount rate is used, future values must reflect today's purchasing power. This analysis used the real discount rate and set future values to today's purchasing power.

Costs

Site preparation costs were assumed to be a constant $87/acre, the average cost reported in Dubois and others (1991). Planting costs were assumed to be $38/acre plus $0.03/tree, the average cost reported in Dubois and others (1991) and Anon. (1989). Costs of marking the thinnings and cruising the clearcut harvests were assumed to be $13.07 and $2.02, respectively, again from Dubois and others (1991). Costs of periodically burning the site, paying taxes, and protecting and maintaining the property were assumed to be $3/acre/year. All costs are expected to increase at the same rate as the rate of inflation.

Management Regimes

The same base management regime, site preparation, and planting, is required to establish the stand whether loblolly pine or slash pine is being analyzed. The number of trees planted is constant (681) for both case 1 and 2. The number of trees planted varies in case 3. Commercial thinning is an option in the analysis--the choices are none, one, or two thinnings at several ages. Final harvest occurs at age 25, 30, or 35, depending on which rotation length yields the highest LEV.

Stumpage Prices

Average stumpage prices from the State of Louisiana were compiled from Timber Mart-South (various). The average product prices for 1991 and the first three quarters of 1992 were:

Sawtimber: $147.07 per mbf, international,
Pulpwood: $ 20.96 per cord.

Two softwood sawtimber stumpage pricing scenarios were examined: (1) increasing and (2) constant. The first scenario used the Haynes and Adams (1992) prediction of increasing softwood sawtimber stumpage prices in the South over the next several decades. Prices are expected to show real growth of 1.5 percent per year between 1986 and 2040. These changes in stumpage values are not uniform, however. Haynes and Adams predict a rapid increase in stumpage until 2010 and relatively constant real stumpage prices thereafter. Their predictions were incorporated by increasing real sawtimber stumpage values by 3.51 percent per year between 1992 and 2000 and 4.35 percent per year between 2000 and 2010. Thereafter, real sawtimber stumpage values were kept constant. Real pulpwood stumpage prices were kept constant throughout.

The second scenario assumes that both sawtimber and pulpwood stumpage prices are constant in real terms into the foreseeable future.

Product Yields

The COMPUTE series models estimate board feet to an 8-inch top using the international 1/4-inch scale; this measure was used to estimate the sawtimber production for all alternatives. In addition, the models provide estimates of cubic foot volume to a 4-inch top, among other measures. The board foot and cubic foot measures are independent of each another, that is, volumes described as board feet are also measured in cubic feet. In order to obtain the board feet volume from the estimated cubic volume, it was necessary to convert board feet volumes to cubic feet volumes and then to subtract these volumes from the gross cubic feet volumes reported in the model. Conversion factors for loblolly and shortleaf pine were used to make all conversions (Koch 1972, page 1597). The net cubic feet volumes were then converted to cords using 76 cubic feet per cord, the conversion factor for slightly rough and knotty loblolly pine 6 to

12 inches in diameter (Koch 1972, page 1557). The remaining products, from less than a 4-inch top, were not valued in this analysis.

Assumptions and Restrictions

All comparisons are based on predictions simulated by the COMPUTE series growth and yield models; hence, no statistical level of significance or validation of results can be provided for any of the differences shown. The models assume plantings on relatively problem-free cutover sites with non-genetically improved seedlings. Neither model specifically considers the effects of insects, disease, or physical causes of mortality, such as severe wind and ice damage, other than what may have occurred during the course of the studies from which the data were obtained. Thus, these factors were not directly addressed in this study. However, their possible influence must be considered in the evaluation of the results and in possible applications.

Results and Discussion

Mensuration

The comparative predicted results at the time of the final harvest are summarized in table 1. Growth trends for some of the key mensurational factors from the time of the first thinning through the end of the rotation, for one case only (high site index, case 2), are illustrated in figures 3 to 7. Note that the comparative trends for each factor for each species, whether the stand was not thinned, thinned once, or thinned twice, are shown in the same graph.

Dominant height growth was almost always greater for slash pine than for loblolly pine no matter what the site quality. Only on the highest quality site did loblolly pine show better dominant height growth, and that occurred only before about age 20 (fig. 3). The slash pine height growth advantage also greatly influenced the volume figures for the species.

On high-quality sites, overall loblolly pine performance, for the variables predicted, was best in all but a few cases (Table 1, Figures 3-7). Slash pine survival in the later years in the unthinned case and medium-thinnings cases was better than loblolly survival. After two heavy thinnings, slash pine also had larger volume, basal area, and diameter predictions. However, these differences only affected loblolly pine's total volume advantage in the heavy two-thinnings case.

It is interesting to observe, though, the generally more rapid predicted diameter, basal area, and volume growth rates of slash pine after each thinning and particularly after the second thinning (Figure 5). This observation supports the finding of Clason and Cao (1983) that slash pine growth was better with less competition. It also shows that slash pine responds well to thinning.

Overall, slash pine performance was better than loblolly pine's on medium-quality sites. However, the differences were not great in most cases. Slash pine produced the highest volumes in all but one case, but only in the heavy-thinning cases did slash pine outperform loblolly pine in basal area and diameter growth (table 1). Loblolly pine survival was consistently better. The main factor in the slash pine's volume advantage probably was its superior height growth, as noted earlier. Thus, all other things being equal, slash pine planted on medium quality sites will likely perform better than, or at least as well as, loblolly pine.

The case 3 scenarios were only simulated on the medium sites. The real advantages of using the density management diagrams is best illustrated by the economic results discussed below. However, from the mensurational point of view, it can be seen that about the same diameter and volume results were obtained for both slash and loblolly pines in 2 to 4 years less time than for cases 1 or 2 (table 1, footnote 3). This finding illustrates the importance of trying to achieve optimum stand density throughout a rotation.

The 11-ft slash pine site index advantage for the low-quality site comparisons was probably the overriding factor determining slash pine's superior performance for all factors in all cases (table 1). However, neither species was able to produce enough basal area growth after a first thinning to make a second thinning very practical, so no second thinning was performed for either the medium- or heavy-thinning cases.

Economic

The choice between planting loblolly or slash pine stands is the same whether one assumes increasing or stable sawtimber stumpage prices. On high-quality sites, loblolly pines produced higher economic values than slash pine plantations; on medium- or low-quality sites, slash pine plantations produced higher economic values than loblolly pine plantations (tables 2, 3). In the case of increasing

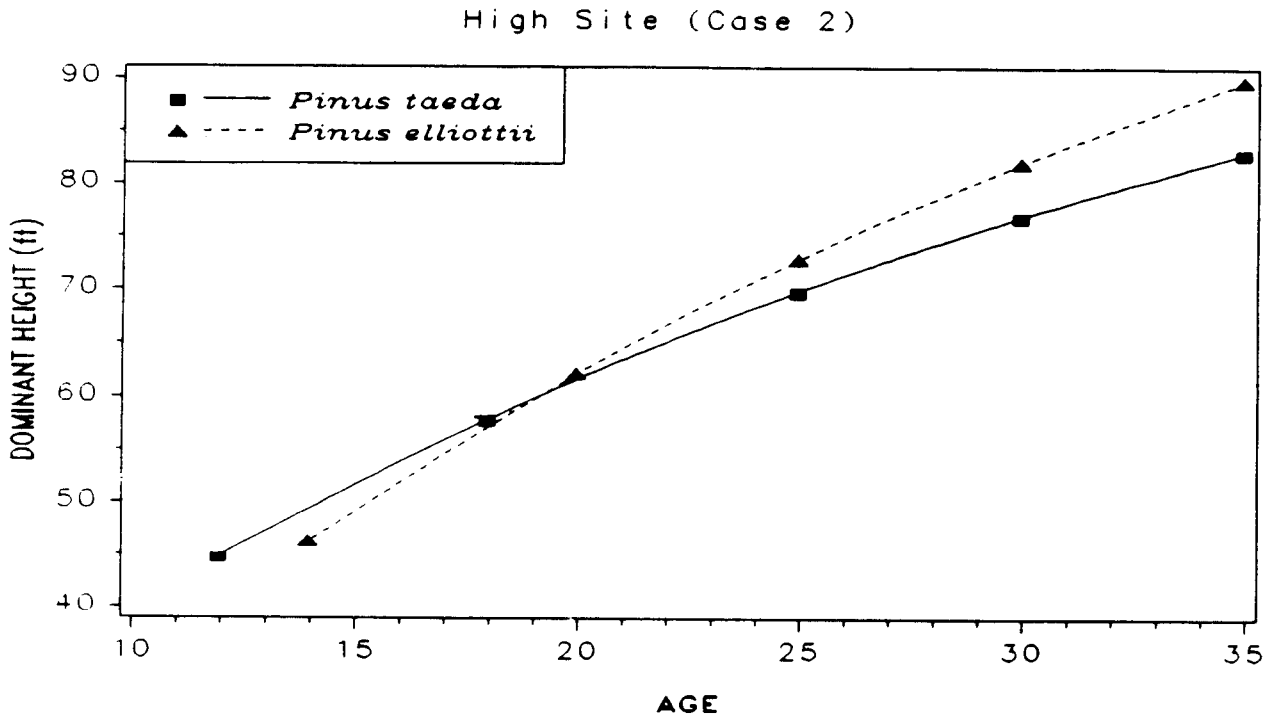

Figure 3. *Relationship between the mean predicted dominant height and age of loblolly and slash pines for the high site index, case 2 scenario.*

sawtimber stumpage prices, at the 5-percent discount rate, the highest LEV was $1,749 for loblolly pine, but only $1,438 for slash pine. The optimal management regime for loblolly pine was case 1 with two thinnings. The optimal management regime for slash pine was case 2 with one thinning (table 2).

Results are similar assuming no real change in sawtimber stumpage prices (table 3). The optimal management regime (case 2, one thinning) for loblolly pine, using the 5 percent discount rate, produced a LEV of $859; the optimal management regime (case 2, two thinnings) for slash pine produced an LEV of only $677.

On medium-quality sites, slash pine outperformed loblolly pine. Assuming rapid sawtimber price increases, the LEV for slash pine ($1,050) exceeded that of loblolly pine ($969) by $81. The optimal regime for both slash and loblolly pine was case 3 with one thinning.

If sawtimber stumpage prices did not increase, the optimal LEV for slash pine ($482) exceeded that of loblolly pine ($427) by $55. The optimal management regime for slash pine remained case 3, but two thinnings were prefered to one thinning.

In general, on low-quality sites, intensive forest management is not nearly as profitable as on medium- or, especially, high-quality sites. The major difference in site indices between slash pine (site index 61) and loblolly pine (site index 50) planted on low quality sites is what likely led to slash pine's $276 advantage over loblolly pine, assuming rapid increases in sawtimber stumpage prices (table 2). Assuming that there were no changes in sawtimber stumpage prices, the optimal slash pine management regime had a value of $205 (5 percent discount rate); the optimal loblolly pine management regime had a value of only $75 (5 percent discount rate).

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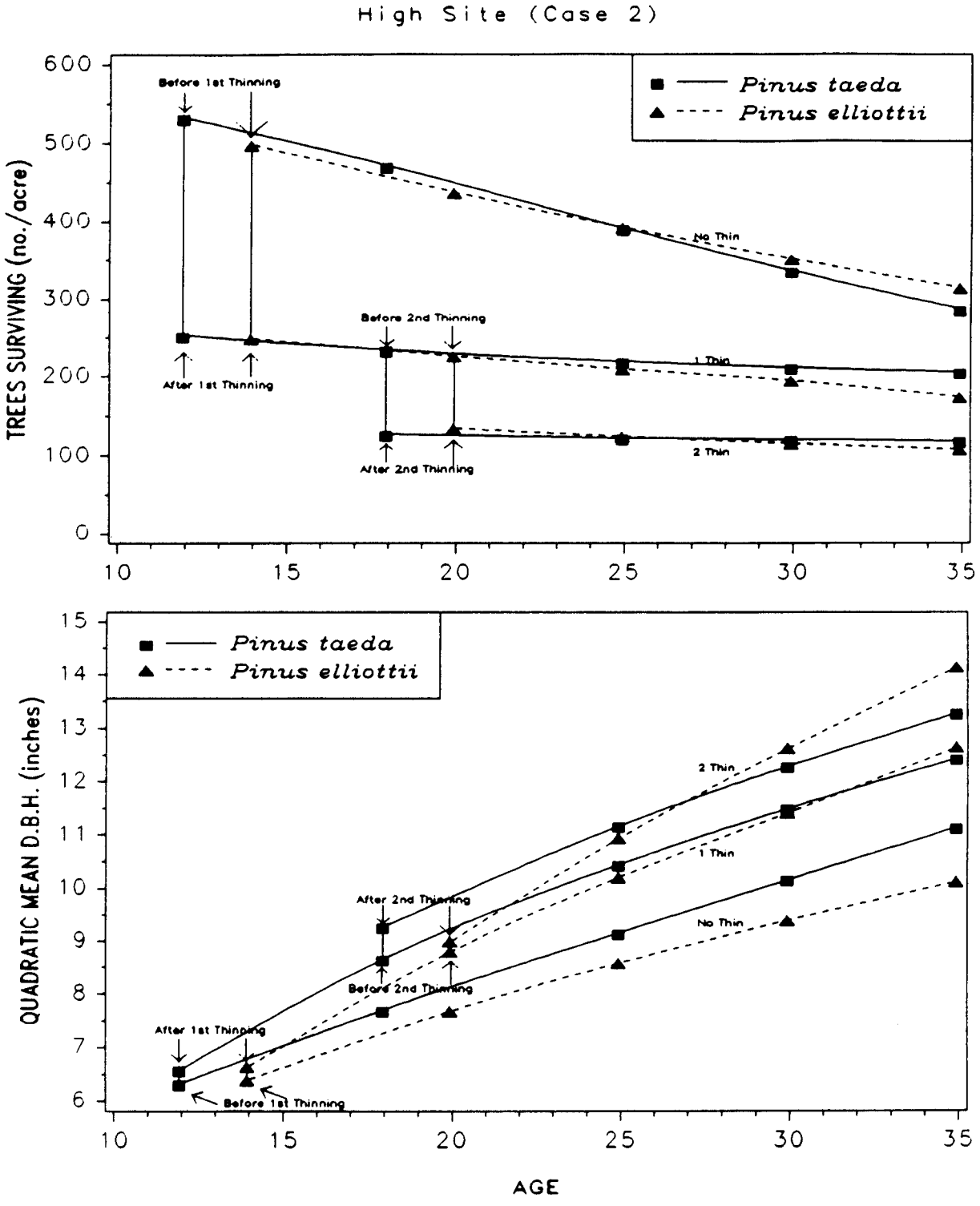
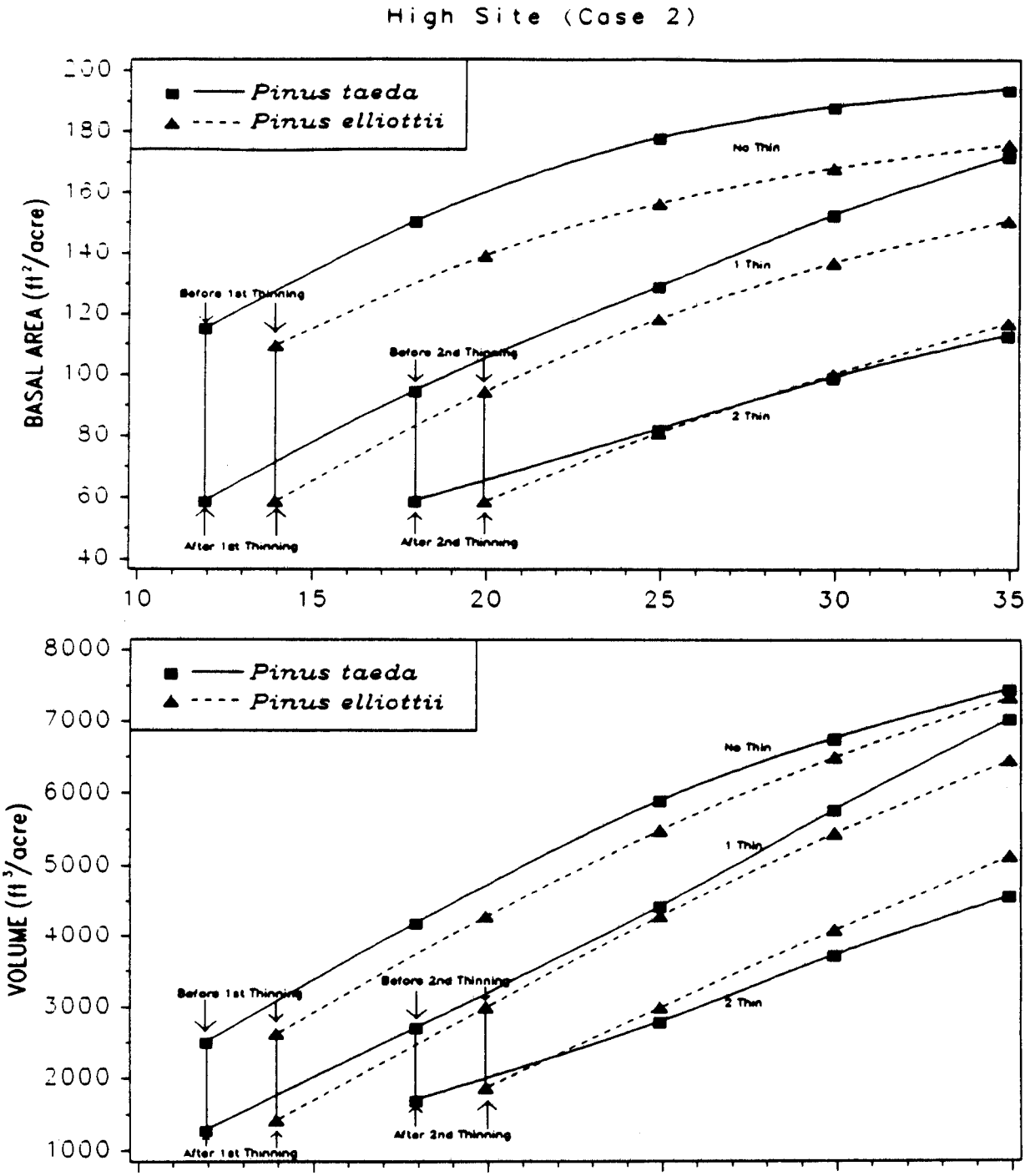


Figures 4 and 5. *Relationships between the mean predicted number of trees surviving and age, and the mean predicted quadratic mean diameter and age, of unthinned, thinned once, or thinned twice loblolly and slash pines for the high site index, case 2 scenario.*



Figures 6 and 7. *Relationships between the mean predicted basal area per acre and age, and the mean cubic-foot total wood and bark volume and age, of unthinned, thinned once, or thinned twice loblolly and slash pines for the high site index, case 2 scenario.*

Table 1. Predicted growth and yield values at final harvest for high, medium, and low site quality loblolly and slash pine plantations.

Species	Site index	Case[1]	Number of thins	1st thin age	2nd thin age	Final values at harvesting[2] HTD	TS	QMD	BA	VOL
High-quality sites										
Loblolly	70	Control	0	--	--	83	286	11.2	194	7463
		Case 1	1	12	--	83	214	12.0	169	6875
			2	12	17	83	153	13.1	144	5884
		Case 2	1	12	--	83	206	12.5	173	7058
			2	12	18	83	119	13.3	114	4590
Slash	73	Control	0	--	--	90	315	10.1	176	7353
		Case 1	1	14	--	90	220	10.8	140	5942
			2	14	19	90	155	11.6	112	4807
		Case 2	1	14	--	90	174	12.7	151	6475
			2	14	20	90	108	14.2	118	5148
Medium-quality sites										
Loblolly	60	Control	0	--	--	71	296	9.9	159	5378
		Case 1	1	16	--	71	223	10.7	138	4832
			2	16	23	71	166	11.4	118	4172
		Case 2	1	16	--	71	188	11.2	127	4439
			2	16	24	71	117	11.7	87	3021
		Case 3	0	--	--	68	129	12.0	101	3241
			1	17	--	67	141	11.9	109	3655
			2	15	24	70	141	12.0	111	3853
Slash	67	Control	0	--	--	83	315	9.5	154	5988
		Case 1	1	17	--	83	221	10.2	124	4886
			2	17	24	83	156	11.8	117	4697
		Case 2	1	17	--	83	175	11.7	131	5248
			2	17	24	83	107	12.9	96	3926
		Case 3	0	--	--	81	89	11.9	69	2814
			1	17	--	77	155	11.9	119	4505
			2	12	18	80	154	12.0	120	4697
Low-quality sites										
Loblolly	50	Control	0	--	--	59	308	8.6	124	3588
		Case 1	1	25	--	59	237	9.2	108	3122
		Case 2	1	25	--	59	180	9.3	85	2444
Slash	61	Control	0	--	--	75	315	8.9	134	4810
		Case 1	1	22	--	75	228	10.0	125	4544
		Case 2	1	22	--	75	168	10.7	104	3843

[1] Harvest age for all control and case 1 and 2 simulations was 35. For the case 3 simulations, optimum harvest ages were, in descending order within the table: 32, 31, 34, 34, 31, 33.

[2] HTD: Height of dominant and codominant trees (ft)
BA: Basal area (ft^2/acre)
QMD: Quadratic mean diameter (inches) 4.5 feet above ground line
TS: Number of trees surviving per acre
VOL: Total outside bark volume (ft^3/acre)

Table 2. Land expectation values per acre for high, medium, and low site quality loblolly and slash pine plantations, assuming a rapid increase in the price of sawtimber.

Species	Site index	Case	Number of thins	Discount rate 3%	5%	7%
				($)		
High-quality sites						
Loblolly	70	Control	0	3,489	1,458	677
		Case 1	1	3,733	1,665	815
			2	3,676	1,671	826
		Case 2	1	4,059	1,749	845
			2	3,062	1,364	683
Slash	73	Control	0	2,650	1,075	441
		Case 1	1	2,453	1,007	450
			2	2,298	1,030	526
		Case 2	1	3,409	1,438	664
			2	3,096	1,330	614
Medium-quality sites						
Loblolly	60	Control	0	1,857	722	267
		Case 1	1	2,073	838	360
			2	2,203	922	378
		Case 2	1	2,105	867	347
			2	1,740	730	296
		Case 3	0	1,664	694	270
			1	2,158	969	432
			2	2,103	883	361
Slash	67	Control	0	1,727	665	226
		Case 1	1	1,665	650	254
			2	2,298	949	381
		Case 2	1	2,461	1,015	409
			2	2,238	942	390
		Case 3	0	1,205	453	139
			1	2,360	1,050	463
			2	2,421	1,043	445
Low-quality sites						
Loblolly	50	Control	0	650	186	(3)
		Case 1	1	803	265	41
		Case 2	1	714	233	30
Slash	61	Control	0	1,025	352	77
		Case 1	1	1,385	524	166
		Case 2	1	1,415	541	176

Table 3. *Land expectation values per acre for high, medium, and low site quality loblolly and slash pine plantations, assuming no change in the real price of sawtimber.*

Species	Site index	Case	Number of thins	Discount rate 3%	5%	7%
				($)		
High-quality sites						
Loblolly	70	Control	0	1,741	701	300
		Case 1	1	1,866	810	376
			2	1,870	833	384
		Case 2	1	2,060	859	392
			2	1,579	690	322
Slash	73	Control	0	1,323	485	163
		Case 1	1	1,214	468	169
			2	1,153	497	221
		Case 2	1	1,698	677	281
			2	1,582	651	271
Medium-quality sites						
Loblolly	60	Control	0	912	302	73
		Case 1	1	1,022	382	126
			2	1,109	427	136
		Case 2	1	1,057	399	128
			2	886	340	104
		Case 3	0	753	265	54
			1	1,028	419	146
			2	1,034	395	121
Slash	67	Control	0	853	276	52
		Case 1	1	822	282	70
			2	1,158	439	136
		Case 2	1	1,216	461	144
			2	1,133	442	146
		Case 3	0	509	138	(15)
			1	1,134	461	161
			2	1,205	482	167
Low-quality sites						
Loblolly	50	Control	0	296	28	(75)
		Case 1	1	379	75	(51)
		Case 2	1	340	64	(52)
Slash	61	Control	0	491	115	(32)
		Case 1	1	669	205	13
		Case 2	1	663	205	1

DENDROECOLOGICAL MODELLING OF THINNED AND UNTHINNED LONGLEAF PINE STANDS IN THE WESTERN GULF REGION [1]

Marian Eriksson, Chii-Dean Lin, Charles E. Thomas, and Richard E. Lohrey [2]

Abstract. Most forest growth and yield models have ignored weather influences and most dendroecological models have ignored stand density or treated it as "noise" to be filtered out. If climate is changing, then forest cultural activities may need to be modified to be consistent with the new biological, economic, and social constraints put onto the system. Growth models may help in assessing the combined influence of weather, stand density, and cultural activities on forest tree growth. Using permanent plot information in conjunction with weather data and increment core measurements, models were developed to describe past radial increment of trees in thinned and unthinned stands in the Western Gulf Region. Models were fitted using (1) ordinary least squares (OLS), (2) random coefficients estimation of the full linear model, (3) OLS of the mean time series (MTS) of ring widths, and (4) conventional dendroecological analyses. Implications of these modelling approaches are discussed. It is concluded that both methods based on means, MTS and the conventional analyses, should be avoided. The choice between OLS or random coefficients estimation of the full linear model depends on ease of use, the appropriateness of error assumptions, and the possibility of negative variance estimates with random coefficients estimation.

Introduction

There has been much speculation regarding climate change. If climate is, indeed, changing, then forest cultural activities may need to be modified to be consistent with the new biological, economic, and social constraints put onto the system. Before modifying cultural activities we must determine how the character of the forest might change in a changing climatic environment; we must be able to predict growth as it is influenced by weather, stand density, and cultural activities. Understanding how these factors, taken together, have influenced growth in the recent past will help in predicting under uncertain future conditions. Unfortunately, however, most forest growth and yield models have ignored weather influences and most dendroecological models have ignored stand density or treated it as "noise" to be filtered out.

A number of approaches to modelling past radial increment of trees as a function of age, competition, and weather are described in the next section. This is followed by a brief description of the longleaf pine (Pinus palustris Mill.) data from thinned and unthinned stands in the Western Gulf Region that were used for model development. The results of fitting four types of linear models to these data are discussed in the fourth section, followed by a few concluding statements.

Approaches to Modelling

Forest Growth Models

A large number of mathematical growth models have been developed. The objectives of these efforts have been to predict growth into the future and to help understand the interaction of potential silvicultural treatments. Typically, some measure of site quality, one or more measures of competition, and often the interaction of these variables are present in a model. Age is also an explanatory variable in most even-aged models for trees and stands. The reasons for the inclusion of these variables have been ease (low cost) of measurement as well as their perceived importance in predicting growth and response to silvicultural treatments. Some measure of competition is usually explicit in modern growth and yield models.

Weather is widely recognized to influence tree and stand growth, but weather variables have typically been omitted from forester developed growth models. Growth model development has, in the past, been based on periodic (five or ten year) growth data; and

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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this for good reason. First, it would be expensive to remeasure plots or trees annually and second, the measurement error would almost certainly dominate the growth model error terms making the analysis considerably more complex. Therefore, foresters have assumed, either implicitly or explicitly, that weather is relatively constant over the period for which the model is developed. That is, although there may be unusual temperature or precipitation in one year, over a ten-year period averages would tend to be relatively equal. Consequently, periodic weather variables could not be significant predictors of periodic growth.

One final observation is that growth in these models is volume increment, while dendroecological models only model radial or diametric growth. This is important because silvicultural manipulations should be based on volume increment and not radial increment which may have significantly different patterns and maxima.

Dendroecological Models

The breadth of dendroecological techniques is rapidly expanding as new applications are envisioned and new investigators are brought into the field. For the remainder of this paper "dendroecology" and "dendrochronology" refer to what can be called the conventional methods[3]. Conventional analytical methods still serve as the basis for most of the newer techniques and are still used, unmodified, by a large number of investigators.

Like foresters, dendroecologists recognize that age, site quality, competition, and weather all influence annual increment. However, whereas the developers of forest growth models have focused on age, site, and competition while assuming that weather is relatively constant over periods of interest, the developers of dendroecological models have controlled for age, site quality and competition while focusing on weather. Unlike periodic forest growth models, dendroecological models are based on the historic annual increment evidenced in tree rings. Consequently, weather variables can be included in these types of models.

Since much of the methodology was developed in the arid southwest or for timberline or other marginal growth situations, dendroecologists were able to subjectively sample open-grown trees and thus ignore the "problem" of competition. Smooth functions in time, such as polynomials and splines, have been used to filter out competition for trees in closed stands (Cook and Peters 1981). Again, this is a means of avoiding the "problem" as opposed to explicitly incorporating it as a determinant of growth. Sample locations were assumed to be similar in terms of productive ability. In addition, smooth functions in age are fitted to the raw ring widths in order to remove the age effect for each tree, separately. Having assumed away site quality effects, ignored or filtered out competition effects, and removed age effects, it is assumed that the remaining signal can be attributed to weather and to random noise.

A conventional dendroecological is broken into four steps. At the first step a growth function is fitted to the raw ring widths in order to remove the growth trend. This is done for each core separately. Next the raw ring widths are divided by the growth-trend-predicted widths in order to stabilize variance and standardize magnitudes. The result is called a tree ring index. In the third step, the tree ring indices are averaged, across cores, for each year, resulting in the so-called mean chronology. Finally, a function of some set of weather variables, called the response function, is fitted to the mean chronology. If z_t is the mean chronology element for year t, SP_t and JMT_t are examples of weather variables and v_t is a random error term for year t, and the b_i's are model coefficients, then an example of a response function is

$$\bar{z}_t = \beta_0 + \beta_1 SP_t + \beta_2 JMT_t + v_t. \qquad (1)$$

Eriksson et al. (1990) discuss some of the problems inherent in using this system of equations.

The linear aggregate model is another hypothetical growth construct which has been suggested in the dendroecological literature (Graybill 1982, Cook 1987a,b). It can be viewed as a decomposition of the ring width into a number of components -- much like an analysis of variance. For example, one might hypothesize that

$$w_{it} = G_{it} + S_{it} + +C_t + D_t + e_{it} \qquad (2)$$

[3] The terminology of Fritts (1976, p. 534) is used here. Dendrochronology is defined as the study of annual increment in trees; dendroecological and dendroclimatological applications use dendrochronological techniques to study ecological and climatological phenomena, respectively.

where i = 1,2,...,N indicates individual, t = 1,2,...,T indicates year, w_{it} is the raw width of ith core at time t, G_{it} is the growth trend, S_{it} are the plot and tree effects, C_t are the climatic effects, D_t are exogenous disturbances, and e_{it} is a random error term.

Eriksson et al. (in revision) note that the linear aggregate model need not be hypothetical; by associating functional forms to each of the terms in (2), a formal model can be fitted to actual data. For example, if the growth trend is a linear function of age, A_t, the plot effect is a linear function of basal area per acre, B_{it}, the climatic effect is a linear function of spring precipitation and July maximum temperatures, SP_t and JMX_t, and there are no exogenous disturbances, then the linear aggregate model can be expressed as

$$y_{it} = \beta_0 + \beta_1 A_{it} + \beta_2 B_{it} + \beta_3 SP_{it} + \beta_4 JMT_{it} + e_{it}.$$

The left hand side of this equation is written as y_{it} rather than w_{it} to indicate that some transformation of the raw ring widths, eg. logarithmic, may be needed to achieve linearity. Eriksson (1989) proposed estimating the linear aggregate model directly in order to integrate forest growth and dendroecological modelling philosophies. A particular implementation for which coefficients are estimated will simply be called a full linear model (FULL).

Random Coefficients Models

Random coefficients regression models are analogous to random effects, analysis of variance models. The later are familiar to many silviculturists. In ordinary least squares (OLS) regression models, the coefficients are assumed to be fixed, unknown, constants. In random coefficients regression models, the coefficients are assumed to be unknown random variables. A linear random coefficients model with a single explanatory variable, x, and no intercept can be written as

$$y_i = \beta x_i + \underbrace{x_i u_i + e_i}_{\text{random}},$$

where i=1,2,...,N, the number of observations, e_i is an error term, and $b_i = b + u_i$ with b fixed and u_i the random part of the random coefficient b_i. Any number of coefficients in a model can be similarly decomposed.

Since the overall error term, $x_i u_i + e_i$, in a random coefficients model are not identically distributed with constant variance (indeed they depend on the explanatory data), estimation of the parameters in a random coefficients model is more complicated than for a fixed effects model. Estimated generalized least squares (EGLS) was used for the Swamy model discussed below. As with random effects models in analysis of variance, one potential problem with EGLS is that negative variance estimates may be obtained.

Swamy Model 3

Trees have different inherent abilities to grow and may be measured at different life stages. That is, they follow different growth trends. By separately fitting a growth trend equation to each core, conventional dendroecological methods allow for a different growth response for each tree. Another approach to achieving different growth trends is to view the full linear model as a random coefficients model (Eriksson 1989). The individuality is captured in the random part of the coefficients.

A number of random coefficients models were considered, each corresponding to different error distribution assumptions. Each of the formulations was based on a set of error assumptions and estimation procedures proposed by Swamy (1970, 1971, 1974). One of those was called the Swamy Model 3 (SWAMY-3). Under this model, the overall error terms, corresponding to the $x_i u_i + e_i$ above, were assumed to be serially correlated within core and independent between cores. These particular error assumptions result in block diagonal covariance matrices and, hence, to computer-efficient EGLS estimation.

Regression on Means

The conventional method for analyzing dendroecological data uses a regression of the mean chronology on the annual weather variables, e.g. equation (1). This is an example of what is called aggregation in the econometrics literature. Under the assumption of constant variance and no serial correlation, coefficient estimates obtained using ordinary least squares on aggregated data will be the same as those obtained using all of the data – providing only weather variables are included in the response function. A similar statement cannot be made for the full linear model since some of the explanatory data differ between cores.

When a regression model is fitted to data, what is really being modeled is the mean of the response variable conditional on the level of the explanatory variable(s). That is, even though we actually fit the model using all of the available data, it is actually the conditional means that are being modeled. When aggregated data are used, only the conditional means are used. Two obvious problems with using aggregated data are that the sample size, and hence the degrees of freedom, is drastically decreased and that the variance estimate captures only the variation between years. It ignores the variation within year. The result is that it gives the false impression that the relationship is stronger using aggregated data. This will typically be manifested in a higher model R^2 value for aggregated data.

Ring widths were averaged, on a year-by-year basis, and regressions fitted to the resulting mean time series (MTS) in an attempt to determine the effect of aggregation under the full linear model. This was not done because we advocate using the MTS, but to obtain results somewhat analogous to those from a conventional analysis.

Sources of Data

Three types of Data were used in this study: permanent plot data were used for the development of competition variables, and tree ring and weather data from locations near the permanent plots.

In 1972 Richard Lohrey of the Southern Forest Experiment Station established thinning studies in five longleaf pine plantations in central Louisiana and eastern Texas. The Louisiana plots were located near Alexandria, LA. Study #313 was actually comprised of two stands, one near Angelina and one near Yellow Pine, TX. Within each installation, permanent plots were established and remeasured at five-year intervals from 1972 to 1987. The different studies are identified by study number and location in Table 1. Table 1 also states whether or not the particular study sites were thinned.

Tree Ring Data

Increment cores were obtained from trees in buffer areas, within the plantations, around the permanent plots. This is contrasted with the design used by Eriksson (1989), whereby the increment cores were obtained from trees within the permanent plots. This distinction was important to the analyses, as will be discussed later. Table 1 lists the number of increment cores obtained in each study and the approximate ending breast height age of the cores.

Weather Data

Weather data were not uniquely associated with the plots. Consequently, frequency-weighted averages (based on numbers of observations available for each month) of two sources were used for the Louisiana locations. Based on latitudes and longitudes, distance-weighted weather variables were calculated and assigned to the Texas plots. Weighting procedures will be documented in a subsequent publication and are available from the authors.

Permanent Plot Data

The number of trees and basal area per acre were used as competition information. Since the increment cores available for this study were not uniquely associated with sample plots and since the weather data extended back to 1952, an adaptation of the spline-fitting procedure proposed by Eriksson et al. (1990) was necessary in order to assign competition levels to each core and to extrapolate the competition information backwards in time.

In addition to having the four remeasurements for each plot, the ages of the plots were known. Using basal area per acre as an example, since the basal area per acre of a new plantation is zero, five data points were, effectively, available for spline fitting. Splines were fitted to these five points for each sample plot. The resulting smooth curves were averaged on a year-by-year basis to form an overall, installation-wide, competition curve. For each year, then, the same competition levels were assumed to affect all trees from which cores were extracted.

Figure 1 shows the resulting basal area per acre curve for study 329. The curve is well behaved between the years 1961 and 1984, the analysis period adopted for 329. Since the curve is averaged over all plots and since the stand was unthinned, it is not surprising that it is highly collinear with age over the period of interest. The "discontinuities" between 1949 and 1958 are apparently due to differences of when trees achieved breast-height age.

Unfortunately, the plot data could only be reconstructed for two of the studies: #329 and #313. In addition, individual tree information was available for unthinned Louisiana study (#329) but only plot summary data was available for the thinned Texas study (#313). Because of the lack of data and the

Table 1. *Longleaf pine thinning studies used for these analyses.*

Study	Location	Thinned	No. Cores	Ending Age
229	LA: Longleaf Tract	Y	58	35
302	LA: Johnson Tract	Y	30	50
313a	TX: Yellow Pine	Y	24	45
313b	TX: Angeline	Y	12	45
329	LA: Johnson Tract	N	22	30-45

collinearity noted above, even though one of our primary objectives was to look at the combined influences of competition and weather on radial increment, most of the analyses had to proceed without competition measures.

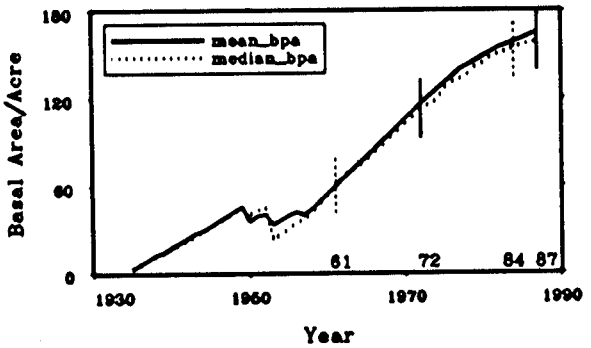

Figure 1. *Average basal area per acre spline interpolation, by year, for Study 329.*

Results and Discussion

Although the main focus of this study was on the full linear model, growth trend models were fitted to each core separately in an attempt to find the best functional form relating age and radial increment. It was assumed that weather would be additive to this basic model. A number of transformations, logarithms, etc., of age and ring widths were considered in an attempt to improve fit and to stabilize variance. Over the majority of cores, none of the transformations were appreciably better than the untransformed data. This was an unexpected result and is probably due to the short usable length of the cores. The results presented below are for untransformed data.

A very large number of weather variables can be considered. Models were run with all one and two weather variable combinations. Many of these combinations contributed significantly to the models considered. When the number of variables in two models is the same, and everything but the weather variables is the same, then the model R^2 is a valid criterion by which to rank models.

For each location, models were ranked by R^2 values. In some instances, the variables that were the best for one location were only marginally significant at another location. However, there were combinations that ranked relatively high across locations. Since the intent of this study was not necessarily to find the "best" models relating age, competition, and weather to radial increment, but to investigate the modelling framework and to identify variables that appear to be important across the region, it was felt that consistency is an important element for variable selection. The pair of variables, average spring (April - June) precipitation and July maximum temperature, ranked highly for different locations. They have the added advantage of being easily interpreted as determinants of radial increment. The results below are for these variables.

Table 2 provides the regression results for study #329, the unthinned Louisiana study. The first panel shows the results from estimating the full linear model using ordinary least squares (OLS), the second panel shows the estimates obtained under the assumptions of SWAMY-3, and the third shows the mean time series estimates.

There are a number of things to note from Table 2. First, with the exception of the age coefficient under SWAMY-3, all of the coefficient estimates are of the same sign and magnitude. Second, the coefficients are interpretable. For example, the July maximum temperature coefficient under OLS-FULL is -0.078. This means that, if every thing else remains the same, for each additional degree of temperature, radial growth can be expected to decrease by 0.078mm. Similarly, for every year in age gained, growth can be expected to decrease by about 0.04mm.

Age was not significant under either of the OLS procedures, and only marginally significant (depending on the α-level employed) under SWAMY-3; under SWAMY-3 the sign is not reasonable. This would appear to indicate that age should not be in the model. However, age and the basal area per acre measure are highly collinear, in addition the basal area per acre measure was ad hoc for study 329 and not available for some other locations. Consequently, rather than dropping age, basal area per acre was dropped and age became quite significant (Table 3, Panel 4).

Table 2. *Regression results for Study 329 using OLS-FULL, SWAMY-3, and OLS-MTS.*

Parameter	Estimate	Std. Error	t	Pr > |t|
OLS-FULL: df = 523, R^2 = 0.46				
Constant	13.17196	2.29350	5.743	0.000
Age	−0.03978	0.03088	−1.288	0.198
Ba/Ac	−0.01840	0.00711	−2.589	0.010
Spring PPT	0.10014	0.02980	3.361	0.001
July Max	−0.07784	0.02587	−3.008	0.003
SWAMY-3: df = 523				
Constant	11.02458	1.99818	5.517	0.000
Age	0.10611	0.05721	1.855	0.032
Ba/Ac	−0.05162	0.01390	−3.714	0.000
Spring PPT	0.10502	0.02053	5.114	0.000
July Max	−0.05014	0.02223	−2.255	0.012
OLS-MTS: df = 19, R^2 = 0.86				
Constant	13.35202	4.50587	2.963	0.008
Age	−0.05336	0.12749	0.429	0.680
Ba/Ac	−0.03896	0.02841	−1.371	0.186
Spring PPT	0.09219	0.05925	1.556	0.136
July Max	−0.07657	0.05080	−1.507	0.148

Table 3. *SWAMY-3 results comparing for all four studies and the corresponding probabilities of greater t's from the OLS-FULL and the OLS-MTS regressions. The asterisk indicates a negative variance estimate.*

Parameter	Estimate	Std. Error	t	Pr > |t|	Pr > |t|	Pr > |t|
229 -- Louisiana Thinned: df = 1446				SWAMY-3	OLS-FULL	OLS-MTS
Constant	7.90816	0.30362	26.046	0.000	0.000	0.016
Age	−0.07424	0.00621	−11.951	0.000	0.000	0.000
Spring PPT	0.03743	0.00504	7.429	0.000	0.017	0.190
July Max	−0.01348	*0.00085	−15.928	0.000	0.002	0.263
302 -- Louisiana Thinned: df = 1016						
Constant	3.44813	1.21900	2.829	0.002	0.090	0.426
Age	−0.06980	0.00786	−8.876	0.000	0.000	0.000
Spring PPT	0.06298	0.01603	3.930	0.000	0.000	0.047
July Max	0.01624	0.01395	1.164	0.122	0.029	0.306
313 -- Texas Thinned: df = 1220						
Constant	7.52558	0.99275	7.5810	0.000	0.010	0.389
Age	−0.03503	0.00738	−4.744	0.000	0.000	0.000
Spring PPT	0.15831	0.01296	12.216	0.000	0.000	0.001
July Max	−0.04185	0.01034	−4.049	0.000	0.868	0.942
329 -- Louisiana Unthinned: df = 524						
Constant	11.87648	1.82002	6.525	0.000	0.000	0.003
Age	−0.11757	0.00913	−12.884	0.000	0.000	0.000
Spring PPT	0.14235	0.01824	7.803	0.000	0.000	0.066
July Max	−0.07003	0.01971	−3.553	0.000	0.000	0.056

Finally, based on the probabilities of a greater t's, it appears that variables are slightly more likely to be called significant under SWAMY-3 than under OLS-FULL, and that estimation under OLS-MTS is much less likely to detect influential variables. These observations are consistent with the facts that more appropriate error assumptions are made under SWAMY-3 than under OLS-FULL and that the degrees of freedom is decreased under OLS-MTS to 19, even though the relationship appears (higher R^2) to be stronger.

While Table 2 compares the different estimation techniques for one study, Table 3 presents the results from one estimation technique, SWAMY-3, across studies. Note that the signs and magnitudes of the estimated coefficients are generally similar across studies. There is one exception: the sign on the July temperature coefficient is different for study 302. In this case, however, the coefficient would not be significant if an α of less than 0.12 were adopted. Notice, too, that estimation under SWAMY-3 produced a negative variance estimate for the July maximum temperature coefficient in study 229. It is believed that this is because this coefficient should be assumed to be fixed, rather than random. An investigation of this mixed model situation is on-going and will be presented at a later time.

Also presented in Table 3 are the probability estimates, Pr > |t|, for OLS-FULL and OLS-MTS for the four locations. It is apparent that the result noted above for study 329 carries over to the other studies: variables are more likely to be deemed significant when estimated under SWAMY-3 and the weather variables are generally unlikely to be considered significant when estimated under OLS-MTS. The signs and magnitudes of the coefficient estimates under the other techniques are quite similar to those under SWAMY-3.

Finally, a conventional dendroecological (DC) analysis was performed on the mean chronology, Table 4. Age does not appear as a variable in this table since its effect is removed at Step 1 in the analysis. Again we see that the coefficients have similar signs and magnitudes across the four studies. However, in this case the coefficients are not interpretable: an increase in July maximum temperature of one degree would result in a decrease of 0.0016 (unitless) in the average tree ring index for study 229. But this decrease has no physical meaning. As expected, the significance level, Pr > |t|, of the estimated coefficients are similar to the corresponding OLS-MTS values.

Conclusions

While the extent of the data for this study was rather limited (usable length of the cores was rather small and competition information weak or missing), a number of conclusions can be made. OLS-FULL, OLS-MTS, and SWAMY-3 all produce similar coefficient estimates. This was expected since these methods all produce unbiased estimates. In addition, the variables are all biologically reasonable and their coefficient estimates have the correct signs and can be directly interpreted. The interpretation of coefficient estimates under the conventional dendroecological method is, at best, difficult. It was also found that the selected variables generally have a similar influence on radial increment across the four studies. This would be important for regional models. There are indications of stronger influences of both weather and age in the unthinned stand, but this effect was not formally tested.

The error assumptions under SWAMY-3 are more reasonable than those under OLS-FULL, and this may be responsible for the smaller probability values under SWAMY-3. If this is, in fact, the case, then SWAMY-3 may be preferable for assessing the significance of marginal variables. However, negative variance estimates may be a problem under SWAMY-3. Consequently, OLS-FULL may often be preferred—especially since it is easier to use. The use of mixed models is under further investigation. Finally, it was apparent that methods based on means (MTS and DC) may under-value the influence of weather by collapsing the data too much.

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Table 4. *Conventional dendroecological response function regression results using Spring precipitation and July maximum temperature.*

Parameter	Estimate	Std. Error	t	Pr > |t|
229 – Louisiana Thinned: df = 24, R^2 = .14 → .68				
Constant	1.13184	0.14668	7.717	0.006
Spring PPT	0.00376	0.00238	1.579	0.127
July Max	−0.00156	0.00156	−0.993	0.331
302 – Louisiana Thinned: df = 31, R^2 = .09 → .60				
Constant	1.03577	0.12619	8.208	0.000
Spring PPT	0.00275	0.00165	1.670	0.105
July Max	−0.00050	0.00135	−0.371	0.713
313 – Texas Thinned: df = 31, R^2 = .01 → .52				
Constant	1.07559	0.14863	7.237	0.000
Spring PPT	0.00613	0.00198	3.103	0.004
July Max	−0.00108	0.00157	−0.684	0.499
329 – Louisiana Unthinned: df = 24, R^2 .37 → .66				
Constant	1.31992	0.14815	8.910	0.000
Spring PPT	0.00639	0.00240	2.658	0.014
July Max	−0.00378	0.00158	−2.387	0.025

VALIDATION AND COMPARISON OF FOUR CUT-OVER SITE PREPARED LOBLOLLY PINE GROWTH AND YIELD MODELS [1]

Michael L. Clutter and James A. Gent [2]

Abstract. The performance of four loblolly pine (Pinus taeda L.) growth and yield models was investigated to determine the accuracy and precision of long-term yield projections. The validation data consist of 111 installations of a region-wide spacing study in cut-over site prepared loblolly pine plantations. The variables validated include surviving stems per acre, basal area per acre, quadratic mean diameter, and total yield. Additionally, the dynamic and limiting behavior of each model is discussed relative to these data and commonly accepted theoretical stand development relationships.

Introduction

Forest managers have come to rely on mathematical models for forest growth and yield to aid in formulating optimal forest planning decisions. Growth and yield predictions are used for such diverse planning purposes as stand level inventory projections, to provide yield estimates for harvest scheduling, and to evaluate such silvicultural alternatives as planting density, fertilization prescription, and treatment with herbaceous weed control (Borders et al., 1991; Broderick et al., 1982; Clutter et al., 1983). Obviously, the quality of these forest management decisions will be affected by the choice of the growth and yield model used.

The use of discounted cash flow analyses in making decisions relating to topics such as site preparation and planting density requires the use of growth and yield models to predict future volumes for a given site index, planting density, initial survival, and rotation age. Past experience with the available growth and yield models indicates that prediction of future volumes can vary greatly from model to model. Considering the fact that discounted cash flow analyses are so sensitive to volume production, it is important to employ the best available growth and yield model to assist in making forest management decisions.

There currently exist a number of loblolly pine (*Pinus taeda* L.) plantation growth and yield models which have been developed for cut-over site-prepared plantations in the Southeast. Each model reflects the level of resolution desired by its developers, the data used to select model forms and estimate parameters, and the modelers' beliefs concerning stand development in loblolly pine plantations. Most of this modeling work has been performed using data obtained from surveys of operational plantations with remeasured fixed-area plots. A number of scientists have long recognized the problems associated with using survey data to establish stand development trends across the range of ages, site indices, and densities required to build a good dataset (Bennett, 1969; Reukema, 1966). Correlations between growth and the independent variables of interest make trends hard to "sort out" when survey data are used. For this reason spacing study data are, in many respects, far superior to survey data for growth and yield modeling activities.

Buford (1991) recently compared the performance of four loblolly pine (*Pinus taeda* L.) growth and yield models and concluded that the North Carolina State (NCSU) growth and yield model was the best. However, there were several problems associated with the data set used to validate the growth and yield models. The data came from a spacing study located on the Calhoun Experimental Forest near Union in the South Carolina Piedmont. This study was installed on an abandoned cotton field. The use of old-field data to validate growth and yield models that predict growth on cutover land is questionable because the site index tend to be higher than that on cutover land and they lack the woody competition that is usually present on cutover sites. These factors may result in differences between the shape of the growth curves found on cutover and old-field sites. Another problem with this analysis is that the data do not provide a totally independent validation data set for the NCSU model. The age 20

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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and 25 year data from the spacing study were used to evaluate, but not fit, the NCSU model; however, the data collected at ages 5, 7, 11, and 15 were used to fit the model.

With the exception of Buford's (1991) study, there is no other information in the literature that specifically addresses the actual performance of these loblolly pine growth and yield models. Therefore, the objective of this paper is to determine which of the available loblolly pine growth and yield models does the best job of predicting rotation-length yields.

Growth and Yield Models

The behavior of the following loblolly pine growth and yield models were examined:

1. Old University of Georgia Model (Bailey et al., 1985)
2. New University of Georgia Model (Borders et al., 1991)
3. NCSU Model (Hafley and Buford, 1985)
4. VPI TruLob Model (Amateis et al., personal communication)

Model Comparisons

As indicated above, several of the available growth and yield models contain separate models for the different physiographic provinces. To simplify the process of making graphic comparisons among the five major growth and yield models, the Piedmont model was chosen to represent those that offer models for the different physiographic provinces.

Since we are interested in the prediction of rotation-length yields for a given site index (base-age 25), we used the last measurement of dominant and codominant height along with planting density and age to predict yields for each model. The intent is to establish the predictive ability of each model for a known site index, not to test the performance of the site index equations in each model.

Mortality

Figure 1 shows the 25-year survival predicted by each model for a range of initial planting densities and site indices. These graphs indicate that the mortality function in the NCSU model "kills" far fewer stems than the mortality functions in the other 3 models, with the exception of the VPI model on high site at high initial densities. The VPI model shows the largest range in mortality across site indices and initial planting densities. The two UGA models behave similarly with the new UGA mortality function exhibiting better survival than the old UGA mortality function. As site index increase, all models except the VPI model show an increase in nonlinearity across initial planting density. It is interesting that the NCSU model predicts the highest survival over most of the range of site indices and initial densities. This may be due to the inclusion of old-field data when developing the model.

Basal Area

Predicted stand basal area at 25 years is shown in Figure 2. In general, the NCSU model predicts the highest basal areas. As with the mortality trends, the VPI basal area model is lowest of the four models on low site indices and near the highest for high site indices. The new UGA model predicts less basal area than the old UGA model at low site indices and more basal area on higher sites.

The graphs in Figures 1 and 2 are useful in terms of comparing the various growth and yield models at a particular age. However, they provide no information on how well the models predict how stands of trees actually develop through time. Considering that basal area is influenced by survival and is so highly correlated with yield, it is important that a growth and yield model accurate and precisely predict basal area. Figure 3 shows basal area growth curves for site index 60 for the old and new UGA models, the NCSU model, and the VPI model. The old UGA and VPI models both indicate that basal area increases with increasing planting density. This suggests that, at least over the range of operational spacings, carrying capacity is a function of density rather then site index. The graph for the new UGA model indicates that the curves for various spacings will reach a common asymptote or carrying capacity which is a function of site index. Finally, the NCSU model shows that basal area reaches a maximum and then declines. The age at which this decline begins is proportional to site index and inversely related to planting density. The differences in basal area prediction among models shown in Figure 3 are the result of a dearth of long-term spacing study information in the South as well as some philosophical differences among modelers (Hafley and Buford, 1985; Amateis et al., 1984; Bailey et al., 1985; Harrison and Daniels, 1988). The lack of replicated long-term spacing data for cut-over site prepared loblolly pine plantations precludes construction of similar graphs with data from the South. Within these

four models there exist three substantially different patterns of basal area development. The Correlated Curve Trend (CCT) Studies installed by the South African Forestry Service probably provide the most definitive information on basal area development for a range of planting densities. Even though these data were collected from stands where conditions are different from the South, we believe they provide a substantial amount of insight into the patterns of basal area development. The curves in Figure 4 show the basal area growth curves from one of their 35 year-old studies (Pienaar it al., 1985). Similar to the curves predicted by the new UGA model, these data suggest that there is a common asymptote or carrying capacity. Thus, carrying capacity is a function of site and not a function of initial density. Based upon this information and other long-term spacing data, many foresters believe that this basal area development trend is correct (Harrison and Daniels, 1986; Pienaar et al., 1985; Borders et al., 1990; Oliver and Larson, 1990; Assmann, 1970).

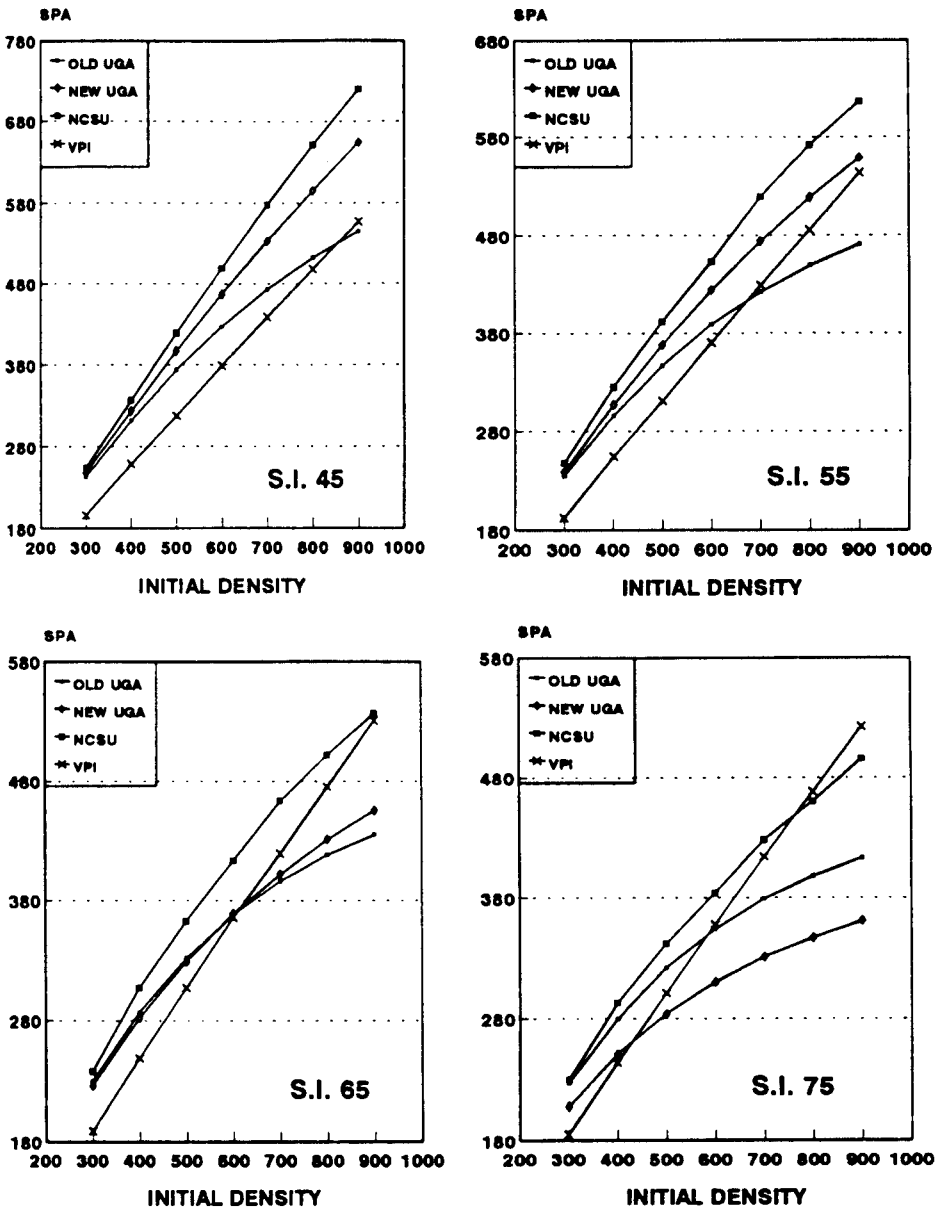

Figure 1. *Number of surviving stems predicted at age 25 by various growth and yield models.*

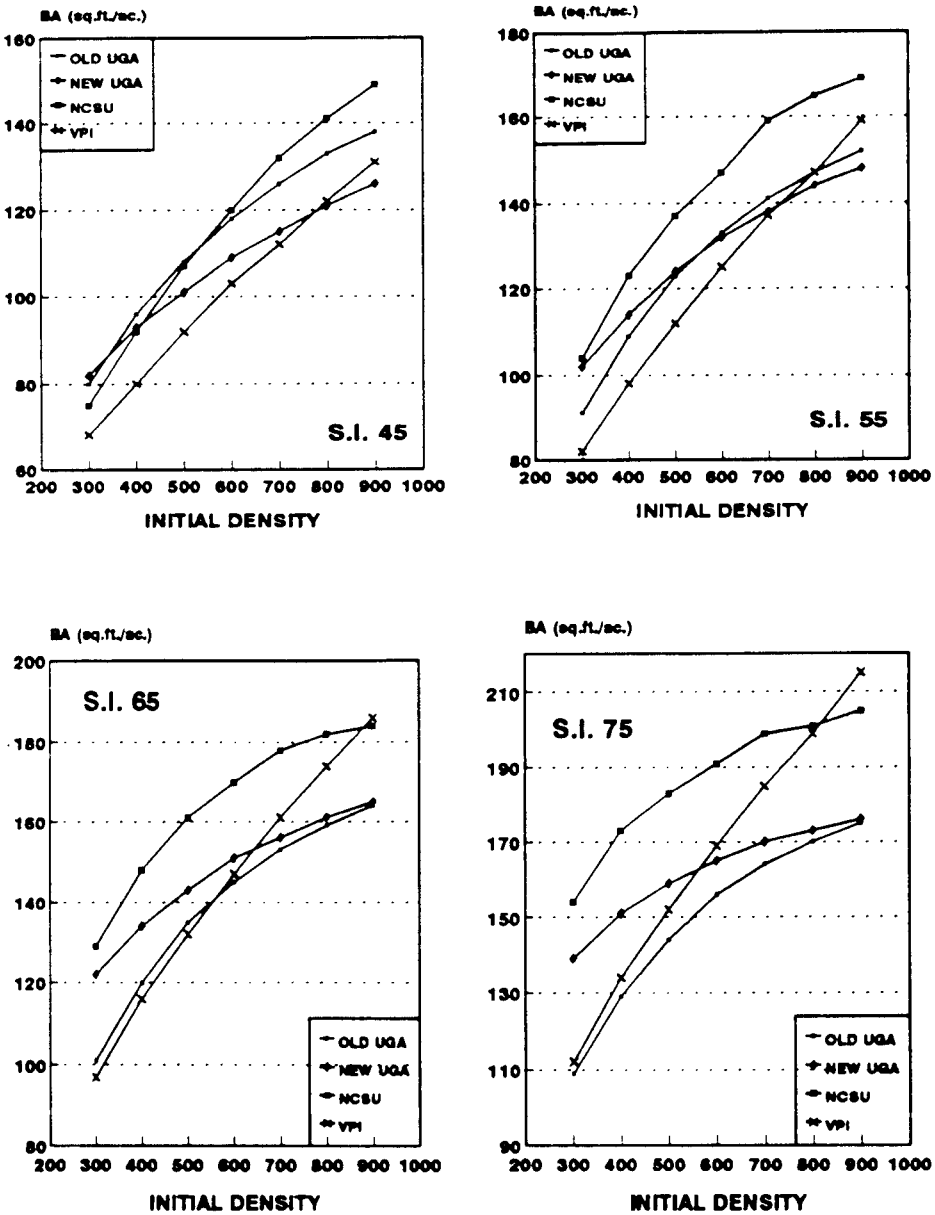

Figure 2. *Basal area predicted at age 25 for various growth and yield models.*

Another approach to basal area modeling has been suggested by researchers at Westvaco (Harrison and Daniels, 1988). They believe that an exception to the concept of asymptotic basal area occurs in particularly dense (≥ 1,200 SPA) stands. As shown in Figure 5, at higher densities, basal area approaches the carrying capacity of the site and then declines or "crashes" substantially with a major wave of mortality. They have observed this basal area crash in their spacing studies for spacings closer than 6 x 6 feet. Westvaco models this "crash phenomenon explicitly with a function to reduce basal from the asymptotic model as average tree sizes approach a biophysical imbalance. (Their) model implies a slow recovery towards carrying capacity as survivors grow" (Harrison and Daniels, 1988).

Our data within the operational planting densities of 300 to 900 stems per acre exhibit the trends displayed by the new UGA model — that all densities converge to a site specific carrying capacity. We have also observed the "crash phenomenon" discussed by Harrison and Daniels but only in stands which were established at densities greater than 1200 stems per acre. Additionally, when such decreases in basal area occurred, these decreases were followed by trends of increasing basal area growth as described by Harrison and Daniels. The continued crash as

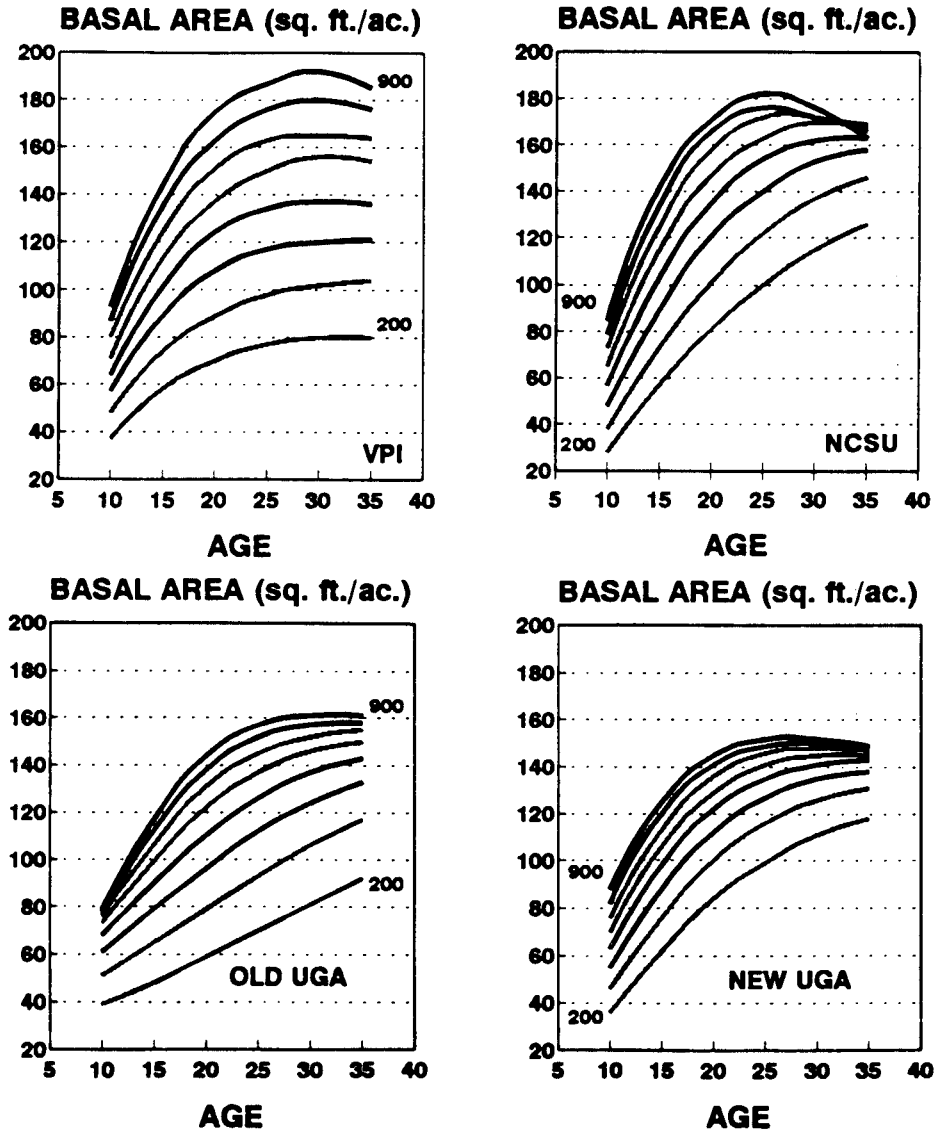

Figure 3. *Basal area growth curves for various initial densities on site index 60 (Base-age 25) land for various growth and yield models.*

depicted by the NCSU model was not evident in our spacing study data.

Model Validation

Data Set

The graphs in Figures 3 and 4 show that the basal area growth curves predicted by the new GAPPS model are more similar in form to the basal area growth curves constructed from long-term (South African) data than the curves exhibited by the other available models. However, to actually validate these models we need to compare the stand parameters predicted by the various models with values actually observed in loblolly pine stands growing in the southern United States. The best data set available to validate southern pine growth and yield models is the St. Regis/Union Camp Pine Growth and Yield (PG&Y) Study. Two other published spacing studies are also available for validation purposes; however, they are much smaller than the PG&Y Study and are located on sites that are not representative of most cutover loblolly pine sites. The first study (Harms and Lloyd, 1981), as discussed in the introduction, is not appropriate to use for validation purposes since it was established on an old-field site. The second study (Sprinz et al., 1979) is located on an alluvial soil in Louisiana. In contrast to these two studies, the PG&Y data base consists of installations established across a wide range of cutover sites with plots located in Alabama, Florida, Georgia, North Carolina, South Carolina, and Virginia. Site index in this data set ranges from 40 to 91 feet; planting densities range from 100 to 1800 stems per acre.

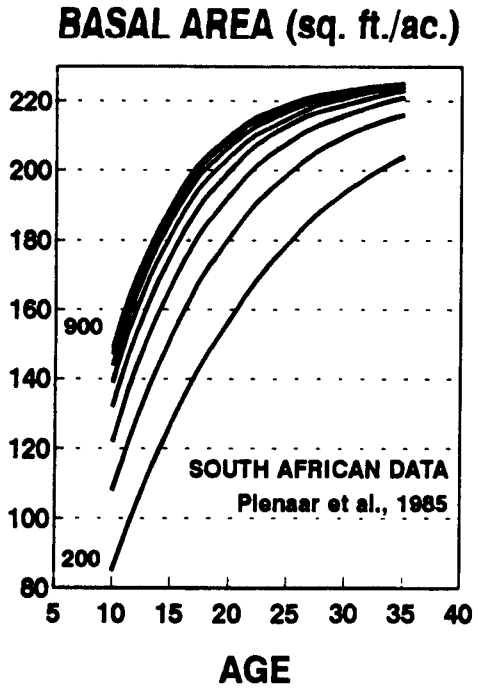

Figure 4. *Basal area growth curves for 35-year-old South African slash pine at various initial densities (Pienaar et al., 1985).*

In validating the models, we used a total of 147 plot measurements. Only data from the oldest measurement age for plots ≥ 17-years-old were used. In addition, we excluded plots where initial densities were < 300 stems per acre (SPA) and > 900 SPA, and/or site index > 85 feet. Low initial densities were excluded because we do not believe that a site will ever be fully occupied at densities less than 300 SPA. Plots with initial densities > 900 SPA and/or site index > 85 feet were excluded because these densities and site indices are outside the range of the data used to fit these growth and yield models.

Validation Criterion

In validating models, we are interested in how close a model comes to predicting observed values. The difference between the observed and predicted value is referred to as the residual:

$$Residual = observed - predicted$$

$$= Y_i - \hat{Y}_i$$

More specifically, we are interested in the average of the residuals calculated across a range of observed values and the variance of these residuals. This mean of the residuals is referred to as the bias:

$$Bias = \frac{\Sigma (Y_i - \hat{Y}_i)}{n}$$

$$where: \; n = number\ of\ observations$$

$$Variance = \frac{\Sigma (\hat{Y}_i - \bar{Y})^2}{n-1}$$

$$= [\ Standard\ Deviation\ ]^2$$

$$where: \; \bar{Y} = mean\ of\ observed\ values$$

The bias and the variance can be combined and expressed as the mean square error (MSE):

$$MSE = \left[\frac{\Sigma (Y_i - \hat{Y}_i)}{n}\right]^2 + \frac{\Sigma (\hat{Y}_i - \bar{Y})^2}{n-1}$$

or

$$MSE = (Bias)^2 + Variance$$

The model that minimizes the MSE for a given parameter does the best overall job of predicting the observed value. Table 1 shows the MSE's calculated for surviving SPA, basal area, quadratic mean diameter, and volume for a number of growth and yield model combinations. With the exception of SPA predicted by the VPI model, the PG&Y data can be used as an independent data set for validation purposes. The PG&Y data set was used to fit the VPI mortality function; hence, it cannot be validated with this data set.

Results

Stems Per Acre

The old UGA mortality function exhibited the best predictive performance using these data. Although the new UGA mortality function has a much lower bias than any other model, the MSE was higher due to a higher variance of the residuals. The mortality function in the NCSU model has the largest bias of all models, overpredicting by an average of 60 stems.

Table 1. Mean square error, bias, and standard deviations for stand parameters predicted by various growth and yield models.

	OLD UGA	NEW UGA	NCSU	VPI
Stems per acre				
MSE	4937	6393	8545	-
Bias	−25	−7	−60	-
S.D.	66	80	70	-
Basal Area (ft^2/acre)				
MSE	454	480	688	594
Bias	3	0	−15	−6
S.D.	21	22	22	24
Quadratic Mean DBH(in.)				
MSE	0.63	0.18	0.19	0.28
Bias	0.42	0.06	0.09	−0.04
S.D.	0.67	0.42	0.42	0.58
VOLUME (ft^3/acre)				
MSE	303,998	277,760	296,593	387,300
Bias	50	−75	−130	−68
S.D.	549	522	529	619

MSE = Mean Square Error
Bias = Mean of Residuals
S.D. = Standard Deviation of Residuals

Basal Area

MSE for basal area was minimized by the old UGA model with the new UGA model performing almost as well. As with stems per acre, the NCSU model displayed a tendency to overpredict basal area by 15 square feet per acre on the average. The VPI showed a tendency to underpredict at low initial densities and overpredict at high initial densities.

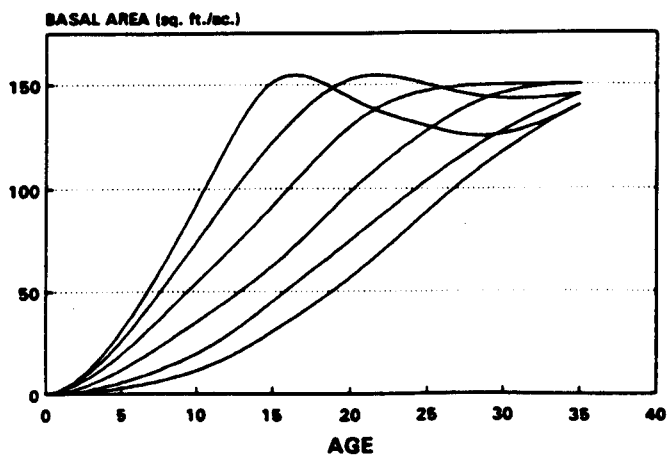

Figure 5. *Westvaco's basal area development model for 6 initial densities (4'x4' to 14'x14' on a 2' interval) after applying the crash factor (Harrison and Daniels, 1988).*

Quadratic Mean Diameter

The new UGA model predicted these data better than the other three models considered. The NCSU model was a close second due to the fact that overpredictions of both survival and basal area "cancelled out" in the calculation of quadratic mean diameter. The old UGA model performed particularly poorly due to an overprediction of survival and an underprediction of basal area which tended to reduce predicted quadratic mean diameter.

Volume (ft^3/acre)

The new UGA model minimized the MSE for predicted cubic foot volume. The NCSU model performance was second with a bias of 130 cubic feet. The old UGA model and the VPI model were third and forth, respectively.

Summary and Conclusions

As noted earlier, the fact that the new UGA basal area function exhibits trends similar to observed trends in long-term spacing data suggests that this model might provide the best long-term yield predictions. This hypothesis is supported by the results of the analysis comparing model predictions

observed in the PG&Y Study. Another important aspect of this study is to show the importance of long-term growth and yield data from a wide range of sites and initial densities. Such validation work simply cannot be performed without such data. The conclusions of model performance are drawn from the comparison against these data. Obviously, if other data are used then the conclusions may differ. However, we believe that the 147 plots spread over some 28 locations represent the best cut-over site prepared loblolly pine plantation spacing data available.

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A NEW GROWTH AND YIELD SYSTEM FOR CUTOVER LOBLOLLY PINE PLANTATIONS IN THE CAROLINAS, GEORGIA, FLORIDA, AND ALABAMA [1]

B.E. Borders [2]

Abstract. A comprehensive growth and yield system has been developed for cutover plantations of loblolly pine. This system was developed using over 4000 individual plot measurements from throughout the coastal plain, upper coastal plain and piedmont areas of the Carolinas, Georgia, Florida, and Alabama. The system allows for yield prediction and growth projection for unthinned, thinned, as well as mid-rotation fertilized stands. The architecture of the model is a modification of an individual tree model that is constrained to be compatible with whole stand estimates of trees per acre and basal area.

[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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Wildlife and Forest Economics

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EFFECTS OF CHEMICAL SITE PREPARATION ON WILDLIFE HABITAT AND PLANT SPECIES DIVERSITY IN THE GEORGIA SANDHILLS [1]

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Abstract. We compared plant species diversity and abundance of food plants of bobwhite quail (*Colinus virginianus*), white-tailed deer (*Odocoileus virginianus*), and gopher tortoises (*Gopherus polyphemus*) among hexazinone, picloram + triclopyr, and imazapyr treated sites at 1 year post treatment. Hexazinone-treated areas produced more quail and deer food plants than the other 2 treatments. The abundance of gopher tortoise foods was similar among treatments although there were major differences in the plant species comprising these foods. Herbaceous plant species diversity was highest on the imazapyr treatment and lowest on the hexazinone treatment, whereas woody species diversity was lowest on the hexazinone treatment and highest on the picloram + triclopyr treatment. Different herbicide site preparation treatments can result in considerable variation in wildlife habitat quality and plant species diversity.

Introduction

Increased growth and survival of planted loblolly pine (*Pinus taeda*) resulting from herbicide application is well documented (Byrd and Foster 1982, Knowe et al. 1985, Bacon and Zedaker 1987, Glover and Dickens 1989, Dougherty 1990). However, forest managers will be more receptive to herbicide use if other ecological benefits accrue. Although herbicides are relatively non-toxic to wildlife, they can produce pronounced shifts in the composition of the redeveloping plant community. These shifts may affect wildlife either beneficially or detrimentally, depending on specific habitat requirements of individual species.

Favorable habitat conditions for bobwhite quail persist only a short-time in pine plantations following mechanical site preparation (Brunswig and Johnson 1972). However, the value of pine plantations as quail habitat may be enhanced or prolonged by herbicide application followed by a prescribed burn (Hurst and Palmer 1988, Witt 1991).

Various herbicides may have different effects on forage for white-tailed deer (Blake 1986, Witt 1991). In young pine plantations, Witt (1991) found lower winter browse production on chopped and chemically-treated plots compared to chopped only plots at 2 years post-treatment; however, at 4 years post-treatment chemically treated areas exceeded chopped plots in browse production. Hexazinone-treated plots had a greater abundance of winter browse plants than triclopyr- or picloram + triclopyr-treated plots. At 1 year post-treatment, Hurst (1987) found less deer forage on imazapyr pine release treatments applied in the fall compared to summer applications or untreated areas.

The gopher tortoise is the only tortoise indigenous to the Southeast and is officially designated as a threatened species in Alabama, Florida, and Mississippi. Of ecological importance, Witz et al. (1991) reported at least 32 species of vertebrates (including the threatened indigo snake (*Drymarchon corais*)) and 302 species of invertebrates that use gopher tortoise dens. Regarded as a "grazing herbivore", any treatment that affects the herbaceous plant community would affect gopher tortoise habitat. Even short-term effects could be highly detrimental to the tortoise because recovery of depleted populations is extremely slow as a result of the low reproductive rate and slow growth to sexual maturity (25 years or more in the Sandhills) (Landers et al. 1980).

Few studies document the effects of herbicide treatment on plant species diversity (Blake 1986, Zutter and Zedaker 1988, Neary et al. 1990), which is an important factor in evaluating habitat conditions for many wildlife species.

The objectives of this study were to quantify and compare the effects of 3 chemical site preparation treatments on wildlife habitat and plant species diversity at 1 year post-treatment. Specifically, we examined vegetative composition, abundance, and diversity. Resulting effects on food plants for bobwhite quail, white-tailed deer, and gopher tortoises

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[1] Paper presented at Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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were evaluated. Although habitat structure, as well as food availability, may greatly influence wildlife populations, the wildlife species chosen are primarily herbivorous or granivorous and should be affected by changes in food plant availability.

Methods

The study area was a 390-acre tract located in Marion County, Georgia, in the Sandhills physiographic province. Soils are acidic, relatively infertile, loamy sands with Vaucluse-Ailey soils occupying most of the site (USDA-SCS unpubl.). In 1989, all merchantable timber was harvested from the pine-hardwood stand. Approximately 30% of the site contained residual hardwoods after harvest. Specific site characteristics are described by Brooks (1992). The study design was a randomized complete block consisting of 3 replications and 3 treatments. Treatment plots ranged in size from 30 to 50 acres. The 3 treatments were:

1) Pronone 10G™ (hexazinone)--3.0 lbs. a.i./ac.
2) Tordon 101™ (picloram + 2,4-D)--0.5 + 2.0 lbs. a.e./ac + Garlon 4™ (triclopyr)--2.0 lbs. a.e./ac.
3) Arsenal™ (imazapyr)--0.75 lbs. a.e./ac.

The imazapyr treatment contained 0.5% volume-to-volume Induce™ as a surfactant. On May 25, 1990, the hexazinone treatment was broadcast with an Omni™ spreader, and on August 23-24, 1990, the other 2 treatments were broadcast-sprayed with manifold nozzles in a total volume of 30 gal./ac. To facilitate root absorption, hexazinone is commonly applied in spring when more rainfall is expected. A prescribed burn in October 1990 completed site preparation, and in January 1991, 1-0 loblolly pine seedlings were handplanted at a 6-X 8-foot spacing.

In March-April 1990 and September 1991, vegetation was assessed pre- and post-treatment, respectively. Woody stem density was examined on each plot in 50, permanently marked, 4-m^2 quadrats systematically located on a 100-X 100-foot grid. Stem diameters were measured at 4 inches above groundline and recorded by species. Frequency of occurrence was used to evaluate herbaceous vegetation and vines found in five-hundred 0.01-m^2 quadrats systematically located on a 10-X 100-foot grid. A 150-foot buffer zone at treatment boundaries was excluded from sampling.

Permanently established quadrats provided a direct comparison of the percent change in number of woody stems from pre-treatment to post-treatment. Analysis of variance was used to determine significant differences ($P < 0.05$) among treatments and means were separated using Duncan's New Multiple Range Test.

Herbaceous vegetation was compared based on frequency of occurrence. Data were normalized with an arcsine transformation (Steel and Torrie 1980). Since herbaceous data were not based on permanent plots, a higher level of significance ($P \leq 0.10$ level) was accepted to account for a potentially higher variability among samples. Plant species valuable to wildlife were grouped and analyzed separately.

Species diversity has 2 components: richness and equitability (Magurran 1988). The Shannon-Wiener index (H'), which incorporates both components, was used as an overall measure of diversity. Since either richness or equitability may influence H', we examined the components separately. The Shannon evenness index (J') measured equitability, and as a measure of richness, we evaluated the mean number of species on each treatment. Botanical nomenclature follows Radford et al. (1968).

Results

Woody vegetation data are presented in 2 diameter classes: $\leq$ 1.0 inch and $>$ 1.0 inches. In general, the smaller diameter class represents resprouting, whereas the larger diameter class represents stems surviving treatment.

Differences in the densities of woody stems occurred among treatments (Table 1). All treatments reduced large diameter woody stems with the exception of sweetgum in the picloram + triclopyr treatments. Seven major woody species resprouted in the hexazinone treatment. None of the major species resprouted in the picloram + triclopyr or imazapyr treatments. Although no significant differences among the other species category could be detected due to a low number of stems and high variability, resprouting in the imazapyr treatment consisted primarily of hackberry (*Celtis occidentalis*) and St. Andrew's cross (*Hypericum hypericoides*), whereas a number of minor species resprouted in the hexazinone-treated plots. Densities of all major woody stems were reduced by the imazapyr treatment. Compared to the hexazinone treatment, the imazapyr treatment showed a significant reduction in blackgum (*Nyssa sylvatica*), sweetgum (*Liquidambar styraciflua*), sassafras (*Sassafras albidum*), sparkleberry (*Vaccinium arboreum*) and all woody species combined in the small diameter class.

Table 1. *Mean percent decrease in number of woody stems on chemically prepared sites at 1 year post-treatment, Marion Co., Ga., 1991. Positive values indicate an increase in the number of stems.*

Species	Diameter ≤ 1 in.			Diameter > 1 in.		
	Treatments					
	Hex	Pic+Tri	Imaz	Hex	Pic+Tri	Imaz
Blackgum (*Nyssa sylvatica*)	+ 31.6A[1]	43.2B	98.8B	100.0	100.0	100.0
Cherry (*Prunus serotina*)	82.0	52.6	96.5	100.0	100.0	100.0
Hawthorn (*Crataegus* spp.)	89.5	61.9	77.8	-	-	100.0
Dogwood (*Cornus florida*)	41.4	41.9	76.8	100.0	100.0	100.0
Sweetgum (*Liquidambar styraciflua*)	+ 42.9A	74.8AB	83.6B	100.0	0.0	66.7
Persimmon (*Diospyros virginiana*)	+ 5.3	0.0	82.0	-	-	-
Oak (*Quercus* spp.)	73.2	24.4	67.3	100.0	100.0	100.0
Winged sumac (*Rhus copallina*)	+ 32.7	44.3	47.1	-	-	-
Sassafras (*Sassafras albidum*)	+ 74.1A	68.1B	90.1B	-	-	-
Sparkleberry (*Vaccinium arboreum*)	+ 120.9A	21.9B	85.8B	100.0	100.0	100.0
Deerberry (*Vaccinium stamineum*)	+ 104.8	61.0	87.5	-	-	-
Water oak (*Quercus nigra*)	96.3A	64.4B	92.2A	100.0	100.0	100.0
Wax myrtle (*Myrica cerifera*)	100.0	70.1	81.1	-	100.0	100.0
Other species	+ 45.4	73.9	+ 51.5	100.0	100.0	100.0
All woody taxa	+ 36.0A	48.9AB	80.4B	100.0	96.7	97.6

[1] Within a diameter class and row, values followed by the same letter are not significantly different at $P < 0.05$ (Duncan's Multiple Range Test).

Hexazinone and imazapyr resulted in a greater reduction in water oak (*Quercus nigra*) stems in the small diameter class compared to picloram + triclopyr. Hexazinone had considerable resprouting of sassafras, sparkleberry, deerberry, and to a lesser extent blackgum, sweetgum, and winged sumac (*Rhus copallina*). All treatments reduced large diameter woody stems with the exception of sweetgum in the picloram + triclopyr treatments.

Post-treatment differences in the abundance of herbaceous species occurred among treatments. Grasses were more abundant on the picloram + triclopyr treatment compared to the imazapyr treatment (Table 2). Conversely, the imazapyr treatment resulted in significantly more legumes than the picloram + triclopyr treatment. Individual legumes that were significantly higher on the imazapyr treatment include: pencil flower (*Stylosanthes biflora*), bicolor lespedeza (*Lespedeza bicolor*), common lespedeza (*L. striata*), dollar pea (*Rhynchosia tomentosa*), sensitive-brier (*Schrankia microphylla*), and hoary pea (*Tephrosia spicata*). No significant differences in the occurrence of remaining forbs were noted.

Overall, vines showed no major differences across treatments; however, individual vine species valuable as forage for deer and other wildlife species did have different responses to the herbicide treatments. Blackberries (*Rubus* spp.) were significantly higher and greenbrier (*Smilax* spp.) significantly lower in abundance on the imazapyr treatment. Although not significantly different, yellow jessamine (*Gelsemium sempervirens*) was somewhat more abundant and Japanese honeysuckle (*Lonicera japonica*) less abundant on the imazapyr plots. Muscadine (*Vitis rotundifolia*) occurred most frequently on picloram + triclopyr plots.

Major quail foods, primarily ragweed (*Ambrosia artemisiifolia*) and various legumes, were significantly higher on the hexazinone treatment compared to the picloram + triclopyr treatment. Woody plants commonly browsed by deer were significantly higher on hexazinone vs. imazapyr treated plots; vines did not differ among treatments. Although not significantly different, gopher tortoise food plants, which include legumes and various grasses, were most abundant on the picloram + triclopyr treatment.

Planted loblolly pine was excluded from diversity analyses. A total of 163 plant species were identified on the study site during both pre- and post-treatment sampling periods (Brooks 1992). The highest woody plant diversity post-treatment occurred with the picloram + triclopyr treatment (Table 3). The imazapyr treatment had a significant reduction ($P \leq 0.10$) in woody species richness. However, the greatest reduction in diversity occurred with the hexazinone treatment. Since species richness in the hexazinone treatment remained unchanged, a lowered equitability was the source of the diversity reduction.

The highest herbaceous diversity occurred with the imazapyr treatment. Forb species dominated

Table 2. *Abundance of vegetation on chemically prepared sites at 1 year post-treatment, Marion County, Ga., 1991. Values for herbaceous vegetation and vines are means for frequency of occurrence. Woody forage values are mean density of stems per 4 m².*

Group	Hexazinone		Picloram + Triclopyr		Imazapyr			
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	F	P
All herbaceous/vines	2.32	0.08AB[1]	2.42	0.12A	2.19	0.10B	5.48	0.07
Grasses	0.33	0.02AB	0.47	0.11A	0.25	0.01B	2.94	0.16
Asters	0.12	0.05	0.08	0.01	0.12	0.01	1.01	0.44
Legumes	0.09	0.01AB	0.06	0.02A	0.12	0.02B	4.89	0.08
Other forbs	1.63	0.04	1.65	0.15	1.56	0.07	0.34	0.73
Vines	0.13	0.03	0.16	0.05	0.14	0.15	0.13	0.88
Wildlife food plants								
Quail foods	0.17	0.02A	0.11	0.01B	0.14	0.01AB	2.77	0.14
Deer forage--vines	0.11	0.03	0.13	0.03	0.12	0.03	0.06	0.94
--woody stems	15.87	6.64A	9.71	2.34AB	3.04	1.61B	4.16	0.10
Gopher tortoise foods	0.30	0.03	0.34	0.10	0.28	0.04	0.43	0.67

[1] Within a row, means and standard errors followed by the same letter are not significantly different at $P < 0.10$.

Table 3. *Plant species diversity on chemically prepared sites at Marion Co., Ga., 1991.*

Group	Index[1]	Hexazinone		Picloram + Triclopyr		Imazapyr	
		$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Herbaceous	H′	3.26	0.25	3.40	0.37	3.73	0.12
post-trt	J′	0.79	0.01	0.82	0.02	0.87	0.36
	n	59.70	4.65	63.30	90.54	72.00	7.26
Woody	H′	2.00	0.03	1.92	0.03	2.01	0.01
pre-trt	J′	0.80	0.00	0.67	0.00	0.69	0.00
	n	13.00	10.60	17.30	2.42	18.70	2.98
Woody	H′	1.57	0.00	1.82	0.00	1.63	0.06
post-trt	J′	0.62	0.01	0.68	0.00	0.66	0.00
	n	13.30	11.69	14.70	1.30	12.00	6.69

[1] H′ = Shannon index; J′ = Shannon evenness; n = mean number of species per plot.

the herbaceous community where imazapyr had the most forb species ($\bar{x}$ = 47, SE = 2.4), followed by hexazinone ($\bar{x}$ = 35, SE = 5.2) and picloram + triclopyr ($\bar{x}$ = 34, SE = 31.4). Of all forb species, legumes accounted for 17 (SE = 1.3), 11 (SE = 0.2), and 10 (SE = 6.8) species in imazapyr, hexazinone, and picloram + triclopyr treatments, respectively. Grass species richness was highest on the picloram + triclopyr treatment ($\bar{x}$ = 16 SE = 8.0), followed by hexazinone ($\bar{x}$ = 15 SE = 3.5) and imazapyr ($\bar{x}$ = 13 SE = 0.2). An average of 10 vine species were found on the picloram + triclopyr (SE = 4.7) and imazapyr treatments (SE = 1.3). The hexazinone treatment had 7 (SE = 0.6) vine species.

Discussion

Major quail foods evaluated include beggarweeds (*Desmodium* spp.), ragweed, common lespedeza, partridge peas (*Cassia* spp.), milk peas (*Galactia* spp.), bush clovers, and wild bean (*Strophostyles umbellata*). The most favorable habitat conditions for bobwhite quail were found on the hexazinone treatment, which had an abundance of ragweed and partridge pea (*C. fasciculata*). Although not significantly different from the imazapyr treatment in abundance of quail food plants, the hexazinone treatment had more annual and perennial grasses and should provide important nesting and brood-rearing

habitat (Rosene 1969). In addition, Florida pussley (*Richardia scabra*) was most abundant on hexazinone treatments and should provide an excellent environment for insect production (Landers and Mueller 1986). The high protein content of insects is particularly important for survival of quail chicks less than 2 weeks old (Stoddard 1931, Hurst 1972).

Similar results were found in other studies in the Southeast. Hurst and Palmer (1988) indicated that a 2-year-old plantation site prepared with hexazinone had many legumes and was excellent bobwhite quail habitat. In South Carolina, Miller et al. (1989) found more legumes on hexazinone vs. roller-chopped treatments and suggested better quail habitat conditions were found on the chemically treated sites. In the Georgia Piedmont, however, Witt (1991) found a higher abundance of legumes and suggested better quail habitat on imazapyr treatments than picloram + triclopyr or hexazinone treatments at 2 years post-treatment.

Our analysis of deer forage focused on vines and woody plants ($\leq$ 1 inch in diam.) that are heavily used by deer in the Coastal Plain. Actual use of plants on the study site would be strongly tempered by the availability of quality foods off the site and in buffer areas. Although white-tailed deer use of various plants and plant parts varies seasonally and locally, general dietary patterns are known. From 48 reports regarding food-habits of white-tailed deer in the Southeast, Harlow and Guynn (1987) summarized the predominate foods. In the Coastal Plain, deer feed heavily on leaves and new growth of the following species present on our study area: greenbrier, yellow jessamine, blackberry, grape (*Vitis* sp.), blueberry (*Vaccinium* spp.), blackgum, and the fruiting heads of sumac. We also included Japanese honeysuckle and sassafras in our deer forage evaluation. Although Japanese honeysuckle is not abundant in the Coastal Plain, it is commonly found in the diet of deer in the Piedmont and was found on all treatments. Sassafras, a major species on the site, was included as an important browse plant since Harlow and Downing (1969) reported continued heavy use of sassafras in clearcuts 1-3 years after cutting.

On an annual basis, the hexazinone treatment should provide the highest abundance of deer foods. Although vines showed no major differences across treatments, the significantly higher abundance of woody browse plants on hexazinone-treated plots could be anticipated from the high degree of resprouting found on that treatment. Moreover, sprouts provide high quality browse in spring which may help offset winter deficiencies.

Similar results were found in several studies. At 2 years post-treatment, Witt (1991) found better browse conditions on hexazinone treatments than picloram + triclopyr or imazapyr treatments. Blake (1986) indicated that a lower biomass of deer forage occurred on hexazinone-treated vs. untreated plots at 1-year post-treatment, though at 2 years post-treatment no difference was noted. In a similar study, at 1 and 2 years post-treatment, imazapyr plots had a lower biomass of deer forage than untreated plots (Hurst and Watkins 1988).

Although 6 tortoise dens were found on the site, only 2 were active prior to treatment and remained active throughout the study. All dens were located on a single ridge of Troup series soils. Major foods of gopher tortoises include broadleaf grasses (*Panicum* spp., *Paspalum* spp.), silk-grass (*Heterotheca graminifolia*), legumes, and fruits (Garner and Landers 1981). Landers and Speake (1980) reported a direct relationship between tortoise density and herbaceous plant biomass. The high abundance of food plants on the picloram + triclopyr treatment was a result of an abundance of broadleaf grasses. Both legumes and grasses contributed to food plants on the hexazinone treatment, whereas legumes and silk-grass were most abundant on the imazapyr treatment. Potential fruit production was not evaluated in this study of food plants, though fruits may be important in the diet.

We conclude that any of the 3 herbicide treatments followed by a prescribed burn should be compatible with maintaining quality habitat for gopher tortoises. Herbicide treatments would be secondary in importance to maintaining an open canopy and prescribed burning at regular intervals (Landers and Speake 1980).

Our assessments of wildlife food plants do not include an evaluation of other important components of habitat such as cover, breeding and nesting areas, and invertebrate production. Further studies of these components are needed for habitat evaluation.

The high herbaceous diversity found on the imazapyr treatment is a result of the abundance of forbs, particularly legumes. Legumes are valuable to many species of wildlife and may improve site quality through nitrogen fixation (Hendricks 1989). Other studies reported the resistance of legumes and other forbs to imazapyr (Hurst and Watkins 1988, Witt 1991). The picloram + triclopyr treatments had a

higher grass component, which may have suppressed asters. Asters and various other forbs cannot successfully compete for moisture with established grasses (Odum 1960). The high abundance of broomsedge (*Andropogon virginicus*), little bluestem (*A. scoparius*) and various annual grasses in the picloram + triclopyr treatment may continue to suppress forbs, thereby reducing plant species diversity and some wildlife food plants throughout the early seral stages (Odum 1960, Pinder 1975, Felix et al. 1986).

In the Florida flatwoods, Conde et al. (1983) found an increase in herbaceous diversity associated with clearcutting, chopping, and bedding. At 2 years post-treatment, species diversity was maintained at a level above that of the natural stand. Neary et al. (1990) reported that annual applications of sulfometuron methyl (Oust™) significantly reduced species richness compared to 2 applications.

Reduced woody species diversity on the imazapyr treatment was a result of reduced species richness, whereas the lower woody diversity with the hexazinone treatment was a result of resprouting creating uneven species distributions. Increased resprouting and differences in susceptibility of various woody species to burning are well documented (Hare 1965, Wentworth 1986). Thus, plants not susceptible to the herbicide can show dramatic increases in the number of stems in response to prescribed burning. Woody plant species vary greatly in susceptibility to hexazinone (Zutter and Zedaker 1988). Least susceptible species are blueberries and sassafras, while oaks (*Quercus* spp.) are highly susceptible (Neary et al. 1981, Gonzalez 1983, Miller 1984). Our results support, in part, findings by Zutter and Zedaker (1988) who reported reductions in woody species diversity with increasing rates of hexazinone, but after 2 years, differences between treated and untreated areas were small. They attributed the initial reduction in diversity to an increase in species dominance and a reduction in species evenness. Conde et al. (1983) reported a recovery in woody species diversity 2 years after an intensive mechanical treatment. Based on these studies, it is doubtful that a single hexazinone application would have significant long-term effects on woody species diversity.

Although this study represents one site with specific environmental and ecological conditions, the results show significant short-term differences in wildlife habitat and plant species diversity among the 3 treatments evaluated. Differences are likely to be less dramatic over time; however, long-term studies are lacking (McComb and Hurst 1987, Witt 1991).

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OVERSTORY-UNDERSTORY RELATIONSHIPS IN NATURAL LOBLOLLY PINE-HARDWOOD STANDS: IMPLICATIONS FOR WILDLIFE HABITAT [1]

Philip A. Tappe, Michael G. Shelton, and T. Bently Wigley [2]

Abstract. Understory characteristics were determined before and two growing seasons after thinning a pine-hardwood stand (initially 119 ft^2/acre of pine and 33 ft^2/acre of hardwood basal area) to three pine densities (60, 75, and 90 ft^2/acre) and three hardwood densities (0, 15, and 30 ft^2/acre). Treatments were arranged in a two-factorial randomized complete block design. Understory coverage and forage biomass were determined on 25 subplots systematically located within each 0.2-acre net plot. Light intensity at 4.5 ft in height was determined at 39 locations within each net plot. Regression models were developed relating understory characteristics and light intensity with the residual pine and hardwood basal areas. Understory coverage, forage biomass, and light intensity were negatively correlated with residual pine and hardwood basal areas, with the hardwood component being the more important variable. Results indicate that thinning and species control can improve habitat quality for certain wildlife species.

Introduction

Two-thirds of the pine stands in the South have been naturally regenerated. Plant succession plays an important role in the development of natural stands because site preparation levels are typically much less intense than those used in artificial regeneration. Virtually all natural pine stands and many plantations have a significant hardwood understory and midcanopy. At best, the most intensive competition control will only temporarily arrest the successional progression to a stand dominated by hardwoods (Cain and Yaussy 1984). Pine-hardwood stands are important wildlife habitat in the South. The hardwood component of such stands undoubtedly increases within-stand habitat diversity. However, the wildlife potential of midcanopy trees that typically occur in pine stands is not certain. Several studies have addressed wildlife habitat quality in pine-hardwood stands (Schuster and Halls 1963, Halls and Schuster 1965, Blair 1971, Blair and Brunett 1980, Hurst et al. 1979, Fenwood et al. 1984, Wigley et al. 1989), but few have examined habitat across varying proportions of pines and hardwoods in managed stands. Because hardwoods are a common and persistent component of natural, even-aged pine stands, we established a study in 1988 to evaluate the interaction of pine and hardwood growth and their effects on wildlife habitat quality. This paper reports 2-year preliminary results.

Study Area

The study was established in an natural, even-aged, 35-year-old loblolly pine (*Pinus taeda* L.) stand located in the School Forest of the University of Arkansas at Monticello, Drew County, Arkansas. Soils of the area were mapped as the Henry (Typic Fragiaqualfs) and Calloway (Glossaquic Fragiaqualfs) series (Larance et al. 1976). Both soils have silt loam surfaces and were formed on windblown silt. These poorly drained soils occur on broad upland flats and have a site index of 90 feet at 50 years for loblolly pine.

The stand was regenerated from an existing hardwood-pine stand in the early 1950's; the hardwood component was killed, and a new pine stand was established from seeds produced by the residual pines. A few remnants of the original stand still existed prior to study installation. This stand was typical of many unmanaged pine stands in the South, which have developed a dense hardwood midcanopy. Before harvest, the pine basal area averaged 119 ft^2/acre and hardwood basal area averaged 33 ft^2/acre (table 1). Most hardwoods formed a uniform midcanopy with occasional individuals extending into the main canopy, which was primarily loblolly pine. The hardwood component was principally willow and water oak (*Quercus phellos* L. and *Q. nigra* L., respectively), with lesser amounts of southern red oak (*Q. falcata* Michx.) and sweetgum (*Liquidambar*

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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styraciflua L.). The stem quality of the pine component often was poor because of past damage from ice storms and stem cankers. Some of the hardwoods stems were hollow or had other obvious stem defects.

Table 1. *Stand basal areas (ft²/acre) before thinning.*

Species	Mean	Standard Deviation
Loblolly pine	119	21
Hardwoods	33	10
Red oaks	20	12
White oaks	2	2
Other trees	11	6
Stand total	152	18

Study Design and Treatment Implementation

Twenty-seven circular, 0.2-acre net plots were established with a 33-foot isolation strip, creating a gross plot of 0.53 acres. Systematically located within each net plot were 25 understory plots. Treatments called for the reduction of the overstory basal area to three levels for loblolly pine (60, 75, and 90 ft²/acre in trees ≥ 3.6 inches in d.b.h.) and three levels for hardwoods (0, 15, and 30 ft²/acre). Treatments were randomly assigned as much as possible in a randomized complete block design with three blocks. Some plots, especially those with the highest level of hardwood retention, were assigned to meet specific targets.

The pine component of each plot was harvested as a free thinning. Most of the harvested trees were below the stand's mean d.b.h., but a few low-quality dominant and codominants also were harvested. Thinning of the hardwood component favored retention of the larger and better quality oaks. However, hardwood treatments were difficult to implement on many plots, and compromises were made to meet specific targets. The net plots and isolation strips were thinned to the same basal areas. The area between the gross plots was marked to leave about 75 ft²/acre of pine basal area and a component of desirable hardwoods.

All trees were harvested as pulpwood to minimize the damage to the residual stand. Logging began during fall of 1988 but was terminated during the early winter because of wet soil conditions. The pine harvest was virtually completed by late spring of 1989, but unusually wet weather during the summer prevented completion of the hardwood harvest until late summer of 1989. Thus, logging continued intermittently for about 1 year, with the pine component being mostly harvested before the 1989 growing season and the hardwoods being harvested at the end of the 1989 growing season. During late winter and early spring of 1990, all submerchantable hardwoods ≥1 inch d.b.h. were killed with stem-injected herbicides.

Measurements

Before harvest, all trees ≥1 inch d.b.h. were inventoried on the net plot by d.b.h. and species group. After the completion of logging in the fall of 1989, all retained trees on the net plots were assigned permanent numbers; measured for d.b.h., total height, and crown dimensions; and had their location mapped. Age was determined on a subsample of about one-third of the residual trees.

Understory coverage and forage biomass were evaluated before harvest and 2 years after harvest using 25 0.5-milacre plots with nested 0.25-milacre subplots. Percent coverage of each species in the understory (≤3.3 ft in height) was ocularly estimated within each 0.5-milacre plot. Forage biomass was determined for the 0.25-milacre subplots by clipping the current annual increments of each species occurring in the understory and obtaining the green and dry weights. Overstory canopy coverage was measured at each point using a spherical densiometer.

Photosynthetically active radiation (PAR) was determined at a height of 4.5 feet on 39 temporary points systematically located within each net plot during clear sky conditions on July 31, 1991 using a Decagon Devices, Inc. sunfleck ceptometer. All measurements were taken within ±1.5 hr of solar noon. Measurements also were made in full sunlight so that relative light intensity could be calculated.

Data Analyses and Modeling

For understory coverage and forage biomass, mean values were calculated by species group (grasses, forbs, vines, and woody vegetation) from the 25 understory plots for each net plot. Overstory basal areas were determined from the inventory conducted after the completion of harvesting. Relative light intensity was calculated by averaging the 39 PAR measurements for each net plot and expressing the mean as a percentage of the PAR in full sunlight predicted for the specific time that the plot was measured. Site index was computed using the

function of Farrar (1973) for the loblolly pine trees sampled for age that showed no periods of past suppression.

After evaluating several candidate functions, the following form was selected for analyses:

$$Y = \exp(b_0 + b_1 PBA + b_2 HBA)$$

where Y is the response variable; PBA is the pine basal area after harvesting in ft^2/acre; HBA is the hardwood basal area after harvesting in ft^2/acre; and the b_i's are the coefficients to be determined. Equations were fitted by nonlinear least squares regression using the SAS procedure MODEL (SAS Institute 1988). Variables were eliminated from the full model if their coefficient did not significantly differ from zero at a probability level of ≤ 0.05. A fit index, analogous to the coefficient of determination, was computed using:

$$1 - \frac{\Sigma(Y_i - \hat{Y}_i)^2}{\Sigma(Y_i - \bar{Y}_i)^2} .$$

Response variables were forage biomass (lbs/acre) and coverage of understory vegetation, canopy coverage, and relative light intensity. The basal areas in the stand before harvest exerted a significant effect on the initial levels of forage biomass and coverage. To compensate for this effect, the change in forage biomass and understory coverage for individual plots (i.e., the after-harvest value minus the before-harvest value) were used as response variables.

Results

Before thinning, understory coverage and forage biomass averaged 27 percent and 46 lbs/acre, respectively. However, the overstory of unmanaged, natural stands often displays considerable variability because of early differences in stocking and composition. This inherent variation in the initial overstory basal areas significantly affected both understory coverage and forage biomass. For example, the coverage of grasses, forbs, woody vegetation, and the total understory was negatively related to the initial pine and hardwood basal areas, with fit indices ranging from 0.27 to 0.46 (table 2). The regression coefficients for hardwood basal area averaged about 60% larger than those for pine basal area, indicating that per unit of basal area the hardwood component had more influence on the initial understory coverage than the pine component. Vine, woody vegetation, and the total forage biomass also were negatively related to pine and hardwood basal areas before thinning, with fit indices of 0.20 to 0.60 (table 2). Regression coefficients for hardwood basal area were about 50 percent larger than those for pine basal area.

Before thinning, overstory canopy coverage averaged 96 percent and was not significantly related to pine or hardwood basal areas. However, the overstory canopy coverage was positively related to the residual pine and hardwood basal areas after thinning, with a fit index of 0.62 (table 3). The regression coefficient for hardwood basal area was about 50 percent larger than that for pine basal area, indicating that the hardwoods contribute more to canopy coverage than an equivalent basal area of pine. This regression equation was solved for the three treatment levels of pine basal area and the 0 to 30 ft^2/acre range of hardwood basal area; these values are plotted in figure 1. Canopy coverage ranged from 70 percent for the lowest basal area (60 ft^2/acre of pine only) to 95 percent for the highest (90 ft^2/acre of pine and 30 ft^2/acre of hardwoods). A total basal area of 90 ft^2/acre composed entirely of pine resulted in a canopy coverage of 77 percent, while the same total basal area composed of two-thirds pine and one-third hardwoods was predicted to have 85 percent coverage.

The reduction in canopy coverage brought about by thinning increased the light intensity in the understory. Relative light intensity was negatively related to the residual pine and hardwood basal areas, with a fit index of 0.93 (table 3). The regression coefficient for hardwood basal area was 45 percent larger than that of pine, indicating that the hardwood component produces more shade per unit of basal area than the pine component. This relationship reflects the fact that hardwoods have larger crowns, broad leaves, and generally are shorter than pines. For example, a stand with 90 ft^2/acre of pine basal area and no hardwoods is predicted to have 35 percent of full sunlight in the understory compared to 25 percent for the same total basal area composed of two-thirds pine and one-third hardwoods.

The understory strongly responded to the increase in limiting factors (viz. light, water, and nutrients) brought about by thinning the overstory and the control of submerchantable hardwoods. Increases in coverage of grasses, woody vegetation, and the total understory were negatively related to the residual hardwood basal area only, with fit indices of 0.20 to 0.60 (table 3). When all hardwoods were removed, the total understory coverage increased by 26 percent

Table 2. *Equations and associated statistics for understory coverage and forage biomass before thinning.*

Equation[1]	Fit index	MSE	Mean Y
Understory Coverage (percent)			
Grass = exp (4.48 - 0.0184 PBA - 0.0262 HBA)	0.39	2.1	5.2
Forbs = exp (5.45 - 0.0192 PBA - 0.0397 HBA)	0.27	5.2	8.9
Woody = exp (4.25 - 0.0154 PBA - 0.0255 HBA)	0.46	1.6	6.0
Total = exp (5.78 - 0.0153 PBA - 0.0275 HBA)	0.41	8.4	26.6
Forage Biomass (lbs/acre)			
Vines = exp (7.78 - 0.0323 PBA - 0.0586 HBA)	0.22	12.4	12.6
Woody = exp (13.60 - 0.0671 PBA - 0.142 HBA)	0.60	11.3	13.2
Total = exp (9.19 - 0.0329 PBA - 0.0605 HBA)	0.31	37.0	46.1

[1] There are 24 degrees of freedom for all equations.

Table 3. *Equations and associated statistics for overstory canopy coverage, relative light intensity, and the increase in understory coverage and forage biomass 2 years after thinning.*

Equation[1]	Fit index	MSE	Mean Y
Canopy coverage (percent)			
Y = exp (4.03 + 0.00355 PBA + 0.00673 HBA)	0.62	6.8	84.8
Relative light intensity (percent of full sunlight)			
Y = exp (5.06 - 0.0169 PBA - 0.0372 HBA)	0.93	3.7	24.2
Increase in understory coverage (percent)			
Grass = exp (1.99 - 0.0207 HBA)	0.20	3.0	5.4
Woody = exp (1.40 - 0.0418 HBA)	0.36	1.7	2.4
Total = exp (3.26 - 0.0173 HBA)	0.20	9.3	20.1
Increase in forage biomass (lbs/acre)			
Grass = exp (5.67 - 0.0575 HBA)	0.36	144.0	148.0
Forbs = exp (5.14 - 0.0536 HBA)	0.20	117.0	91.3
Vines = exp (6.40 - 0.0227 PBA - 0.0321 HBA)	0.42	36.4	61.9
Woody = exp (4.88 - 0.0498 HBA)	0.60	36.7	71.9
Total = exp (6.53 - 0.0498 HBA)	0.45	260.0	373.0

[1] There are 24 degrees of freedom for equations with 2 independent variables and 25 degrees of freedom for those with 1 independent variable.

(from an average of 27 percent before thinning to 53 percent 2 years later; fig. 2). When a hardwood basal area of 30 ft²/acre was retained, the increase in understory coverage was only 16 percent (from 27 percent before thinning to 43 percent 2 years later).

Changes in forage biomass of grasses, forbs, vines, woody vegetation, and the total forage also were negatively related to overstory basal areas, with fit indices of 0.20 to 0.60 (table 3). Hardwood basal area was the most important variable, and pine basal area was significant only for vine biomass. When all hardwoods were removed, the total forage increased by 685 lbs/acre 2 years after thinning (from 46 lbs/acre before thinning to 731 lbs/acre 2 years later; fig. 3). By contrast, retaining 30 ft²/acre of hardwoods resulted in an increase in total forage of only 154 lbs/acre (from 46 lbs/acre before harvest to 200 lbs/acre 2 years later). The species groups contributing to the increase in forage was in the following order: grasses > forbs > woody vegetation > vines.

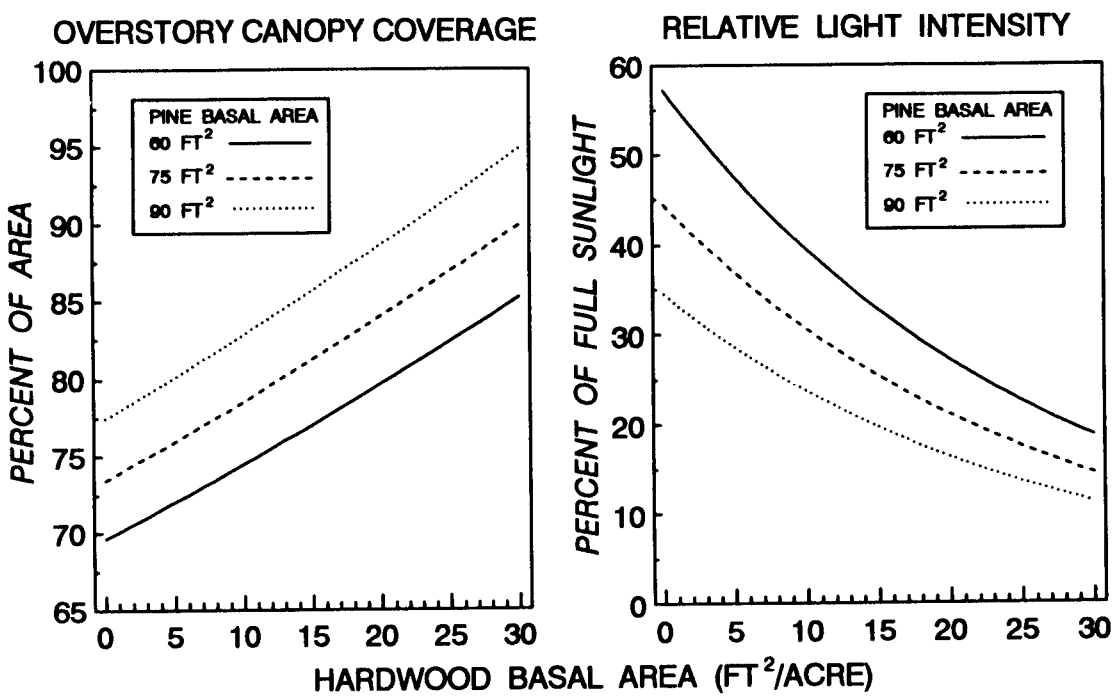

Figure 1. *Effects of residual pine and hardwood basal areas on the overstory canopy coverage and relative light intensity 2 years after thinning a 35-year-old pine-hardwood stand.*

Conclusions

Understory coverage and forage biomass responded to changes in environmental factors resulting from thinning a 35-year-old natural pine stand with a dense hardwood midcanopy. The level of understory response depended on the density and composition of the residual stand. Retained hardwoods resulted in more overstory canopy coverage and shade than an equivalent pine basal area, and this adversely affected forage production. Thus, the short-term habitat quality for wildlife species depending on understory vegetation, such as white-tailed deer (*Odocoileus virginianus*), probably is highest in relatively pure pine stands. Midcanopy hardwood trees generally are too small in size and low in vigor for prolific mast production at this stage of development. Thus, mast production will not immediately compensate for the reduction in forage production resulting from retaining midcanopy hardwoods. However, retention of a component of desirable hardwoods will improve habitat quality when mast production commences and will enhance the vertical stratification needed by some wildlife species. It also is likely that thinning will enhance the potential of retained hardwoods to produce mast.

Based on these preliminary results, differences in residual pine basal area of 60 to 90 ft²/acre had little initial effect on forage production. However, more time will be needed to fully assess the long-term relationships between the understory and the overstory of this study.

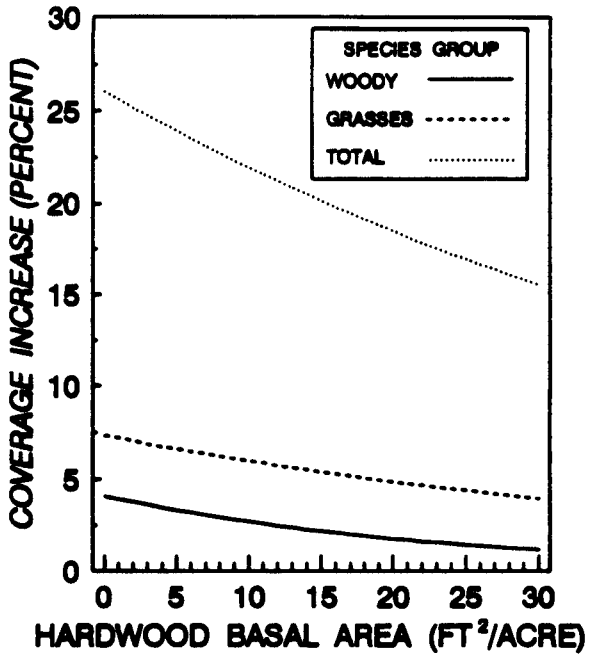

Figure 2. *Effects of residual pine and hardwood basal areas on the increase in understory coverage 2 years after thinning a 35-year-old pine-hardwood stand.*

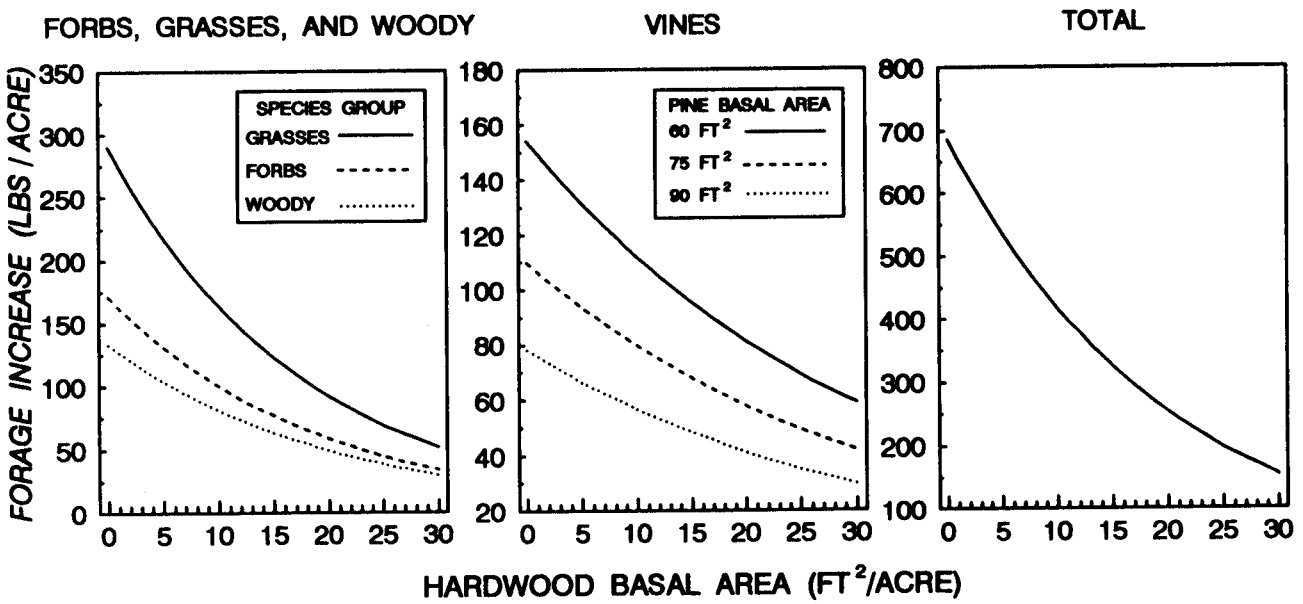

Figure 3. *Effects of residual pine and hardwood basal areas on the increase in forage biomass 2 years after thinning a 35-year-old pine-hardwood stand.*

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CHARACTERISTICS OF TIMBER STANDS CONTAINING SUFFICIENT HEARTWOOD FOR CAVITY EXCAVATION BY RED-COCKADED WOODPECKER CLANS [1]

Alexander Clark, III [2]

Abstract. The relationship of heartwood development in loblolly (*Pinus taeda* L.) and longleaf (*P. palustris* Mill.) pine stands with site quality, stocking, stand age and average d.b.h. of dominant and codominant trees is presented. This information is important to forest managers and biologists managing the recovery of the endangered red-cockaded woodpecker (*Picoides borealis*) (RCW). Twenty-nine loblolly and 22 longleaf pine stands representing a range of age classes (30 to 100 years) and site indexes (50 to 120 feet) were sampled in the Southeast for heartwood and sapwood content at 22 feet above the ground. Regression equations are presented for estimating average heartwood diameter and sapwood thickness at 22 feet using stand age and site index as independent variables. Results indicate that fast-growing loblolly and longleaf pine stands on the better sites will have the highest probability of developing sufficient heartwood for RCW cavity excavation at the earliest age.

Introduction

Information is available on foraging habitat and trees selected for cavity excavation by RCW clans (Lennartz and Henery, 1985) but little information is available on what timber stands have the highest potential for developing acceptable cavity trees at the earliest age.

The RCW requires a cross-section of at least 5 inches of heartwood at cavity height to envelope its nesting cavity. Cavities can be excavated into sapwood or a combination of heartwood and sapwood but it is rarely done. The RCW normally excavates cavities totally in heartwood and prefers redheart (*Phellinus pini*) heartwood infected trees for easier cavity excavation (Jackson 1977, Conner and Locke 1982, Hooper et al. 1991).

Many of the changes that occur when sapwood converts to heartwood are known (Kramer and Kozlowski, 1979). Basically, extractives resulting from differentiation, respiration, synthesis, and degradation of starch are translocated along ray parenchyma cells toward the pith where they accumulate. With restricted respiration because of aspirated pits, starch grains hydroloize and disappear, phenols oxidize and polymerize to form pigments in cell voids and the ray parenchyma cells die in the transition zone between sapwood and heartwood to form heartwood. Thus, heartwood forms an irregular cylinder at the center of the bole and generally decreases with tree height.

Little research has been conducted on southern pine heartwood formation as influenced by environmental factors since the 1930's. The relative proportion of heartwood has been reported to vary directly with tree age and negatively with rate of growth (MacKinney and Chaiken 1935). Loblolly and longleaf pines with large crowns and rapid growth on good, moist sites are reported to contain a smaller proportion of heartwood than trees with small crowns from closely stocked stands on poor drier sites (Paul 1932, Bray and Paul 1934).

This paper discusses the relationship of site quality, stocking, stand age, tree d.b.h. and total height with heartwood formation at 22 feet in loblolly and longleaf pine sampled in the Southeast. Linear equations are presented for predicting diameter of heartwood and sapwood thickness at 22 feet using stand characteristics as independent variables.

Materials and Methods

A series of stands representing a range of age classes (30 to 100 years) and site indexes (50 to 120 feet) were sampled for heartwood and sapwood content. A total of 29 loblolly pine stands and 22 longleaf pine stands were sampled. Loblolly stands sampled were located on the Oconee National Forest

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992. This study was partially supported with funding from the U.S. Dept. of Interior, Fish and Wildlife Service, Atlanta, GA and USDA Forest Service, Southern Region, Fisheries, Wildlife and Range, Atlanta, GA.

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in Georgia, the Francis Marion National Forest, and Belle W. Baruch Forest Science Institute Hobcaw Forest in South Carolina. Longleaf stands sampled were located on the Francis Marion NF and Hobcaw Forest in South Carolina and the Talladega and Conecuh National Forests in Alabama. Four to five dominant or codominant trees were randomly selected within each stand. D.b.h., total height, height-to-base of full live crowns were recorded for each tree. A competitive index or point density measurement (ft^2/acre) was determined for each tree using a 10 BAF prism (Spurr 1962). A 12-mm increment core was extracted from each tree at breast height and a 5-mm increment core was removed from each tree at 22 feet.

Each increment core was dried, glued to a core holder, and sanded before staining with a benzidine-sodium nitrite solution to distinguish heartwood and sapwood (Kutscha and Sacks 1962). The age and length of heartwood and sapwood was recorded for each core. Age at 4.5 feet was converted to tree age at stump by adding 3 years for loblolly pine and 6 years for longleaf pine. The age and measurements collected for each tree within a stand were averaged to obtain average stand characteristics. Site index was determined using curves developed by the USDA Forest Service (1976).

Correlation coefficients (r) were developed to evaluate the relationship of heartwood diameter and sapwood thickness at 22 feet with site index, stand age, basal area, average d.b.h. and total height of dominant and codominant trees, crown ratio, and growth rates. Linear equations were developed for each species to predict average diameter of heartwood and sapwood thickness at 22 feet. The following models were used:

$$Y = a + b\,(AGE) \quad (1)$$
$$Y = a + b\,(AGE) + c\,(SI) \quad (2)$$
$$Y = a + b\,(AGE) + c\,(THT) \quad (3)$$
$$Y = a + b\,(AGE) + c\,(DBH) \quad (4)$$

where: Y = average diameter of heartwood or sapwood thickness at 22 feet in inches

AGE = stand age in years
SI = site index in feet
THT = average total height of dominant and codominant trees in feet
DHB = average d.b.h. of dominant and codominant trees in inches

Results and Discussion

Average stand age of the two species sampled was 64 years for loblolly and 63 years for longleaf. Average site index of the longleaf stands was 76 feet compared to 86 feet for the loblolly stands (table 1). The loblolly stands were growing at an average rate of 0.24 inches per year compared to 0.20 inches for the longleaf. The sampled loblolly pine averaged 15.7 inches d.b.h. compared to 13.3 inches for the longleaf pine. There was little difference in the average diameter of heartwood between the two species, loblolly averaged 4.4 inches of heartwood compared to 4.3 inches for longleaf but loblolly contain an average of 0.8 inches more sapwood at 22 feet than the longleaf.

Table 1. *Average stand characteristics of the 29 loblolly and 22 longleaf pine stands sampled for heartwood content at 22 feet.*[1]

Stand Characteristic	Loblolly Pine	Longleaf Pine
Age (yr)	64	63
Site index (ft)	86	76
Basal area (ft^2)	106	70
DBH (in)	15.7	13.3
Total height (ft)	87	74
Crown ratio (%)	37	20
Growth rate (in/yr)	0.24	0.20
Diameter heartwood at 22 feet (in)	4.4	4.3
Thickness of sapwood at 22 feet (in)	3.7	2.9

[1] Dominant and codominant trees.

Heartwood diameter at 22 feet was significantly correlated with stand age and d.b.h. of dominant and codominant trees (table 2). Diameter of heartwood was not significantly correlated with basal area of either species. Site index was not significantly related with heartwood diameter in the loblolly stands but was significantly correlated with heartwood diameter in the longleaf stands. This significant negative relationship occurred because no old longleaf stands on good sites were sampled and the longleaf stands with the most heartwood were old stands growing on the poorest sites. Average annual diameter growth at d.b.h. was negatively correlated with heartwood diameter at 22 feet because the sample trees with the most heartwood were the oldest and growing the slowest.

Sapwood thickness at 22 feet in the longleaf stands was not correlated with any of the stand characteristics measured (table 2). However sapwood

Table 2. Correlation coefficients for diameter of heartwood and sapwood thickness at 22 feet with stand characteristics for loblolly and longleaf pine stands. [1,2]

Stand Characteristic	Diameter of heartwood		Sapwood thickness	
	Loblolly Pine	Longleaf Pine	Loblolly Pine	Longleaf Pine
Age	0.87**	0.88**	−0.46*	−0.23^{NS}
Site index	0.06^{NS}	−0.60**	0.51*	0.28^{NS}
Basal area	0.01^{NS}	−0.26^{NS}	−0.19^{NS}	−0.31^{NS}
DBH	0.78**	0.90**	0.26^{NS}	0.33^{NS}
Total height	0.79**	0.57**	0.04^{NS}	0.25^{NS}
Crown ratio	−0.42*	−0.25^{NS}	0.23^{NS}	0.07^{NS}
Growth rate	−0.66**	−0.68**	0.72**	0.41^{NS}

[1] Dominant and codominant trees
[2] Significant at P = .01 = **
Significant at P = .05 = *
Not significant = NS

thickness was positively correlated with site index, negatively correlated with stand age and highly correlated with rate of growth in the loblolly stands. This indicates, as expected, that young, fast-growing stands contain more sapwood than older slow-growing stands.

Series of linear regression equations was developed to estimate diameter of heartwood at 22 feet using stand characteristics as independent variables (table 3). Stand age and site index as independent variables accounted for 78 to 79 percent of the variation in heartwood diameter at 22 feet. The equation based on stand age and average dbh of dominant and codominant trees was the best predictor of heartwood diameter, accounting for 85 percent of the variation in loblolly pine and 93 percent in longleaf pine.

Average predicted diameter of heartwood at 22 feet increased with dbh and stand age (table 4) and with increasing site index and stand age (table 5). Thus, the youngest trees that contain sufficient heartwood for normal RCW cavity excavation ($\geq$5 inches) were the fastest growing trees on the best sites. Based on the values shown in table 4, sufficient heartwood for RCW cavity activity does not occur in the average dominant on codominant tree until age 50 in loblolly pine and age 60 in longleaf pine and then only in the larger diameter trees. When diameter of heartwood is predicted using site index and stand age the equations show 70-year-old loblolly stands with a site index $\geq$90 and 70-year-old longleaf stand with a site index $\geq$80 will contain sufficient heartwood for RCW cavity activity.

The same stand characteristics used to estimate heartwood diameter were used to estimate sapwood thickness at 22 feet. However, the only variable combination which accounted for more than 36 percent of the variation in sapwood thickness was equation (4) which is shown below for each species:

LOBLOLLY PINE

$$SAP = 1.74006 - 0.02776\ (AGE) + 0.23516\ (DBH) \quad (5)$$

LONGLEAF PINE

$$SAP = 1.40648 - 0.02487\ (AGE) + 0.23290\ (DBH) \quad (6)$$

where

SAP = sapwood thickness at 22 feet in inches

The sapwood thickness equation accounted for 79 percent of the variation in sapwood in loblolly pine and 73 percent of the variation in sapwood in longleaf pine. Predicted thickness of sapwood decreased with increasing stand age and increased with dbh.

Conclusions

Diameter of heartwood at 22 feet increases significantly with stand age and tree dbh. Fast-growing loblolly and longleaf pine stands on the better sites will have the highest probability of developing sufficient heartwood for RCW cavity excavation at the earliest age. At age 70, the average dominant or codominant tree in a loblolly stand with a site index $\geq$90 and in a longleaf stand with a site index $\geq$80 will contain sufficient heartwood ($\geq$5 inches at 22 feet) for RCW cavity activity.

Table 3. *Regression coefficients for estimating average diameter of heartwood at 22 feet using stand age and age in combination with site index, average dbh and average total height of dominant and codominant trees as independent variables for loblolly and longleaf pine stands sampled in the Southeast.*[1,2]

Equation/Species	Regression parameters and coefficients					Standard error of estimate $S_{y.x}$	Coefficient of determination R^2	Coefficient of variation C.V.
	Intercept	Age	Site Index	DBH	Total Height			
						(Inch)		(Percent)
Equation 1								
Loblolly	−0.82375^{NS}	0.08150**				1.1	0.75	24.4
Longleaf	−0.99334^{NS}	0.08408**				1.0	0.77	22.6
Equation 2								
Loblolly	−3.56019*	0.08533**	0.02895*			1.0	0.79	22.8
Longleaf	−4.26668^{NS}	0.10046**	0.02989^{NS}			1.0	0.78	22.2
Equation 3								
Loblolly	−4.74120**	0.05748**		0.34677**		0.8	0.85	19.1
Longleaf	−5.33817**	0.03882**		0.54004**		0.6	0.93	12.7
Equation 4								
Loblolly	−3.42810**	0.05684**			0.04812**	0.9	0.84	19.5
Longleaf	−3.71733*	0.07402**			0.04556*	0.9	0.82	20.6

[1] Dominant and codominant trees
[2] Significant at P = .01 = **
Significant at P = .05 = *
Not significant = NS

Table 4. *Average predicted diameter of heartwood at 22 feet by stand age and average dbh.*[1]

Average dbh	Stand age (years)					
	50	60	70	80	90	100
(inches)	(inches)					
			Loblolly pine			
14	3.0	3.6	4.1	4.7	5.3	5.9
16	3.7	4.3	4.8	5.4	6.0	6.6
18	4.4	4.9	5.5	6.1	6.7	7.2
20	5.1	5.6	6.2	6.8	7.4	7.9
22	5.8	6.3	6.9	7.5	8.1	8.6
			Longleaf pine			
14	4.2	4.6	4.9	5.3	5.7	6.1
16		5.6	6.0	6.4	6.8	7.2
18		6.7	7.1	7.5	7.9	8.3
20			8.2	8.6	9.0	9.3

[1] Dominant and codominant trees

Table 5. *Average predicted diameter of heartwood at 22 feet*[1] *by stand age and site index.*

Site index	Stand age (years)					
	50	60	70	80	90	100
(feet)	(inches)					
			Loblolly pine			
70	2.7	3.6	4.4	5.3	6.1	7.0
80	3.0	3.9	4.7	5.6	6.4	7.3
90	3.3	4.2	5.0	5.9	6.7	7.6
100	3.6	4.5	5.3	6.2	7.0	7.9
110	3.9	4.7	5.6	6.4	7.3	8.2
			Longleaf pine			
50	2.3	3.2	4.2	5.3	6.3	7.3
60	2.5	3.6	4.6	5.6	6.6	7.6
70	2.8	3.9	4.9	5.9	6.9	7.9
80	3.1	4.2	5.2	6.2	7.2	8.2
90	3.4	4.4	5.5	6.5	7.5	8.5

[1] Dominant and codominant trees

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SILVICULTURAL TREATMENTS TO MAINTAIN RED-COCKADED WOODPECKER HABITAT [1]

Earle P. Jones, Jr. [2]

Abstract. The red-cockaded woodpecker (*Picoides borealis*), an endangered species, prefers park-like stands of older sawtimber pines for its nesting habitat. Natural, 60+-year-old stands of loblolly pine (*Pinus taeda* L.) and hardwood on the Hitchiti Experimental Forest and the Piedmont National Wildlife Refuge in the Lower Piedmont of Georgia were opened up by felling the hardwoods and the midstory trees and shrubs on 2-acre plots in May 1989. Five study treatments were then applied in summer and winter of 1989-90: herbicide with summer burn, herbicide only, summer burn only, winter burn only, and untreated check. The herbicide, imazapyr in water, was applied by tractor sprayer. Third-year results showed that only herbicide with summer burning was significantly (0.05) more effective than no treatment in controlling all stems together (pines, hardwoods and shrubs); effects on separate species groups were not significant.

Introduction

Because the red-cockaded woodpecker (RCW) is an endangered species, populations must be maintained wherever they are found on federal land. RCW populations below the calculated carrying capacity of the land are designated "recovery populations", and regulations require maintenance of existing habitat and creation of new habitat for recruitment and expansion of the population. Certain stand conditions are recognized as desirable for RCW foraging and nesting habitat (Hooper et al. 1980). This study is concerned only with the nesting habitat, and how it may be silviculturally maintained after it has been created.

RCW's are unique among woodpeckers in that they excavate and exclusively nest in cavities made in living southern pine trees. Forest Service Region 8 interim guidelines (USDA Forest Service 1990) for management of RCW habitat define potential RCW cavity trees as 60 years or older in age, over 14 inches d.b.h., and preferably with red-heart disease, caused by the fungus *Phellinus pini* (Jackson 1977).

Past research has shown that the RCW prefers open stands of mature pine, with little or no midstory, probably because midstory trees provide access to the nest cavity by predators, such as rat snakes (*Elaphes* spp.) and flying squirrels (*Glaucomys volans*) (Lennartz and Heckel 1987; Loeb et al. 1992; Van Balen and Doerr 1978). Park-like conditions must be maintained indefinitely.

The objective of my study was to compare silvicultural treatments using herbicide and fire, alone and in combination, for maintaining the preferred RCW habitat for up to 20 years.

Methods

The study is on two areas on the Hitchiti Experimental Forest and two on the Piedmont National Wildlife Refuge. All plots are in the Lower Piedmont of central Georgia, 25 to 30 miles north of Macon. Topography is hilly, and cut by gullies. All study sites are within 5 miles of each other. They were selected for their large, mature loblolly pines, age 60 or older, and for the presence of a heavy hardwood component. The RCW was not known to be present within 3/4-mile of any of the study sites.

Blocks were laid out in fairly uniform portions of each stand. Each block contained five adjacent 2-acre square plots (approximately 4.5 chains on each side) arranged in various patterns. Blocks are generally on the upper slopes. Gullies were the chief obstacle in block layouts and in treatment applications. Measurement plots were located to avoid gullies as much as possible. After the hardwood midstory and overstory trees were cut, study treatments were randomly assigned to the 2-acre plots in each block.

The experimental design included randomized, complete blocks with 5 replications, 2 on the Hitchiti and 3 on the Piedmont Refuge. Five treatments included four to control regrowth of the midstory for maintenance of the open condition favorable for RCW nesting habitat, and an untreated check. Treatments were:

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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Herbicide and No Burn (H_NB)
Herbicide and Summer Burn (H_SB)
No Herbicide and Summer Burn (NH_SB)
No Herbicide and Winter Burn (NH_WB)
No Herbicide and No Burn (NH_NB) (Check).

The winter burn without herbicide is the cheapest treatment and the one most extensively used by forest managers. Summer burns have potential for best hardwood control, but are more difficult to conduct because of weather and fuel variables. The herbicide and burn combination, sometimes called "brown and burn", offers potential for maximum vegetation kill and site clean-up; the herbicide kills most of the susceptible, unwanted vegetation and provides added fuel for a complete debris reduction burn 6 or more weeks later.

The pre-treatment cut was made to create the RCW's desired nesting habitat by removing all of the large hardwoods and most of the midstory trees. All hardwoods larger than 2 inches d.b.h. and pine stems from 2 to 7 inches d.b.h. were felled with chainsaws. Felled trees were left where they lay, but tops were lopped down to about 2 feet above the ground. Hardwood stumps larger than 4 inches diameter were sprayed with Garlon 3A™ (triclopyr) to prevent stump sprouting on the plots. Pre-treatment cutting was completed by June 8, 1989.

Three sizes of measurement plots were established to sample different vegetation strata (Figure 1). The overstory pine stand was measured on a 0.2-acre circular plot located in the approximate center of the treatment plot, but avoiding eroded areas as much as possible. On each of these plots, all residual pines were measured for diameter and given a permanent, numbered metal tag; and three dominant or codominant trees were measured for total height, and height to crown. Increment cores were taken from several trees in each stand to estimate stand age. Vegetation was measured first in mid-June 1989, after completion of the pre-treatment cut but before treatment applications. Beginning overstory conditions, given in Table 1, were fairly uniform on the four study sites. Age averaged 67 years old, d.b.h. averaged 14 inches, and basal area averaged 69 square feet per acre. Periodic remeasurement of these plots will monitor changes in the overstory.

Midstory vegetation is the focus of this report. It consisted of all trees or shrubs over 4.5 feet tall, but less than 4.6 inches d.b.h. Midstory plants were measured on a 0.02-acre circular plot (Figure 1) having the same center as the larger 0.2-acre plot. All stems on this plot were counted and placed in seven species groups: pine, oak-hickory, dogwood, sweetgum, yellow-poplar, other hardwoods, and shrubs. Species in the "other hardwood" and "shrub" groups were noted.

Lastly, ground vegetation was sampled on 10 circular milacre plots located with plot centers at 10-foot intervals on a line tangent to the edge of the 0.2-acre plot (Figure 1). These plants consisted of all trees, shrubs, and herbs up to 4.5 feet tall. The transect was positioned to sample across slope gradient; thus, milacre plot number 1 was upslope and number 10 was downslope. Ground vegetation was very sparse at the start of the study. The original pine-hardwood overstory had been so dense that little sunlight was reaching the forest floor. Furthermore, felling the overstory hardwoods caused a lot of disturbance to small vegetation and soil cover, creating much debris and exposing soil. This report does not include any additional information on ground vegetation.

The herbicide selected for use in this study was Arsenal Users Concentrate™(imazapry) which is labeled for loblolly pine site preparation and release and has low impact on wildlife. The application rate was 32 ounces per acre with Ortho X-77™ as a surfactant. Herbicide was applied in 40 gallons of water mixture per acre in early August 1989, using a boom sprayer mounted behind a JD 450 crawler tractor. The sprayer was calibrated to apply 40 gallons per acre in a 50-foot-wide swath. Swath center lines were measured and flagged across appropriate plots before treatment.

Summer burning was done in the second week of October 1989, 9 weeks after herbicide application. October is not summer, but it is during the growing season in the Lower Piedmont of Georgia. All burns were made within prescribed conditions. Winter burning was included in only one treatment, and it was done in February 1990.

Results and Discussion

Results reported here emphasize the midstory of the stand, which is the major focus of the study. Table 2 presents the mean number of midstory stems for each species group on the 0.02-acre measurement plots in 1989 and 1992. The intermediate 1990 data are not included in Table 2 but are included in later graphic analysis. The five hardwood groups were totaled and labeled "all hardwoods", and the total of all groups (pine, hardwoods and shrubs) is labeled "all

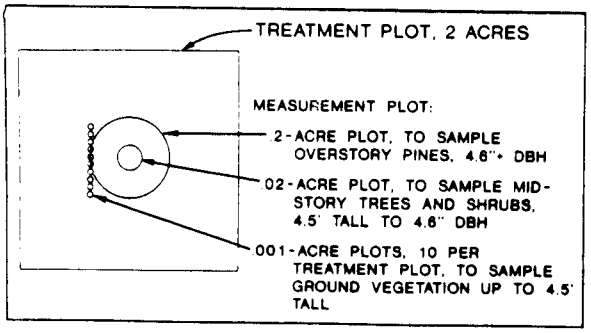

Figure 1. *Diagram of a treatment plot with three sizes of measurement plots within it to sample different vegetation strata.*

stems". The mean number of stems in most categories made a sharp increase from 1989 to 1992, except yellow-poplar.

Randomized block analysis of variance (SAS Institute, Inc. 1987) was used to compare the number of midstory stems per plot in each of the vegetation categories, by years. Comparisons were made at the 0.05 level of significance. In 1989, before treatments were applied, there were no significant differences among plots in any of the categories (Table 2). Therefore, any significant differences detected in the 1992 stem-count data could be attributed to treatments. Three years after treatments, "all stems" was the only category to show a significant effect of treatments. "Other hardwoods" and "all hardwoods" approached significance, as indicated by the probability of obtaining a larger F value (Pr>F) in Table 2.

Mean numbers of midstory stems per acre are shown by treatments in Figure 2. Treatment effects can be followed over the three measurement dates: 1989, before treatments were applied; 1990, one growing season after treatments; and 3 years later in 1992. The check is NH_NB, the second set from the left in each bar graph.

The number of pine stems increased sharply on the two no-burn treatments, with or without herbicide. There was a minor increase in pines on the two summer burn treatments, and the winter burn treatment had a decrease from 340 to 70 trees per acre. This is the distinguishing feature of using fire with most herbicides: herbicide alone will control hardwoods and release the pines; but by adding fire, the smaller pines in the midstory are also controlled.

Hickories (*Carya* spp.) and oaks (*Quercus* spp.) were recorded as a single group, but most were oaks. Both herbicide treatments and both summer burn treatments effectively controlled hickories and oaks. Compare this to the more than 4-fold increase after the check treatment (NH_NB). Winter burning reduced the hickory-oak group in the first year, but by the third year there were more than 4 times as many as at the start.

Dogwood (*Cornus florida* L.) was the most prevalent midstory hardwood, averaging 722 stems per acre over all plots in 1992. The most intensive treatment (H_SB) was the only one that effectively controlled dogwood. After all other treatments, the number of dogwood stems in 1992 was greater than the number on check plots.

Sweetgum (*Liquidambar styraciflua* L.) was also persistent, but at a lower level than dogwood. Herbicide alone (H_NB) was the only treatment that reduced the number of sweetgum stems in the midstory.

There was very little yellow-poplar (*Liriodendron tulipifera* L.) on the study plots. In the two treatments where it did occur, the combination of herbicide and summer burning (H_SB) eliminated it. Its numbers more than doubled with summer burning only (NH_SB).

The "other hardwood" group consisted mostly of red maple (*Acer rubrum* L.), persimmon (*Diospyros virginiana* L.), winged elm (*Ulmus alata* Michx.), black cherry (*Prunus serotina* Ehrh.), and red bud (*Cercis canadensis* L.). This group was controlled reasonably with herbicide and/or summer burning, but not with winter burning or no treatment.

The shrub group was mostly blackberry (*Rubus* spp.), *Vaccinium* spp., and sumac (*Rhus* spp.). Except after the herbicide-only treatment (H_NB), shrub presence in the midstory increased considerably. Winter burning (NH_WB) caused the greatest increase, from 0 to 220 stems per acre. The multiple stems of shrubs make them very difficult to count. Also, some plots had very rank growth of blackberry canes over 4.5 feet tall, which accounted for some of these high numbers.

There was a great deal of variation among plots in species and stem counts. Some effect was caused by midstory stems being mashed to the ground during the preparatory felling of large hardwoods, then coming back as multiple vertical stems from one prone stem. This effect was observed several times for dogwood. Also, no doubt, there were different effects of the herbicide treatment of stumps after the pre-treatment cut. Where stump sprouts had grown above 4.5 feet tall, each was counted as a separate stem.

The 1992 "all stems" data was subjected to Tukey's means separation test (SAS Institute, Inc.

Table 1. *Characteristics of overstory pines after hardwood removal but before study treatments were applied, by blocks.*

Block	Age	50-year site index	D.b.h.	(Range)	Total height	Trees per acre	Basal area per acre
	yrs.		---------- in. ----------		ft.	number	sq. ft.
1	63	94	15.2	(8-28)	101	47	65
2	79	89	15.2	(8-22)	98	57	76
3	77	80	13.0	(8-23)	85	61	60
4	62	89	14.1	(8-23)	92	65	76
5	54	95	14.2	(8-26)	96	55	68
Avg.	67	89	14.3	--	94	57	69

Table 2. *Mean number of midstory stems on 0.02-acre plots and the probability of a larger F value (Pr>F) obtained in ANOVA, by species group, for 1989 and 1992.*

Year	Item	Pine	Hick-oak	Dog-wood	Sweet-gum	Yel-pop	Other hdwds	Shrbs	All hdwds	All stems
1989	Mean no.	3.36	0.84	2.44	1.20	0.16	1.96	0.04	6.60	10.00
	Pr>F	.1673	.6955	.4876	.4979	.5315	.1706	.4362	.5206	.4292
1992	Mean no.	15.04	3.08	14.44	4.76	0.28	7.40	1.72	29.96	46.72
	Pr>F	.2159	.1680	.5984	.6237	.4362	.0630	.4402	.0919	.0179*

* Significant at 0.05 level.

1987) and the mean number of midstory stems per 0.02-acre plot are shown below for each treatment.

NH_NB (Ck)	NH_WB	H_NB	NH_SB	H_SB
82.2a	56.2ab	54.2ab	34.0ab	7.0b

Means with the same letter adjacent are not significantly different from each other at the 0.05 level. Herbicide and summer burning (H_SB), the most intensive treatment, had the greatest effect on all-stems, but was significantly better than only the untreated check (NH_NB).

This study of vegetation is not dependent on the RCW being in the area. However, an interesting sidelight is that artificial nesting cavities were installed in two of the study areas in 1990. Since then a breeding pair and a single bird have been observed on the study sites. Furthermore, there are two start holes on one of the herbicide-and-summer burn plots.

Conclusions

The herbicide-and-summer burn (H_SB) treatment was the most effective in controlling midstory stems 3 years after treatment, when all species are taken as a group. Although not statistically significant, H_SB also tended to be more effective in controlling dogwood, and summer burning, with or without herbicide, was also more effective in controlling the "other hardwoods" group. It should also be pointed out that H_SB was the most expensive treatment; the cost of the material alone (herbicide and surfactant) was $75 per acre in 1989.

Lacking more definitive results after only 3 years, these speculative points may be stated:

1. All herbicide and summer burning treatments probably will control hardwood midstories if repeated often enough.
2. The most intensive and expensive treatment probably will get more complete control faster.
3. Treatment schedules may include initial use of herbicide and fire, followed by periodic use of fire only, and a repeat of herbicide when it appears that burning is not maintaining the desired control.

The study will continue with additional analysis of the ground vegetation data, which includes number of stems and percent coverage, by species, below 4.5 feet tall. Field observations will be made periodically over 20 years and treatments will be re-applied as needed.

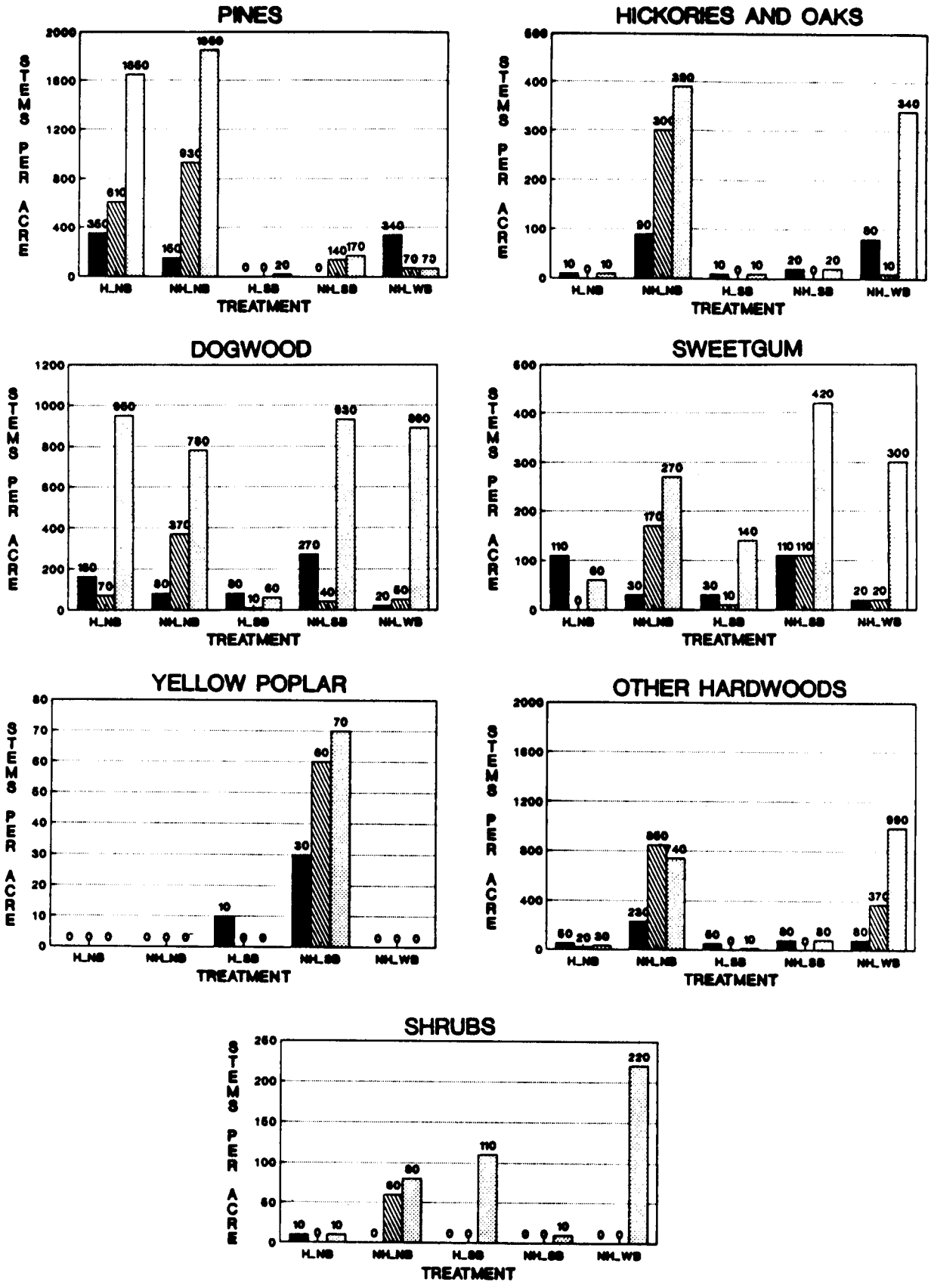

Figure 2. *Number of trees per acre compared among treatments, by species group and year. Treatments are: herbicide only (H_NB); untreated check (NH_NB); herbicide and summer burn (H_SB); summer burn only (NH_SB); and winter burn only (NH_WB).*

Acknowledgements

A portion of the study is located on the Piedmont National Wildlife Refuge, U.S. Department of Interior, Fish and Wildlife Service. American Cyanamid Company supplied a portion of the herbicide used. The Georgia Forestry Commission provided herbicide spray equipment and operator. The study has been partially funded by Region 8, USDA Forest Service. All these cooperators are acknowledged with thanks.

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BOOTSTRAP CONFIDENCE INTERVALS FOR STAND-LEVEL ECONOMIC LOSSES FROM SOUTHERN PINE BEETLE INFESTATIONS [1]

Thomas P. Holmes [2]

Abstract. Data for estimating average rates of southern pine beetle mortality are relatively sparse. The lack of good data is important because imprecise estimates of stochastic mortality rates result in uncertain economic benefits associated with hazard mitigation. In this paper, a method is introduced for testing hypotheses regarding economic benefits associated with various levels of southern pine beetle hazard mitigation. Analysis of data for east Texas reveal that: (1) bootstrap estimates of the standard error of average pine beetle-induced mortality are relatively high, and (2) relatively large decreases in average mortality rates are required before statistically significant improvements in economic returns are realized for short-rotation pine plantations. Consequently, it may be difficult to motivate landowners to take steps to reduce pine beetle hazards unless costs are very modest or more precise data are developed regarding the efficacy of hazard mitigation activities.

Introduction

Catastrophic forest losses from such factors as fire and insect outbreaks are essentially driven by stochastic processes. Economic models developed to evaluate the influence of catastrophic mortality on optimal management behavior have recommended reducing the exposure of forest assets to potential disturbances by shortening the rotation period (Martell 1980, Routledge 1980, Reed 1984, Reed and Errico 1985). By treating the parameters characterizing stochastic processes as certain, analytical and empirical results have been derived that indicate the benefits of reductions in the rate of catastrophic disturbances. Such benefits can then be compared with the costs of hazard mitigation efforts and rational forest protection policies can be evaluated.

The information base on which estimates of empirical hazard functions are computed is typically very sparse. Consequently, the usual economic analysis is conducted by using a sensitivity analysis to evaluate economic response over a hazard set that presumably bounds the actual hazard rate. While useful, this line of reasoning fails to consider means of evaluating the economic efficacy of prescriptions to reduce catastrophic hazards. That is, efforts to persuade land managers to engage in hazard mitigation efforts must demonstrate that economic rewards are attainable with some degree of confidence. We argue that, from this perspective, the sparse data problem is important because imprecise estimates of key stochastic parameters result in uncertain economic benefits. We anticipate that landowners who care about the variability as well as the expected value of returns to management will be influenced in their decision to undertake hazard mitigation activities by the degree of certainty associated with various degrees of hazard reduction.

In this study, we develop a method of estimating confidence bounds and testing hypotheses regarding the economic benefits of mitigating insect-induced forest mortality. Our primary emphasis is method development. Consequently, we use a single illustration of our method that is not generalizable to all conditions in the South. Future research will evaluate a wider range of conditions.

Our study proceeds as follows. In section II we briefly review economic strategies for mitigating stochastic mortality factors and present the basic damage assessment model. In section III we introduce (i) a method of estimating annual pest risk utilizing hazard functions, and (ii) a method for testing hypotheses regarding optimal strategies for reducing uncertain hazards using the bootstrap resampling scheme. In section IV we present our data and data analysis. In section V we discuss our results.

Mitigating Biologic Risk in a Forest Plantation

To understand the impacts of potential catastrophic mortality on managerial decisions, we need a model of timber producer behavior. We

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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assume that the timber production objective is to maximize discounted economic yield from a plantation forest. In keeping with the standard tradition, we consider that forestry will continue to be the highest and best land-use for the land under consideration.

It is well known (e.g. see Clark 1976) that the optimal discounted economic yield is given by the solution to

$$V'(T) = \delta[V(T) - k] + \delta\frac{V(T) - k}{e^{\delta T} - 1} \qquad (1)$$

where:

V(T) = stand value at rotation age T
V'(T) = marginal stand value at age T
δ = continuous time discount factor
k = cost of replanting an acre.

Equation (1) is known as the Faustmann formula. It says that, at the optimum, marginal value growth is exactly equal to the opportunity cost on timber and the opportunity cost of holding land.

Let λ represent the average rate of pest-induced forest mortality. Reed (1984) shows that the effect of catastrophic mortality on the optimal rotation is to add the risk factor λ to the discount rate in the Faustmann formula:

$$V'(T) = \frac{(\lambda + \delta)(V(T) - k)}{1 - e^{-(\lambda+\delta)T}}. \qquad (2)$$

It can be shown that the presence of risk decreases the optimal rotation.

Once we have computed optimal rotation ages using equation (2), we can compute the land expectation value J as

$$J(\lambda;\delta) = \frac{(\lambda + \delta)(V(T) - k)e^{-(\lambda + \delta)T}}{\delta(1 - e^{-(\lambda + \delta)T})} \qquad (3)$$

where T is the optimal rotation age. We define the economic benefit associated with reducing pest risk as the difference between the maximum land expectation value with pest risk at estimated current levels, λ^+, and the maximum land expectation value with pest risk at some lower level, λ^h:

$$\Delta J = J(\lambda^+;\delta) - J(\lambda^h;\delta). \qquad (4)$$

Based on the standard capitalization formula, average annual economic benefit is computed as ΔJ times the discount rate δ.

Pest Incidence and Severity

Hazard Functions

In the long run (that is, over many rotations) pest infestations reduce the timber yield from any particular forest site. Similarly, in any particular year forest pests reduce the timber yield aggregated over many forest sites. Let X_k represent the time between the occurence of the k^{th} and $k + 1^{st}$ *D. frontalis* spot on any particular tract of land. If the random variables X_k are independent and identically distributed, then the process is called a *renewal process*, since the process is statistically renewed after each occurence of an event. Given the number of spots N(t) occuring in time t, define

$$M(t) = E[N(t)] \qquad (5)$$

that is, M(t) is the average number of spots occuring in time t.

We assume that SPB spots occur as a Poisson process at the average rate λ and that

$$Pr\ (pest\ infestation\ within\ dt) \approx \lambda\ dt \qquad (6)$$

for some small time dt. The cumulative distribution function for X_k is written as

$$F(x) = 1 - e^{\lambda x} \qquad (7)$$

that is, the probability of a spot occuring increases exponentially as time increases, and M(t) = λt. Let μ_A = E[X] be the average length of a "renewal period". Then the average number of spots over a long time t is M(t) = t/μ_A, or, in the limit

$$\lim_{t\to\infty} \frac{M(t)}{t} = \frac{1}{\mu_A}. \qquad (8)$$

Let the severity of a *D. frontalis* spot be given by the random variable B with mean value μ_B. If we let Q(t) represent total forest mortality over t, then the average rate of forest mortality equals

$$\lim_{t\to\infty} \frac{E[Q(t)]}{t} = \frac{\mu_B}{\mu_A} = \mu_B\lambda = \lambda^+. \qquad (9)$$

That is, the average rate of forest mortality from *D. frontalis*, λ^+, is computed as the average spot size times the average rate of spot occurence.

Bootstrap Hypothesis Testing

Once we have estimates of λ^+ and λ^h, we can compute optimal rotation ages by substituting λ^+ and λ^h for λ and solving equation (2). We are interested in testing the hypothesis that economic benefits from reducing *D. frontalis*-induced mortality are significantly different than zero. To do so we need a measure of whether the difference $J(\lambda^+;\delta) - J(\lambda^h;\delta)$ is large or small relative to the variability of $J(\lambda^+;\delta)$. Consequently, we need an estimate of the variability of our estimate of $J(\lambda^+;\delta)$, which depends on the variability of our estimate of λ^+.

From equation (9) we can see that an estimate of λ^+ is constructed as an estimate of average spot size, μ_B, times the average rate of spot occurence, λ. Because $\lambda = 1/\mu_A$, λ^+ can be viewed as the ratio of average spot size to the average length of a renewal period. The dispersion of λ^+ is therefore a non-linear function of the dispersion of μ_B and λ. Because there is not an analytical formula for the standard error of the ratio of two averages, we introduce a method known as the bootstrap to compute this measure. Further, because optimal rotation age and land expectation value are non-linear functions of λ^+ (which precludes an analytical estimate of variance) we also use the bootstrap method to evaluate the variance of $J(\lambda^+;\delta)$. In this way we are able to evaluate uncertainty regarding our parameter estimates and to test hypotheses regarding economic damages under different rates of insect-induced mortality.

The bootstrap algorithm is based on the idea of a bootstrap sample (Efron 1982). Using the original data set $x = (x_1, x_2, \ldots, x_n)$, the bootstrap sample $x^* = (x_1^*, x_2^*, \ldots, x_n^*)$ is drawn with replacement using a uniform probability distribution. Each x_i^* is one of the original observations. Bootstrap samples are generated a large number B of times. Statistics computed from the B bootstrap samples are nonparametric maximum likelihood estimators.

The bootstrap estimate of the standard error of λ^+ is computed as follows. First, using a random number generator, create a large number B of independent bootstrap samples of size n for $\underline{D}$. *frontalis* spot size and compute the average $\bar{\mu}_B$. Second, create B independent bootstrap samples of size n for SPB infestation probabilities and compute the average $\bar{\lambda}$ Third, create B independent bootstrap samples of size n for D. frontalis hazard, λ^+, by multiplying $\bar{\mu}_B$ by $\bar{\lambda}$element by element. The standard error for the B bootstrap estimates of λ^+ can then be computed.

Bootstrap hypothesis testing is not as well understood by practitioners as other applications of the method. In particular, care must be taken to resample in a way that reflects the null hypothesis. Failure to do so may result in a bootstrap test with low statistical power (Hall and Wilson 1991).

Bootstrap hypothesis testing is carried out as follows. First, estimate the absolute value of the difference between the maximum land expectation value computed from the original data, $J(\lambda^+;\delta)$, and the maximum land expectation value under the null hypothesis, $J(\lambda^h;\delta)$:

$$|J(\lambda^+;\delta) - J(\lambda^h;\delta)|. \tag{10}$$

Second, compute the absolute value of the difference between the estimated maximum land expectation value for each bootstrap sample estimate λ^{+*} and the maximum land expectation value from the original data:

$$|J(\lambda^{+*};\delta) - J(\lambda^+;\delta)|. \tag{11}$$

This step results in a set of B observations on the computed difference. Third, sort the set of differences to obtain the bootstrap distribution of $J(\lambda^{+*};\delta) - J(\lambda^+;\delta)$. Call this estimated difference θ^*. The cumulative distribution function of θ^* is then

$$CDF = Prob[\theta^* \le x] \tag{12}$$

which is approximated by

$$number[\theta^* \le x]. \tag{13}$$

Then, for a given level of significance α, define

$$\begin{aligned} \theta_{low}(\alpha) &= CDF^{-1}(\alpha) \\ \theta_{up}(\alpha) &= CDF^{-1}(1 - \alpha) \end{aligned} \tag{14}$$

The percentile method for estimating the confidence interval for θ is then

$$[\theta_{low}(\alpha), \theta_{up}(\alpha)]. \tag{15}$$

Finally, if the difference estimated in the first step, equation (10), falls within the confidence interval computed by equation (15), the null hypothesis of no difference in the amount of economic damage between current and reduced insect-induced mortality rates is not rejected.

Empirical Analysis

Data

Daniels et al. (1979) used a logistic regression model to estimate a continuous measure of the probability of a *D. frontalis* spot occuring in a forest stand. They found that the probability of *D. frontalis* incidence increased with stand basal area and the proportion of stand basal area in pine.

One limitation of the Daniels et al. model is that it only correctly predicts outbreak probability for years in which conditions are the same as the year in which the data were collected. Subsequently, Reed et al. (1982) presented a method to incorporate annual variability in regional outbreak levels into the predicted outbreak probabilities. This method uses observations on the number infested (n1) and uninfested stands (n2) used to estimate the model, the number of *D. frontalis* spots occuring regionally, and the total number of stands in the region (N2) in a weighting scheme that adjusts the intercept parameter in the estimated equation.

Values for n1, n2, and N2 are provided by Reed et al. (1982). Data on N1, the number of *D. frontalis* spots on non-Federal land in east Texas are provided by Turchin et al. (1991). Given this data, we are able to estimate predicted outbreak probabilities for the years 1958 to 1987.

Forest mortality from *D. frontalis* is a function of both the incidence and severity of outbreaks. Some data are available on spot sizes as collected by the Texas Forest Service (R. Billings, personal communication). For our analysis, we used data reported by Leuschner et al. (1976) collected from the Trinity District of the Davy Crockett National Forest in Texas. Although the Leuschner et al. data includes observations on all spots regardless of size, we use only the portion of the data for spots including ten or more trees because the regional spot data is so constructed.

The model is operationalized using the North Carolina State University growth and yield simulator to perform computations related to stand volume. Volume estimates are computed for five year intervals and are joined using cubic spline interpolation. Parameter values for the economic variables representative of conditions in east Texas are also used in the empirical analysis:
(i) stumpage price = \$0.20 per cubic foot for pulpwood and \$0.50 for sawtimber, (ii) continuous discount rate = .04, (iii) regeneration cost = \$200 per acre, (iv) site index = 75 base age 25, (v) initial planting = 700 trees per acre, and (vi) planting success = 80%.

Results

Given the stated initial conditions and economic parameters, the average rate of forest mortality from *D. frontalis* in east Texas was estimated to be $\lambda^+ = .010004$ or about 1% of the stand is destroyed each year. Using the bootstrap algorithm, the standard error of λ^+ was computed to be 0.003272 and the coefficient of variation is about 0.326. Consequently, we are 95 percent confident that λ^+ falls in the range .00346-.016548/year.

Using equations (2) through (4), we found that the optimal rotation age varies by less than one year as insect-induced mortality is varied from 0 to 1%/year. Consequently, we would not expect that changes in average mortality rates would influence land managers to alter current rotation ages that maximize economic yield.

The results of our bootstrap hypothesis testing show that there is no significant difference at the 0.05 significance level between the level of economic damages at current rates of *D. frontalis*-induced forest mortality and reduced rates that represent 75% of current levels. That is, if hazard mitigation efforts reduced the average mortality rate for our test stand from .01 to .0075, economic returns from the stand not receiving mitigation would exceed economic returns to the hazard reduced stand about 20% of the time. However, we did find that statistically significant economic benefits could be realized if average mortality rates could be reduced to 50% of current levels. In particular, if hazard mitigation efforts reduced the average mortality rate from .01 to .005, economic returns from the "no mitigation" stand would exceed economic returns from the "hazard reduced" stand only about 2% of the time.

Discussion

In this study, we introduced a method for testing hypotheses regarding economic losses associated with varying levels of *D. frontalis*-induced mortality. Because *D. frontalis* population levels are highly variable, bootstrap estimates of the standard error of the average mortality rate are also relatively high. Consequently, large reductions in average mortality rates are required before statistically significant benefits are found for short-rotation pine plantations. Given the specific parameterization of the problem investigated in this paper, risk averse

landowners will probably be reluctant to undertake *D. frontalis* hazard mitigation efforts that have a modest impact on hazard rates unless mitigation costs are likewise very modest.

Economic benefits computed for short-rotation plantations probably represent a lower-bound to overall economic benefits because beetle-hazard is a cumulative function of time. In future research, we will evaluate the economic benefits of hazard mitigation for longer rotations which are oriented to the production of other forest outputs such as wildlife habitat and recreation. We anticipate that economic benefits associated with hazard mitigation for long-rotation stands will be more sensitive to changes in *D. frontalis*-induced mortality rates.

Two caveats are in order. First, the results presented here are designed to demonstrate a method for comparing damages and depend on the specific parameters used to construct the experiment. Sensitivity tests will reveal the robustness of our results to key parameters such as rotation length, site index, initial planting densities and output prices. Second, our analysis can be no better than the data available for analysis. Although we have used the best data available, we look forward to testing our hypotheses on experimental data designed to shed light specifically on the the efficacy of stand and landscape-level treatments to reduce *D. frontalis*-induced damage.

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OPPORTUNITY COSTS OF STREAMSIDE MANAGEMENT ZONES ON AN INDUSTRIAL FOREST PROPERTY [1]

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Abstract. The opportunity costs of streamside management zones (SMZs) on an industrial forest ownership in Georgia were estimated by calculating the present value of the timber revenue obtainable from the ownership over an infinite time horizon, and reducing that value by the potential revenue that would be lost from SMZ set-asides. The magnitude of SMZ opportunity costs depended on how an SMZ would otherwise be managed. Although the total area in SMZs was only 8.2% of the ownership, opportunity costs were as high as 14.4% of total forest production value. Allowing thinning in the SMZs decreased opportunity costs markedly.

Introduction

The impact of environmental protection practices on the profitability of timber growing concerns most forest owners. Whether increased protection levels are imposed by government edict or voluntary, questions arise over the magnitude of costs and benefits associated with low impact forest management.

Environmental protection measures exist as "best management practices" (BMPs). BMPs are harvesting and roadbuilding practices which have as objectives reductions in sedimentation and soil compaction. In most southern states, BMPs are voluntary. But a number of states are currently considering various regulations requiring BMPs on private lands. A partial list of BMPs recommended by state agencies includes installation of culverts, water bars, proper road/landing/skid trail placement and streamside management zones (SMZs) (Alabama Forestry Commission 1991).

SMZs are non-cut or partially cut buffer strips of trees adjacent to a stream. The purposes of SMZs are to reduce sedimentation from harvesting, maintain wildlife habitat, and aid in regulating stream temperatures (Georgia Forestry Commission 1990).

There is considerable variability in what constitutes an SMZ in practice. Most state guidelines stress that proper SMZ establishment depends on on-site evaluation. In Georgia, for example, suggested minimum SMZ widths range from 20' in the lower coastal plain to 80' on either side of piedmont and mountain streamcourses (Georgia Forestry Commission 1990).

Several studies examine the economic impacts of BMPs. Dykstra and Froelich (1976) studied the costs of three stream protection alternatives, including SMZs, in western Oregon. They found no clear distinction as to which protection alternative was most cost-effective.

Hickman and Jackson (1979) employed linear programming to determine potential economic losses in a Texas county if timber management practices were constrained by limits on soil erosion rates. Compared to the unconstrained case, economic losses ranging from 7% and 77%, were estimated. Losses increased with increasing restrictions on erosion rates.

Barringer (1987) estimated the costs that would be incurred on a 30-acre Oregon timber sale from designating an SMZ. In that instance, the owner would have left 24% of the value of the trees in the SMZ.

Until recently, most researchers examined BMPs for forestry operations in midwestern or western states. A new study by Lickwar et al. (1992) provides an economic analysis of 22 timber harvests in Alabama, Florida and Georgia, to estimate the marginal costs of implementing 6 different BMPs recommended or required in each state. The cost of implementing BMPs ranged from 2.9% to 5.1% of gross timber sale revenue.

Several features are common to most BMP studies. Usually, a case study approach is employed, with the case ranging from a small timber sale (Barringer 1987), a county (Hickman and Jackson 1979) or a group of tracts spread over several physiographic regions (Lickwar et al. 1992).

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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A second common feature is that the costs of several different BMPs are evaluated. These may be limited to different harvesting alternatives, as described in Dykstra and Froehlich (1976), or encompass an array of harvesting, roadbuilding and post-harvest practices, as in Lickwar et al. (1992).

Finally, while several studies consider the opportunity costs of lost timber revenue from imposing BMPs, most implicitly assume these costs accrue only to the current crop of timber. An exception is the Hickman and Jackson study, which employs an infinite time horizon.

This research employs a case-study approach to estimate the cost of implementing BMPs. But the case considered, that of an actual industrial forest, differs from other work. This study is more narrowly defined than previous work because it examines only one BMP, the establishment of SMZs. Finally, the cost of establishing SMZs is examined from the standpoint of a continuing forestry enterprise, rather than a single timber harvest.

The study objective was to estimate the potential opportunity costs of SMZs on an industrial forest ownership in the Georgia piedmont, by calculating the dollar value of these costs. This was measured by calculating the present value of the timber revenue obtainable from the ownership over an infinite time horizon, and reducing that value by the potential revenue that would be lost from SMZ set-asides.

Background

The forest analyzed is managed by Mead Corporation and consists of 51,266 acres in the Georgia piedmont. The forest is comprised of a number of non-contiguous tracts of timber, in an unregulated condition. There are 331 mapped timber stands on the ownership, which include several distinct timber types. The forest represents a typical cross-section of piedmont conditions, ranging from bottomland hardwoods to upland pine sites.

The timber classifications employed by Mead are:

1. Natural pine (upland pine sites)
2. Pine plantation
3. Bottomland hardwood
4. Cove hardwood
5. Upland hardwood

These are managerial rather than ecological classifications, and are based on the predominant ecological class of a specific timber type in a stand. The total forest area in each timber type appears in table 1.

Table 1. *Areas in Streamside Management Zones in Each Timber Type.*

Timber Type	Total Acres	Acres in SMZ	Percent SMZ	Mean SMZ Size
Planted and Natural Pine	39,140	0	0	-
Bottomland Hdwd.	5160	1571	30.4	27.1
Cove Hdwd.	6457	2522	39.1	44.3
Upland Hdwd.	509	112	14.2	14.2
Total:	51,266	4205		

Individual stands range from 0 to 70 years old, with the oldest age classes in the hardwood stand types. The average age is 41 for hardwoods and 16 for pine. Approximately 30% of the natural pine was felled since 1984 and regenerated to plantation. Site indexes were measured to the nearest 5 feet for pines and more broadly on hardwood sites.

The primary ownership objective is to maximize the economic returns from growing timber in a manner consistent with environmentally sound management. All timber was assumed to be cut as pulpwood. This reflects some data limitations which are discussed later, and Mead's primary role as a paper manufacturer.

Streamside management zones were established by company foresters in stands in the bottomland, cove and upland hardwood types. SMZs are areas in which either no cutting takes place when the adjacent stand is harvested or where thinnings may be permitted.

Company foresters establish SMZs with a minimum width of 50' on each side of a stream. The areas delineated are often substantially wider for several reasons. First, the minimum SMZ widths may not be appropriate when two streams meet one another at an acute angle. In such instances it often is operationally more convenient to include all the area between the two streams in the SMZ. Physiographic conditions can also cause SMZ widths to vary. There is considerable diversity in SMZ size. They range from 3.4 to 273.7 acres, and average 33.4 acres (table 1).

Methods

To determine the economic impact of SMZs, estimates of timber volumes and values were generated for each stand. Individual stand values were summed to obtain total forest value. The value of non-SMZ and SMZ acres were included in this total. The impact of SMZ set-asides was defined as the potential timber revenue lost from these acres.

Value was defined as the sum of current stand values, plus the net present value of a perpetual series of even-aged stands, following the current stand. This is simply Faustmann's LEV criterion (1849). But some adjustments had to be made.

A 30-year rotation was used for all stands. However, existing stands range in age from 0 to 70. For stands younger than 30, the projected value at age 30 is discounted to the present and added to the discounted value of all future rotations. For stands now 30 years or older, value is the current stumpage value plus the discounted value of future rotations.

The Southeastern Twigs (SETWIGS) growth and yield model (Meldahl et al. 1987) was used to predict standing and future timber volumes for existing stands of mixed-pine hardwood and natural pine. Inputs include a stand tree list, age, site index, and projection period. These came from cruise data. To predict pine plantation yields the NCSU loblolly pine growth and yield simulator was employed (Hafley and Smith 1989).

To predict hardwood volumes on areas regenerated to hardwood after clearcutting, yield relationships developed by the NC State Hardwood Cooperative, as adapted by Mead for local conditions, were used. These project volume in terms of mean annual increment (Gardner et al. 1982).

Determining the opportunity costs of SMZs is complicated by the fact that value loss depends on what a site would be used for if it were not an SMZ. For the 39,140 acres of existing natural pine stands and pine plantations this was not an issue because no SMZs were designated in these areas. All acres now in natural pine stands or pine plantation will be regenerated to pine plantation following harvest.

Estimating volume and value is more difficult on hardwood sites. Some acres can be converted to pine plantation, or naturally regenerated back to hardwood after clearcutting. Each alternative has different associated revenues and costs. Therefore, measuring the cost of setting aside SMZs requires that the total value of the forest for timber production first be determined. If there are several potential management alternatives available, several costs can also be calculated. Therefore, the revenue "loss" from SMZ sites depends on how the site would be managed if it were not an SMZ.

To account for the different possible regeneration alternatives on hardwood sites, several scenarios were considered. First, hypothetical maximum and minimum timber production values for the entire forest were estimated. More realistic management scenarios were then introduced, including the one Mead currently employs. The scenarios evaluated were:

1. The hypothetical maximum production value (MAX scenario) of the forest was determined by assuming all cut stands were converted to pine plantation, regardless of a stand's initial timber type. This provided a hypothetical maximum because the per-acre LEV from pine plantations was higher than from other management systems. The total value of current stands, plus that of all future stands from each initial forest type were summed, to obtain the maximum production value. The SMZ opportunity cost was the value lost from setting aside those acres, assuming that they would otherwise be regenerated to pine plantation.

2. The hypothetical minimum production value (MIN) of the forest was calculated by assuming all acres in the hardwood forest type remained uncut. Natural pine stands and existing pine plantations were assumed regenerated to pine plantations. This scenario provided a minimum because it eliminated entirely the production value of the hardwood forest type.

3. The current situation (CURRENT PRACTICE, or CP) reflects the current company management practice. As in scenarios (1) and (2), all pine sites are regenerated to pine plantations. The regeneration of non-SMZ hardwood sites is split between pine plantation and "hardwood clearcut management" (HDWCC). HDWCC management is used in hardwood stands, or portions of stands, not suitable for conversion to pine. Areas designated HDWCC management are clearcut, residual non-merchantable stems felled, and naturally regenerated to hardwood. Other hardwood sites, typically uplands or ridges, are regenerated to pine. The division of hardwood sites between areas suitable for pine conversion and hardwood clearcut management is made on the ground by company foresters. The timber value loss from the SMZ areas uses the assumption that if the SMZs were

regenerated, hardwood clearcut management would be employed on those acres.

4. A fourth scenario assumes that no hardwood stand would be converted to pine plantation (HARDWOOD). Instead, all hardwood stands are regenerated back to hardwood. Pine stands are as in the situations described above. This scenario examines the cost of a situation that preserves more of the hardwood timber type, while not ruling out hardwood production in non-SMZ areas, as in the MIN scenario.

5. The final scenario assumes that SMZs are periodically thinned (THINNING). At age 30, 40% of merchantable volume, or a minimum of 10 cords per acre, whichever is greater, is removed. The stand is then thinned every 30 years thereafter. In each thinning following the first one, the mean annual increment produced by the stand over 30 years is removed. Thinning is superimposed on MAX, CP and HARDWOOD, but not the MIN scenario.

The economic parameters used in the analysis are averages obtained from the literature and a telephone survey of woodlands managers in Georgia and Alabama. These are:

a. 4% real discount rate
b. Stumpage price of $11/cord for hardwood and $24/cord for pine, (Timber Mart South 1991 averages for the Georgia piedmont)
c. Regeneration and management costs:
    i. Site preparation, seedling and planting costs of $210/acre when converting hardwood to pine plantation.
    ii. Site preparation, seedling and planting costs of $150/acre when regenerating pine plantation or natural pine to pine plantation.
    iii. Management costs of $1/acre in year 1 and $11/acre in year 3 of the life of pine plantations.
    iv. Felling residuals in hardwood clearcut management costs $10/acre.
    v. Pine plantations were established with 726 trees/acre. No thinnings or intermediate cutting carried out.
    vi. Rotation ages for all harvestable stands was 30 years.
d. Analysis is on a before-tax basis

Results

For the MAX scenario, the timber production value for the entire forest was calculated (table 2). It should be stressed that this represents a hypothetical maximum value because some hardwood sites are not appropriate candidates for conversion without expensive site preparation.

The timber production value calculated for the MAX scenario is $15.5 million. This is probably conservative because it assumes all timber is cut as pulp. Merchandizing sawtimber would increase this value because many hardwood stands contain significant hardwood volumes. Although SETWIGS projects gross sawtimber volumes, it does so based solely on tree diameter. Because merchantable hardwood sawtimber volume is very sensitive to tree quality, which SETWIGS does not account for, the potential for sawtimber production is omitted.

To account for the value loss from SMZs, the total production value of non-SMZ hardwood stands was calculated and deducted from the total value of all hardwood stands (table 2). The cost of $2.24 million represents 14.4% of the total production value of the forest, or 35.6% of total hardwood stand value, assuming that claercut hardwood stands would be converted to pine.

The minimum production value for the forest (MIN scenario) is the total value of existing pine stands, assuming they are regenerated to pine plantation (table 2). This establishes a hypothetical floor on forest production value. This came to 40.5% of total forest value and 100% of hardwood value.

In the Current Practice scenario (CP), all pine stands are regenerated to plantation. Non-SMZ hardwood stands are converted to pine plantation on appropriate sites, or managed with HDWCC on other areas. SMZs remain uncut. However, the value of timber on SMZ lands is calculated assuming that if cut, they would have been managed using hardwood clearcut management.

In this case, setting aside SMZs results in a loss of $1.69 million, or 11.4% of total forest production value (table 2). This is a loss of 30.3% of the potential value of the hardwood type. Although less than the losses in the MAX scenario, these still represent substantial opportunity costs.

In the HARDWOOD scenario, it is assumed that pine stands remain in pine, as before. But now, HDWCC management is assumed to be employed in

all non-SMZ hardwood stands. If SMZ stands were managed, they would be managed in the same manner. The dollar cost of SMZs is identical to the CP scenario (table 2). The $1.69 million represents an 11.5% loss of total timber production value of the forest, or 30.8% of the hardwood type. The percentage losses are slightly higher than the CP case.

The THINNING scenario consists of several sub-scenarios. If an SMZ is thinned, the value loss from the SMZ consists of the loss from the uncut timber, plus the loss from all future stands that could be grown on the site, minus the value of the thinned trees. Again, the value of the future stands depends on how clearcut SMZs would otherwise be regenerated. In the MAX scenario the SMZs would be regenerated to pine. In the CP and HARDWOOD scenarios, they would be regenerated using HDWCC management.

The timber value of the thinned SMZs was estimated at $1,139,035. This includes the value of trees thinned from existing stands, plus the discounted value of future thinnings.

The impact of thinning on the opportunity cost of the SMZs, versus the cases in which no thinning was permitted, is illustrated in table 3. The opportunity costs for the MAX, CP and HARDWOOD scenarios without thinning are presented alongside the costs if thinning is permitted. The decrease in value loss is substantial. Thinning essentially cuts the loss by half for the MAX scenario, and by two thirds for the CP and HARDWOOD scenarios.

Table 2. *Timber Production Value and Opportunity Cost of SMZs by Forest Type ($ million).*

Scenario	Forest[1]	Pine	Non-SMZ Hardwood[2]	SMZ Opportunity Cost[2]	Percent Loss from: Forest	Hardwood
MAX	15.559	9.259	4.055	(2.245)	14.4[3]	35.6[4]
MIN	15.559	9.259	(4.055)	(2.245)	40.5	100.0
CP[5]	14.839	9.259	3.888	(1.692)	11.4	30.3
HARDWOOD	14.754	9.259	3.803	(1.692)	11.5	30.8

[1] FOREST = PINE + NON-SMZ HARDWOOD + SMZ
[2] Parentheses indicate costs, or non-realized values
[3] 14.4 = (2.245/15.559)x100
[4] 35.6 = (2.245/(2.245+4.055))x100
[5] CP = Current Practice

Table 3. *SMZ Opportunity Cost for Each Scenario With and Without Thinning ($ million).*

Scenario	Opportunity Cost: +thin	no thin	Percent Value Losses From: Forest +thin	Forest no thin	Hardwood +thin	Hardwood no thin
MAX	1.105	2.244	7.1	14.4	17.5	35.6
CP[1]	0.552	1.692	3.7	11.4	9.9	30.3
HARDWOOD	0.552	1.692	3.8	11.5	10.1	30.8

[1] CP = Current Practice

Discussion

The opportunity cost of SMZ set asides depends largely on how the SMZ would otherwise be managed. Without thinning, the cost was highest for the most intensive management system and lowest for the least intensive system. Thinning in the SMZs decreased the opportunity costs for each case.

Although the number of acres set aside for SMZs was a fairly small proportion of the total forest (8.2%), the opportunity cost can be substantial. With current stumpage prices, value losses of more than $2.2 million, or 14.4% of the total forest value were realized for the most intensive management scenario.

Thinning played a major role in mitigating value losses. Removing 40% of merchantable volume at age 30 or later, combined with periodic thinning at 30-year intervals decreased value losses as much as two-thirds.

Several issues not addressed in the study should be noted. First, results are strongly influenced by the initial forest condition. The forest examined has a high proportion of young pine plantation, with low per-acre value. This contrasts to the hardwood stands, which constituted a minority of the acreage, but were mostly stocked with mature trees. Accordingly, SMZ opportunity costs were high relative to the forest value.

However, assuming that all wood from the forest is sold as pulp means that the opportunity cost of the SMZs is probably understated. It is certainly true that the total production value calculated for the entire forest is conservative. This is a promising area for further investigation.

Finally, the study calculates only the dollar value loss from SMZ set-asides. But there are additional, less easily quantifiable benefits provided by SMZs. SMZs provide wildlife habitat, reduce erosion, and aid in regulating stream water temperatures. If these benefits could be calculated in dollar terms, they would likely decrease the opportunity cost estimates. Further research is needed in this area.

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POTENTIAL PRODUCT VALUES FROM THINNED LONGLEAF PINE PLANTATIONS IN LOUISIANA [1]

Rodney L. Busby, Charles E. Thomas, and Richard E. Lohrey [2]

Abstract. The objective of this study was to determine the potential harvest value of thinned longleaf pine (*Pinus palustris* Mill.) plantations. Longleaf has long been recognized as having reduced risk of rust and bark beetle attack compared to other species. Because of the development of new techniques that speed longleaf's transition through the grass stage, establishing longleaf pine plantations is becoming more attractive. Analyses were done on a subset of an existing spacing and thinning study in longleaf plantations. Land expectation values were computed on the basis of current product prices, assumptions employing more than 2,000 individual trees, and a dynamic programming solution to economic conditions. Both the biological and financial results point to rotations of more than 40 years for longleaf. This information will provide assistance for decision-makers considering establishing longleaf pine plantations.

Introduction

The southern forest, particularly the Coastal Plain, was once dominated by longleaf pine (*Pinus palustris* Mill.). Utilization of the species was the basis for the establishment of the forest industry in the South. Unfortunately, difficulty in regenerating longleaf has led to the decline in importance of the tree in the species mix of the southern commercial forest. On the other hand, it appears that the tree has been unreasonably excluded, and a reevaluation of its possible role in the integrated forest may be overdue.

The potential for growing longleaf pine in plantations continues to improve. After a long period of declining acreage, longleaf acreage appears to be stabilizing at about 3.75 million acres (Kelly and Bechtold 1989). On the National Forests, total acreage may be increasing and plantation establishment is increasing[3]. This trend accompanies the recognition that a number of risks such as rust and bark beetles associated with loblolly and slash are lower for longleaf. Good progress has been made on the establishment of longleaf, and prescriptions for hastening the passage through the grass stage have been developed; regeneration techniques are well documented (Croker and Boyer 1975; Mann 1969).

The history of longleaf pine establishment bears reexamination in view of current technology. The establishment of seedlings and emergence into height growth have not been as simple with longleaf as with slash or loblolly. Costs associated with seedling production and site preparation are generally 20 to 25 percent higher than for the other southern pines. Because reductions in the time the trees take to reach breast height are important to our economic considerations, we will briefly cover technological innovations that support our modeling assumptions.

Successful regeneration requires attention to both the seedling and the site preparation. Growth of the seedling in lower density seed beds, inoculation with *Pisolithus tinctorius* (Pers), and lateral root pruning can be expected to contribute to healthier more vital seedlings (Hatchell 1985). To ensure vigor and survival, planting should follow within a week of lifting.

Longleaf is known to be one of the most intolerant of southern pine species. Its successful regeneration requires thorough mechanical or chemical site preparation. Among mechanical treatments, shearing and piling are required, whereas simple shearing may be sufficient for other species. Barnett and others (1989) suggest that chemical preparation has several distinct advantages over mechanical preparation, including retention of nutrients, more effective hardwood control, and lowered herbaceous cover in the spring following application. This analysis did not examine the economics of the chemical alternatives, an obvious area for further scrutiny.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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[3] Stoneking, K. 1992. USDA Forest Service, Atlanta, GA. Personal communication.

The current technology for handling longleaf has reduced to only 3 or 4 years the 7 or more years the plants needed to emerge into height growth when these study plantations were established. In this analysis we assume that a 4-year gain in reaching emergence has been made possible by site preparation and seedling treatments. Other researchers have recognized these changes and have adjusted their analyses (Shoulders 1989).

Data

Plots

Data for these analyses were collected in longleaf pine plantations near Alexandria, Louisiana. All were on cutover forest sites. Their current age is about 55 years, and data were available up to age 50. After the previous stands were clearcut, frequent fires controlled woody competition and allowed the pines to be planted without mechanical or chemical site preparation. The 0.1-acre plots were originally established to test initial stand densities from 1,000 to 2,500 trees per acre. They were first measured at 16 years old and showed no evidence of severe insect or disease damage.

Trees

The d.b.h. of each 0.6-inch or larger d.b.h. trees was measured with a steel diameter tape to within 0.1 inch. Tree were remeasured at 5-year intervals just prior to thinning. More than 2,000 individual tree age-d.b.h. measurements were taken. Total height from a 1-foot stump was measured on sample trees in all 1-inch-diameter classes. Height equations, based on age and d.b.h., used 9,200 tree measurements taken over a 30-year period in the study.

Measurements on a separate set of 147 felled trees were used to compute taper equations for stem volume. These felled trees were selected from thinned trees or from trees in the original isolation strip. Thinned stands had been repeatedly cut to residual basal areas of 60 to 100 ft^2/acre for at least 15 years before the sample trees were felled. Only sound trees that did not fork were selected. Some had been marked for cutting in regularly scheduled thinnings, but the sample also included some high-quality fast-growing trees that ordinarily would have been left to grow.

Treatments

We are reporting on a small subset of an original spacing study that was extended and converted into a thinned plantation study. From the original spacing trials, we selected a single block that included three replicates of the thinning levels. Residual density levels of 60, 80, and 100 ft^2/acre were established in these plots. Most plots were thinned at age 20, 4 years after the first tree measurements. A few that were assigned to, but had not reached, higher stand densities were allowed to grow until they surpassed the assigned density at a 5-year remeasurement occasion. Stands were repeatedly thinned to maintain the target basal area assigned to them. Trees with smaller diameters, diseases and insect infestations, defects, and poor form were removed first. A few rough, limby dominants were given second priority for cutting. Additional trees from the lower crown classes were then removed to achieve the assigned density. A second criterion used in the thinnings was to provide a uniform distribution of residual growing stock trees on the plot.

Methods

Biological Evaluation

We examined the periodic annual increment (based on the 5-year remeasurement interval) and mean annual increment in basal area and volume. Classical analysis of forest growth employs the mathematical fact that so long as the periodic increment remains above the mean annual increment, the plot or stand will continue to increase in volume increment. Assmann (1970) notes that volume increment will almost always continue to increase after the basal area increment has begun to decline. Therefore we examined both volume and basal area increment as well as the trend in the volume-to-basal-area ratio.

Economic Evaluation

The criterion used to evaluate investments in longleaf pine is land expectation value (LEV), the value of bare land used for growing perpetual rotations of even-aged stands of timber. LEV is calculated by finding the discounted present value of costs and revenues resulting from managing a stand in longleaf pine production for infinity. Revenues occur

when products are harvested from the stand either in a final harvest or as the forested tracts are thinned. Costs are incurred when the site is brought into production, and there is an annual cost to pay property taxes, fire protection and miscellaneous costs of keeping the land in forestry production. The formula for LEV is as follows:

$$LEV = \sum_{t=0}^{\infty} \frac{R_t - C_t}{(1+i)^t}, \qquad (1)$$

where:

LEV = land expectation value,
R_t = revenue occurring at year t,
C_t = cost occurring at year t, and
i = discount rate per year expressed as a decimal.

All costs and prices are expressed in terms of their 1992 purchasing power; these values are expected to increase at the rate of inflation. The discount rate used was the real (after inflation) discount rate.

Costs

Establishment costs were estimated from Dubois and others (1991) and personal contact with E. Sirmon[4]. Intensive mechanical site preparation (shearing, raking, and piling) is required, costing $118.52/acre. Planting costs are assumed to be $38.00/acre plus $0.05/tree. Costs of marking the thinnings and cruising the clearcut harvests were assumed to be $13.07 and $2.02/acre, respectively. The annual cost of periodically burning the site, paying taxes, and protecting and maintaining the property was assumed to be $3.00/acre.

Management Regimes

In our model, we assumed that the stands in all management regimes were established by means of intensive site preparation and planting 681 trees per acre. Thinnings to basal area 60, 80, or 100 ft^2/acre were examined. Commercial thinnings were assumed to occur every 5 years beginning at age 16, provided that enough basal area existed to put the area over the target basal area. Final harvest could occur from ages 16 to 46 in 5-year increments. For each plot, an optimal management regime was chosen for maximum LEV. The optimal management regime for plot 108, for example, included commercial thinning at ages 16, 21, 26, 31, and 36, and final harvest at age 41. Analysis of a different thinning schedule (e.g., every 10 years) was not possible, because historical plot data were used. A growth and yield model would have allowed projection of other possible management regimes, but none was available. Ages in the data have been adjusted downward for the 4-year acceleration in development through the grass stage that is possible with current technology.

Stumpage Prices

Current stumpage prices from the State of Louisiana were compiled from Timber Mart-South (various). The product prices (averages for 1991 and the first three quarters of 1992) were as follows:

Poles, $282.29/M bd. ft., Scribner,
Sawtimber, $163.57/M bd. ft., Scribner,
Chip-n-saw, $35.41/cord, and
Pulpwood, $20.93/cord.

We assumed that sawtimber stumpage prices would change only as much as the inflation rate over time. This assumption is conservative, given the large increases in sawtimber stumpage prices forecast by Haynes and Adams (1992).

Product Yields

A computer model was developed to simulate merchandising the longleaf stands. Dynamic programming subroutines from MERCHOP (Busby and Ward 1989) were adapted for use on the longleaf data base by using a taper function for Louisiana longleaf[5]. The products, diameter and length constraints, and the expected defect for each product is listed in table 1.

Table 1 shows that the amount of defect in these stands of longleaf was very low. In our example plots, 90 percent of the trees that met the diameter and length requirements were also sufficiently free of defect to produce a pole. This proportion of poles may be rather high for an average stand, but the thinnings and cleanings that were performed on the stands in this study have yielded

[4] Sirmon, E. 1992. USDA Forest Service, Jackson, MS. Personal communication.

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very good potential for production of poles and sawtimber, especially as the stands have matured.

Table 1. *Product size assumptions used, with percent defect.*

Product	Diameter inside bark (inches)	Piece length (feet)	Defect (percent)
Poles	4.00-10.00	35.00-90.00	10
Sawtimber	9.50-18.00	8.00-16.00	5
Chip-n-saw	6.00-12.00	6.00-16.00	0
Pulpwood	3.50-12.00	5.00	0

Results and Discussion

The results of our analysis of the biological data show the rotation for even-aged stands. Figures 1 and 2 show the periodic and mean annual increment curves of the basal areas and volumes for the observed data. Simple quadratic plotting routines from SAS© were employed to demonstrate the continued dominance of the periodic increment. That is, the stands continue to produce at higher biological rates than are traditionally used to determine the age of rotation. These plots appear to have the potential for continuing to produce wood at high rates for the next 10 to 20 years. A third graphic is included to show the progression of volume-to-basal area ratio (fig. 3). Foresters are frequently exhorted to harvest tracts in which there is a slowing in the accumulation of basal area. This figure emphasizes that volume continues to accumulate rapidly even after basal area growth has slowed. The only true measure of culmination of growth should be volume, definitely not diameter increment.

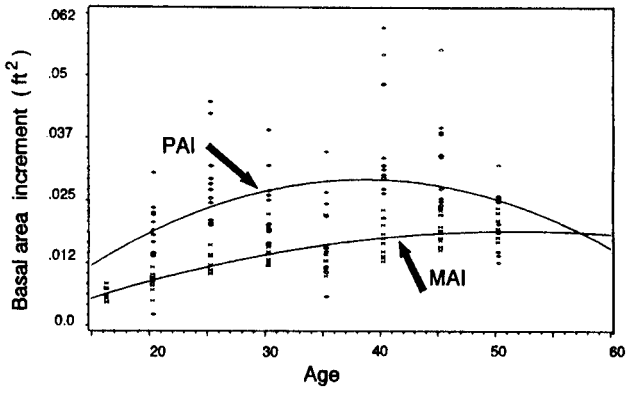

Figure 1. *Mean and periodic basal area increment thinned longleaf pine plantations.*

For the financial analysis, thinning to a basal area of either 80 or 100 ft²/acre proved to be the best management strategy at the 3-percent real discount rate; average LEVs were $1,743 and $1,744, respectively (table 2). In contrast, the average LEV of the three stands managed to a basal area of 60 ft²/acre had an LEV of only $1,424. The combination of thinnings every 5 years and the production of high-valued poles through diameter and height growth and low levels of defect allowed fairly long rotations. In fact, eight of the plots had optimal rotations of 41 years or more.

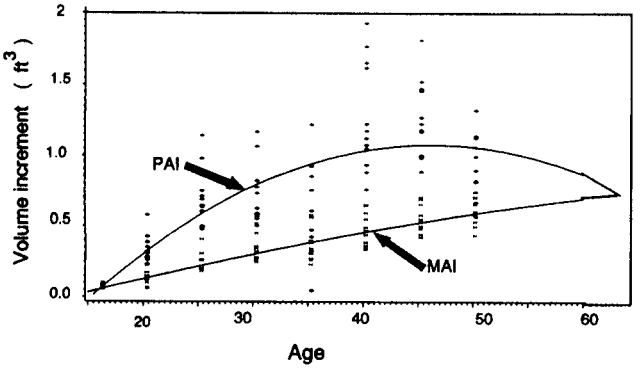

Figure 2. *Mean and periodic volume increment thinned longleaf pine plantations.*

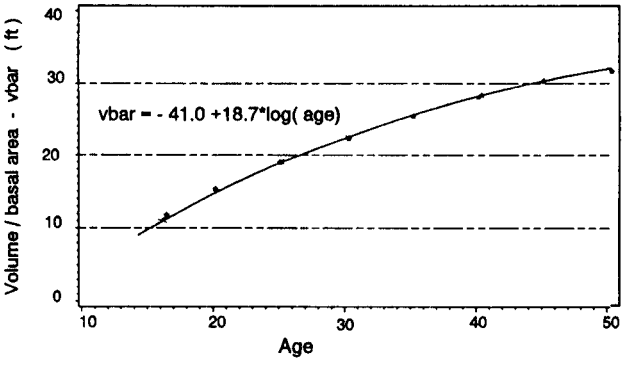

Figure 3. *Regression of volume-to-basal-area on the thinned longleaf pine plantations.*

Higher interest rates reduce LEVs, of course, and as expected, they reduced the optimal rotation age in our study. At the 5-percent real discount rate, the best management strategy is to thin to 80 ft²/acre (LEV $573); the second best is to thin to 100 ft²/acre (LEV $542); and third is to thin to 60 ft²/acre (LEV $457) (table 2). Five of the nine plots had optimal rotation ages of 41 years; the remaining four had optimal rotation ages of 36 years.

These rankings are not conclusive, since there is much variability in the individual plot data. Analyses of more plots to reach more definitive conclusions are in order. Two trends are obvious, however. First, these stands are excellent pole

producers, and optimal management should be geared to pole production. Intensive early thinnings yield relatively low-valued pulpwood and chip-n-saw products. These thinnings should be done only to improve the pole crop for future years, either to rid the stand of defective trees or to make room for pole production. Early thinnings that reduce future pole production do not make economic sense; early thinnings that increase future pole production will significantly improve returns.

Table 2. *Per-acre land expectation values for longleaf pine plantations based on thinning to 60, 80, or 100 ft² of basal area (BA).*

Thinning target	Plot	Discount rate 3%	5%	7%
		($)		
BA 60	113	1,402	448	127
	102	1,273	391	76
	101	1,596	532	145
	Avg.	1,424	457	116
BA 80	112	1,872	627	181
	109	1,599	616	135
	114	1,759	577	162
	Avg.	1,743	573	159
BA 100	108	2,198	745	244
	104	1,530	458	93
	111	1,505	422	78
	Avg.	1,744	542	138

A second trend discovered in the anlysis is that optimal rotation ages in longleaf are fairly long. Intensive thinnings allow early cash flows, and the change in product mix from pulpwood to higher valued products causes optimal rotation ages at the 3- to 5-percent level to be approximately 41 years.

Conclusion

This study is preliminary for several reasons. Only a few of the Louisiana plots were included, partly because of time constraints. We spent considerable time reviewing the technical changes for seedling culture, planting, and competition control because these factors are crucial to our economic assumptions for the future establishment of longleaf plantations. Our assumption that current technology bestows a 4-year early growth advantage may still be on the conservative side.

Longleaf has considerable advantage over other southern yellow pines in the proportion of potential poles and pilings in sawtimber size stands. The product price differential currently available to sellers of poles is significant: $282 versus $164, on average. These price differentials can be translated into a longer rotation under the LEV criteria we have presented. Rotations on the order of 35 to 40 years with pole production were demonstrated to be financially profitable.

In addition, we have shown that biological rotation for the plots we have been considering is considerably longer than is normally assumed for other southern yellow pines: on the order of 60 years (age corrected for establishment). Finally, we should make the point that even after 50 years the volume-to-basal-area-ratio continues to increase rapidly. Managers who cut longleaf because of the slowing of diameter growth completely disregard the increases in volume-to-basal-area ratio, thus tending to harvest trees long before their volume growth culminates.

The results presented in this study are from a small subset of available longleaf thinned plantation plots; we hope to conclude analyses of the complete data set in the near future.

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THE IMPACT OF GROUP SELECTION SILVICULTURE ON TIMBER HARVESTING PRODUCTIVITY AND COST IN THE SOUTHERN APPALACHIANS [1]

Robert M. Shaffer, Kenneth R. Brummel, and Bryce J. Stokes [2]

Abstract. National Forest timber management in the southern Appalachians is changing from traditional even-aged management and clearcutting to uneven-aged management, including group selection silviculture. Group selection, with its small 0.5- to 2-acre regeneration cuts widely dispersed throughout a timberstand, has the potential to substantially increase timber harvesting costs over the traditional 20-acre clearcut. This could exacerbate the below-cost timber sale issue. The objective of this study was to assess the impact of group selection silviculture on timber harvesting productivity and cost in southern Appalachian hardwood timberstands. This was accomplished by collecting and analyzing one full week of field production and cost data from three typical Appalachian loggers operating on group selection timber sales in the Jefferson National Forest in Virginia. The logging systems chosen for the study were: (1) a cable yarder (skyline) system, (2) a feller-buncher/cable skidder system, and (3) a motor-manual chainsaw felling/cable skidder system. Historic production and cost data from recent previous clearcut sales were obtained from the cooperating loggers to provide a comparison. Study results show that production was reduced and unit cost increased for all three logging systems when operating on the group selection sales. In all cases, this was primarily due to a dramatic increase in delay, or nonproductive time, directly attributed to the characteristics of the group selection sales.

Introduction

The Forest Service has announced a policy of ecosystem management for the nation's National Forests. This translates into a 70 percent reduction in clearcutting, with alternative harvest and regeneration techniques like group selection moving to the forefront. Group selection silviculture is not new. The technique of cutting small (< 2 acres) patches widely dispersed throughout a timberstand in an effort to naturally regenerate shade-intolerant species while creating an uneven-aged forest has been examined periodically since the turn of the century.

The impact of this change from clearcutting to group selection and other alternative harvesting techniques on logging productivity and cost is important. If unit logging cost increases with group selection, National Forest timber purchasers will bid less for stumpage sold in group selection sales. This may push additional sales into the below-cost category and further erode the National Forest timber sale program.

Bell (1989) used computer simulation to compare clearcutting and group selection timber harvesting costs in hardwood stands. He found that felling productivity decreased by 26 percent and skidding by 15 percent. Kellogg (1991) studied the effects of group selection on cable yarding operations in the Pacific Northwest. He found that yarding costs increased by 24 percent when yarding group selection sales.

The objective of this study was to document the impact of group selection silviculture on the productivity and unit cost of three representative timber harvesting operations in the southern Appalachians.

Study Procedures

Three loggers operating on group selection timber sales on the Jefferson National Forest in Virginia were chosen and agreed to cooperate for the study. They were:

System 1 -- A cable yarder operation. This 9-man crew used a large skyline yarder, a large knuckleboom loader with hydraulic sawbuck, a rubber-tired skidder, a dozer, 6 chainsaws, a crew truck, and 2 tractor trailer log trucks.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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System 2 -- A feller-buncher, cable skidder operation. This 4-man crew used a small 3-wheeled feller-buncher with chainsaw felling head, a rubber-tired skidder, a knuckleboom loader with hydraulic sawbuck, a crew truck, 2 chainsaws, and 2 straight-frame tandem-axle log trucks.

System 3 -- A motor-manual chainsaw felling, cable skidder system. This 3-man crew used a rubber-tired skidder, a knuckleboom loader, 3 chainsaws, and 1 straight-frame tandem-axle log truck.

During the study, System 1 logged 5 "patches" on the Southfork group selection timber sale (Table 1). System 2 logged 5 patches on the Wildcat timber sale, and System 3 logged 2 patches on the Cherokee timber sale.

Standard time study techniques were used to collect one full week of production data on the felling and skidding functions of each of the three operations (Sobhany 1984). Total daily and weekly production was determined by the loggers' load tickets. Cost data for the study period were provided directly by each logger, and previous clearcutting production data came directly from the loggers' records. In addition, the study team carefully noted any obvious effects that the characteristics of the group selection sales had on the normal operating procedures and work flow of each logging system.

Study Results

Compared to their normal average productivity and unit cost when clearcutting, all three loggers experienced significant reductions in productivity and increases in unit cost when logging the group selection sales (Table 2).

Analysis of the time study data shows that the major impact of group selection on all three logging systems was a dramatic increase in delays and unproductive time. For example, System 1's skyline yarder actually yarded logs only 5.5 hours out of a 50-hour work week. This 11 percent productive rate was due to the long amount of time it took to take the rigging and tail hold down, move to the next landing, align and fell a yarding corridor, and re-rig the yarder compared to the short time it took to actually yard the small patch after everything was set up.

The feller-buncher operator in System 2 was felling trees only 36 percent of the time. Much of the rest of the time he was waiting outside the patch as the skidder operator entered the small patch, hooked the chokers to the trees previously felled, and skidded them out of the patch. Forced to work in such close confines due to the relatively small patch size, the feller-buncher operator could not fell too many trees ahead of the skidder or he would bury them in tops and make it difficult for the skidder operator to set the chokers (a Forest Service contract provision stipulated that all trees be directionally felled so that the tops remained within the patch). When the skidder operator returned from the landing, the feller-buncher operator had to exit the patch each time to give him room to maneuver safely to hook the next drag.

The small patch size never allowed the study loggers to reach and maintain a steady state of production. They were nearly always in the load or purge stages of production--opening up a new patch, winding down and cleaning up the previous one, or moving to the next one.

Conclusions

Compared to clearcutting, harvesting group selection timber sales in appalachian hardwood stands is less productive and more expensive. For the two skidder systems studied, the unit cost increased from 15 to 25 percent. The skyline yarder system unit cost increased approximately 50 percent. Of course, these are individual case studies and other loggers on different group selection timber sales may experience different impacts. Our study found that most of the production decrease was associated with increased nonproductive time in the felling and skidding (yarding) functions. This was directly attributable to the problems associated with concentrating the activity of men and machines in a small confined area, increased move time and associated delays, and the lack of being able to reach and maintain a steady state of production for any length of time. Concentrating men and machines in a small area also raises safety concerns.

The Forest Service should proceed cautiously with alternative silvicultural systems such as group selection until the full impact of these changes on the overall timber program can be fully assessed.

Table 1. *Pre-harvest group selection timber sale data.*

Sale	Patch	Area	Total # trees	Total volume (cu.ft.)	Median vol/tree (cu.ft.)	Slope (%)	Distance to landing (ft.)
Southfork	A	1.03	99	1,955	13.24	53	87
	B	1.32	163	3,186	9.43	77	193
	C	1.39	192	3,227	10.73	52	157
	D	1.89	249	3,574	8.83	67	153
	E	1.38	204	3,527	10.73	66	403
Wildcat	A	2.87	174	2,578	9.44	12	1,062
	B	1.40	108	1,228	7.11	9	966
	C	4.46	130	1,438	10.90	3	591
	D	1.95	119	773	6.50	17	438
	E	1.11	110	1.002	8.51	9	75
Cherokee	A	0.98	135	2,607	16.87	0	255
	B	0.31	43	671	14.33	2	1,122

Table 2. *Comparative production and cost by logging system.*

	Logging System [1]		
	1	2	3
Group selection weekly production (tons) [2]	195	354	147
Average clearcutting weekly prod. (tons) [3]	405	424	196
Production decrease in group selection (%)	52%	17%	25%
Group selection cost per ton	$40.18	$14.79	$16.15

[1] 1 = cable yarder; 2 = feller-buncher, cable skidder; 3 = chainsaw fellings, cable skidder.
[2] during study period.
[3] from loggers' records.

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ASSESSMENT OF COSTS AND IMPACTS FOR ALTERNATIVE HARVESTING METHODS IN MIXED STANDS [1]

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Abstract. Clearcut, shelterwood and single-tree selection harvesting methods were evaluated for production, cost, and residual site impacts. A stand was harvested by each method in the summers of 1991 and 1992. The same contractor used chain saws and skidders to harvest all six tracts. All stands and sites were similar in tree sizes, species composition, and slope.

Only the production data for the 1991 studies have been analyzed and included in this report. System productivity was highest with the clearcut method and lowest with the single-tree selection method. Total felling and grapple skidding costs were $10.64, $9.24, and $8.18 per 100 ft^3 for the single-tree selection, shelterwood, and clearcut harvesting methods, respectively.

The residual site disturbance analysis was completed for both years. Percent of area in skid trails was 6.9, 16.8, and 15.0 for the single-tree selection, shelterwood, and clearcut methods, respectively. The single-tree selection method had the most undisturbed area (42.4 percent) after harvesting as compared to 17.3 percent for the shelterwood and 10.5 percent for the clearcut. The single-tree selection method had the largest and only significant increase in bulk density in the skid trails because of the concentrated traffic pattern. Residual tree damage was greater for the single-tree selection method than the shelterwood method.

Introduction

Harvesting operations are used to recover forest products and to perform silvicultural treatments. As a regeneration tool, alternative harvesting methods include intensive stand clearing to selective, single-tree removals. Even-aged and uneven-aged management use different types of harvesting methods to obtain regeneration. There is little information on harvesting productivity, cost, and site impacts for various types of harvesting methods for uneven-aged management as compared to even-aged management.

Many research studies have evaluated a single harvest method (Erickson and others 1992, Kellog and others 1991). Previous studies with more than one method were often confounded by differences among stands or harvesting crews and equipment (Bell 1989, Hannah and others 1981, Miller and Sarles 1986, Sloan 1991). Harvesting methods using the same equipment and crew configuration to harvest similar stands are evaluated here.

Field evaluation of three harvesting methods are reported here: clearcutting and shelterwood (used in even-aged management) and a single-tree selection (used in uneven-aged management). The single-tree selection method studied was a first conversion cut of an even-aged stand to an uneven-aged stand structure. Each method was tested in the summer of 1991 and was replicated in the summer of 1992. Machine productivity and cost data were collected for both years; only the 1991 data are summarized in this report. A more detailed analysis of the productivity of these systems was reported by Kluender and Stokes (1992). An assessment of site disturbance and residual tree damage is included in this paper for both years. The effect of harvesting traffic on soil structure for the treatments was evaluated for 1992 and is summarized in this paper.

Methods

Stands

Three harvest methods were evaluated in mature, even-aged, mixed shortleaf pine (*Pinus echinata* Mill.) and hardwood stands. Clearcut and single-tree selection harvests represent opposite tree removal intensities. Shelterwood harvest is an intermediate tree removal treatment. Three stands were harvested by each treatment method in 1991, and these treatments were replicated in 1992. All six stands were located in the Ouachita National Forest.

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[1] Paper presented at the Seventh Biennial Southern Silvicultural Research Conference, Mobile, AL, November 17-19, 1992.

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Stand and site conditions for the study are summarized in table 1. The stands were selected for compatibility and uniformity of stand structure and ground slope as much as possible. A small hardwood component was present in all six stands.

The terrain was varied with moderate slopes (less than 17 percent). Tract size averaged 55 acres for the single-tree selection method, 17.5 acres for the shelterwood method, and 31 acres for the clearcut method.

The six stands were similar in diameter distribution and height for pine trees 6 inches in d.b.h. and greater. The 1991 stand summary has been updated since it was reported by Kluender and Stokes (1992). Additional post-harvest cruise information was added to the reported preliminary data. For the 1991 stands, preharvest quadratic mean diameter (QMD) was 10.5 inches for the single-tree selection stand, 11.8 inches for the shelterwood stand, and 10.9 inches for the clearcut stand. In 1991, initial pine stems per acre stocking was 135 for the single-tree selection stand, 92 for the shelterwood stand, and 124 for the clearcut stand. Pre-harvest QMD in 1992 was 11.2, 11.0, and 10.4 inches for the single-tree selection, shelterwood, and clearcut stands, respectively. The single-tree selection stand had orignial stocking levels of 152 stems per acre, the shelterwood stand, 114, and the clearcut stand, 113, in 1992.

Production Study

Pine trees to be felled were marked in the shelterwood and single-tree selection stands. All merchantable pine trees were felled in the clearcut stands. There was little directional felling used in the study with many trees being hung in the partial-cut stands. Hung trees were pulled or pushed to the ground by skidders. Trees were processed into tree-length stems at the stump. Most of the stems were merchandized into sawlogs, but some were used for pulpwood.

Randomly chosen felling cycle observations were timed as work progressed through the stand. Production and delay times were recorded. The d.b.h. and merchantable length (to a 5.0 inch top) of the felled trees were measured. Individual tree volumes were calculated using a volume formula (Clark and Saucier 1990). Mean cycle times and production rates (excluding delays) in 100 ft^3 per productive machine hour (100 ft^3/pmh) were calculated by harvest method. Differences in mean times were detected by Tukey's HSD pair-wise comparison test at the 0.05 level. Production rates were determined for the three harvesting methods by standardizing tree volume, that is same diameter trees had the same volumes across treatments.

Two 120 horsepower, turbocharged, Caterpillar® 518 skidders equipped with 34-inch tires, skidded the tree-length stems. One skidder was equipped with a 1-cord grapple, the other was a cable-skidder using six chokers. The cable-skidder operator hooked his own chokers. Skidder delays included interaction at the deck, downing hung trees, and waiting on wood.

Stems were measured at the deck to obtain d.b.h., top diameter, and length. Volume equations were again used to estimate volume. For each skidder cycle timed, skidding distances along skid trails were measured. Mean cycle times and production rates (100 ft^3/pmh) were calculated by harvesting method. Significant differences among distances and times by tract were tested using Tukey's HSD pair-wise comparisons test.

Site Disturbance

A post-harvesting site damage assessment included area disturbed, residual tree damage, and soil bulk density. A 1-chain by 1-chain grid was established on each of the tracts. At grid intersection points, site disturbance was identified and classified by disturbance class. Disturbance classes included: (1) undisturbed-untrafficked; (2) disturbed-trafficked, litter in place; (3) disturbed-trafficked, exposed; (4) disturbed-trafficked, exposed-depression; (5) disturbed- slash; (6) disturbed-nonsoil (rock). At every fifth point along grid lines, a 1/10-acre circular plot was installed in the shelterwood stands and a 1/20-acre circular plot was installed in the single-tree stands to assess residual tree damage. Tree damage was classified as either bark damage, cambium exposed, or wood damage, and the area of damage was measured. Lengths of primary and secondary skid trails were measured in all six stands. Widths for each trail were measured at 100 ft intervals, and average widths were used to calculate the total area in skid trails.

Table 1. Stand and site characteristics for 1991 and 1992.

	Harvest method					
	Single-tree selection		Shelterwood		Clearcut	
	1991	1992	1991	1992	1991	1992
Area (acre)	52	58	11	24	40	22
Slope (percent)	10-15	5-17	5-10	12-16	0-15	10-15
QMD[1] (inches)						
Initial	10.5	11.2	11.8	11.0	10.9	10.4
Harvested	10.9	10.0	10.8	10.4	10.9	10.4
Residual	10.3	12.5	13.5	12.9	0.0	0.0
Merchantable height (ft)	50	55	60	48	53	49
Pine trees per acre						
Initial	135	152	92	114	124	113
Harvested	39	82	62	90	124	113
Residual	96	70	30	24	0	0

[1] Quadratic mean diameter. All pines; d.b.h.'s ranged from 2 to 20 inches.

Postharvest soil samples were collected only on the 1992 stands. Disturbed samples were taken in the rut of three primary skid trails in each stand at 100, 300, 500, and 700 ft from the deck. With each disturbed sample, a corresponding undisturbed sample was taken along a perpendicular line to the trail from the disturbed sample. The distance from the disturbed sample to the first undisturbed sample was measured. Disturbed and undisturbed samples were also taken along three secondary trails 100 ft from their junction with the primary trail.

The samples were weighed wet, dried at 105 °C for 72 hours, and reweighed to obtain dry weight. Bulk density and percent moisture content were then determined for each sample. Bulk density was adjusted for rock content according to American Society for Testing and Materials Standards (ASTM 1992) for samples that had 40 percent or more total dry weight in rock.

Results

Stands

The single-tree selection method had pine tree (6 inches in d.b.h. and greater) removal levels of 29 percent in 1991 and 54 percent in 1992. Removal levels for the shelterwood method were 67 percent in 1991 and 79 percent in 1992. The clearcut had 100 percent of the pine trees 4 inches in d.b.h. and greater were removed in each year.

In the single-tree selection stands, the distribution of removed stems was similar to a mixed thinning, with cutting in the 6 to 10 inch classes (low thinning) and in the 14 to 18 inch classes (thinning from above). The treatment was the first attempt to convert an even-aged stand to uneven-aged structure and may not typify an established uneven-aged single-tree selection harvest. In 1991, the distribution of harvested trees was not as uniform as in 1992. Also note that more trees were removed in 1992 as compared to 1991.

The QMD of the clearcut harvested stand was 0; the QMD of the shelterwood residual stand was 13.5 inches in 1991 and 12.9 inches in 1992 (table 1). The QMD of the single-tree selection residual stand was 10.3 inches in 1991 and 12.5 inches in 1992. The QMD's of the harvested trees from the single-tree selection, shelterwood, and clearcut 1991 stands were 10.9, 10.8, and 10.9 inches, respectively. For the 1992 stands, the QMD's of the harvested trees from the single-tree selection, shelterwood, and clearcut were 10.0, 10.4, and 10.4 inches, respectively. In 1991, average merchantable height were 50, 60, and 53 ft, respectively, for the single-tree selection, shelterwood, and clearcut stands. Average merchantable heights in 1992 were 55 ft for the single-tree selection stand, 48 ft for the shelterwood stand, and 49 ft for the clearcut.

Production and Costs

Only the 1991 productivity data has been analyzed to date. The average diameter of the trees felled was similar for all three harvesting methods in 1991 (table 2). The intertree distance was much higher for the single-tree selection method than other

Table 2. Results of the felling study on three harvesting methods in 1991.

	Harvest Method[1]		
	Single-tree selection	Shelterwood	Clearcut
Average d.b.h. (inches)[2]	11.4a[3]	11.5a	11.7a
Merchantable height (ft)	53.7a	61.6b	52.8a
Average stem volume (ft^3)	24.6a	28.0a	24.5a
Inter-tree distance (ft)	74.6a	45.6b	48.6b
Total-time per tree (min.)	2.16a	2.06a	1.86a
Adjusted Productivity[4] ($100\ ft^3$/pmh)	6.8a	7.1b	7.8b

[1] The number of observations for each variable is: single-tree selection, 51, shelterwood, 50, and clearcut, 61.
[2] Differences in QMD in text and here reflect the differences in the diameter of all harvested stems in the stand and those stems that were actually measured in the felling study.
[3] Letters indicate groups that were similar at the 0.05 level in a means separation test using Tukey's HSD multiple comparisons test.
[4] Adjusted for mean tree diameter and length across treatments, that is same diameter trees would have the same merchantable lengths and volumes for all treatments. PMH is productive machine hour.

methods. Felling cycle times increased for the single-tree selection method because of the longer walk distance and obstacle of working around unharvested trees.

The felling productivity was adjusted for mean tree diameter and length, that is same diameter trees had the same volumes across treatments. The single-tree selection method produced significantly less than the other treatments (table 2). The shelterwood method produced 5 percent more volume per hour, and the clearcut method produced 15 percent more volume per hour than the single-tree selection method.

The grapple skidder had consistently larger loads than the cable skidder (table 3). Skidded volumes for the grapple skidder averaged 81 ft^3 for both the single-tree selection and shelterwood methods and 99 ft^3 for the clearcut method, whereas the cable skidder load volumes for the same methods averaged 51, 62, and 76 ft^3, respectively. The operators were either able to or tended to more fully load their skidders to capacity in the clearcut stand.

An average turn took longer for the grapple skidder by the single-tree selection method than by the shelterwood or clearcut method. The cable skidder took significantly longer time per cycle for the single-tree selection method than for the other methods. This was due to more time required to position and choke the stems that were spread across the site.

For both skidders, there was a strong positive relationship between productivity and increasing harvest intensity (table 3). Skidding production was adjusted for standardized volumes per tree diameter. Productivity was not standardized by a common travel distance since these are only case studies. There was a significantly larger overall production volume with the grapple skidder than the cable skidder for all three methods. The grapple skidder was 33 percent more productive in the clearcut stand and 17 percent more productive in the shelterwood stand than in the single-tree selection stand. The cable skidder was almost 200 percent more productive in the clearcut stand and 180 percent more productive in the shelterwood stand than in the single-tree selection stand.

A felling cost for the sawyer and the saw was calculated using a machine rate analysis (Miyata 1980) to be \$10.44 per pmh (table 4). This leads to a total felling cost of \$1.54/100 ft^3 for the single-tree selection method, \$1.46/100 ft^3 for the shelterwood method, and \$1.33/100 ft^3 for the clearcut method (table 4) when using the average adjusted productivity estimates from the study.

Costs and adjusted productivity for both skidders are presented in table 4. Assumed availability for the skidders was 67 percent (Miyata 1980) and purchasing prices were \$130,000 for the grapple skidder and \$120,000 for the cable skidder. These are estimated replacement costs and not the actual costs of the machines used in the study. Total costs for the cable skidder are \$36.10, \$12.87 and \$12.08/100 ft^3 for the single-tree selection, shelterwood, and clearcut methods, respectively, versus \$9.10, \$7.78 and \$6.85/100 ft^3, respectively, for the grapple skidder.

Using the more economical grapple skidder and assuming that it can work under the necessary ground slope conditions, total system costs would be \$10.64, \$9.24, and \$8.18/100 ft^3 for the single-tree selection, shelterwood, and clearcut methods,

Table 3. *Results of the skidding study on three harvesting methods in 1991.*

	Harvest method[1]		
	Single-tree selection	Shelterwood	Clearcut
Grapple skidder			
Total time per turn (min.)	10.23a[2]	8.09b	8.61b
Travel empty distance (ft)	708a	581a	700a
Travel loaded distance (ft)	648a	502a	628a
Intermediate travel distance (ft)	87a	33b	0c
Total travel distance (ft)	1437a	1115b	1328ab
Volume per turn (ft^3)	81.8a	81.5a	99.4b
Stems per turn	4.1a	4.1a	4.5a
Adjusted productivity[3] (100 ft^3/pmh)	6.2a	7.2a	8.2b
Cable skidder			
Total time per turn (min.)	19.28a	9.33b	10.69b
Travel empty distance (ft)	1225a	690b	982c
Travel loaded distance (ft)	1129a	678b	881c
Intermediate travel distance (ft)	163a	33b	11b
Total travel distance (ft)	2517a	1401b	1874c
Volume per turn (ft^3)	51.1a	61.8a	76.7b
Stems per turn	4.1a	3.7a	3.6a
Adjusted Productivity (100 ft^3/pmh)	1.57a	4.1b	4.4b

[1] The number of observations for each variable associated with the grapple skidder is: single-tree selection, 53, shelterwood, 50, and clearcut, 65. The number of observations associated with the cable skidder is: single-tree selection, 8, shelterwood, 35, and clearcut, 34.

[2] Letters indicate groups that were similar at the 0.05 level in a means separation test using Tukey's HSD multiple comparisons test.

[3] Adjusted for mean tree diameter and length across treatments, that is same diameter trees would have the same merchantable lengths and volumes for all treatments. PMH is productive machine hour.

respectively. These estimated costs are for cutting and moving the wood to the roadside and do not include log processing at the deck, loading, wood transport, support equipment, overhead, etc. Also, these system costs do not reflect the cost of a cable machine for working the more difficult terrain.

Under the above cost assumptions, the single-tree selection method cost \$2.46/100 ft^3 (about 30 percent more than the clearcut method) and \$1.40/100 ft^3 (about 15 percent more than the shelterwood method). The shelterwood method cost \$1.06/100 ft^3 (13 percent more than the clearcut method).

Site Disturbance

Trees with cambium exposed were considered damaged. All cambium exposure was counted, regardless of area. Average exposure area was as low as 0.1 ft^2 per tree (3.79 inches by 3.79 inches) in 1991. The 1991 postharvest damage assessment (table 5) revealed 16 residual trees per acre damaged from the single-tree selection method. There were only six damaged trees per acre from the shelterwood method. The 1992 postharvest damage assessment revealed that the single-tree selection method resulted in 10.2 damaged trees per acre. The shelterwood method resulted in 2.5 damaged trees per acre. There was a decrease in damage between the 2 years that may have resulted from gaining experience with the harvesting method. The average number of damaged trees per acre for the 2 years from the single-tree selection method was 13.1, whereas the shelterwood method averaged only 4.3 damaged trees per acre for the 2 years.

Primary and secondary skid trails accounted for 3.6, 7.6, and 12.3 percent of the total area for the single-tree selection, shelterwood, and clearcut methods, respectively (table 5). Primary trails were defined as those having branching trails, whereas

Table 4. *Cost for felling and skidding by single-tree selection, shelterwood, and clearcutting methods of harvesting in 1991.*

Harvest function/method	Cost per PMH ($)[1]				100 ft³/pmh	$/100 ft³
	Fixed	Variable	Labor	Total		
Felling						
Single Tree	0.60	1.86	7.98[2]	10.44	6.8	1.54
Shelterwood	0.60	1.86	7.98	10.44	7.1	1.46
Clearcut	0.60	1.86	7.98	10.44	7.8	1.33
Skidding						
Grapple Skidder						
Single Tree	29.28	16.19	10.64	56.11	6.2	9.10
Shelterwood	29.28	16.19	10.64	56.11	7.2	7.78
Clearcut	29.28	16.19	10.64	56.11	8.2	6.85
Cable Skidder						
Single Tree	26.82	15.35	10.64	52.81	1.5	36.10
Shelterwood	26.82	15.35	10.64	52.81	4.1	12.87
Clearcut	26.82	15.35	10.64	52.81	4.4	12.08

[1] Fixed and variable costs per hour are derived using a machine rate calculation method described by Miyata (1980). Purchase price for the chain saw was $500, $130,000 for the grapple skidder, and $120,000 for the cable skidder. PMH is productive machine hour and is based on 50 and 67 percent availability to convert fixed costs from scheduled machine hour to PMH.
[2] Chainsaw operator did other duties as well; wage was proportioned.

Table 5. *Postharvest residual damage assessment for three harvesting methods for 1991 and 1992.*

	Harvest method								
	Single-tree selection			Shelterwood			Clearcut		
	1991	1992	Mean	1991	1992	Mean	1991	1992	Mean
Tree damage due to cambium exposure (trees/acre)	16.0	10.2	13.1a[1]	6.0	2.5	4.3a	NA	NA	NA
Area of cambium exposure (ft²/tree)	0.4	0.4	0.4a	0.1	0.2	0.2a	NA	NA	NA
Area in skid trails (percent)									
Primary	2.0	6.6	4.3a	7.0	19.1	13.0a	7.5	10.1	8.8a
Secondary	1.6	3.6	2.6a	0.6	6.9	3.7a	4.8	7.6	6.2a
Total	3.6	10.2	6.9a	7.6	26.0	16.7a	12.3	17.7	15.0a
Stand disturbance (percent)									
Undisturbed									
Untrafficked	48.3	36.6	42.4a	18.0	16.7	17.3b	9.6	11.5	10.5b
Disturbed									
Litter in place	22.3	29.2	25.7a	29.2	27.6	28.4a	25.6	23.7	24.6a
Exposed	5.6	15.1	10.3a	11.2	21.1	16.1a	8.0	16.5	12.2a
Exposed - with depression	9.9	9.2	9.5a	14.6	10.9	12.7a	15.2	14.3	14.7a
Slash	13.9	9.1	11.5b	27.0	21.8	24.4ab	40.8	30.2	35.5a
Non-soil	0.0	0.7	0.3a	0.0	1.9	0.9a	0.8	4.3	2.5a

[1] Letters indicate groups that were similar at the 0.05 level in a means separation test using Tukey's HSD multiple comparisons test.

secondary trails did not. From the 1992 harvests, total skid trail area accounted for 10.2, 26.0, and 17.7 percent of the total area for the single-tree selection, shelterwood, and clearcut methods, respectively. The 2 year skid trail area averages were 6.9, 16.8, and 15.0 percent of the total area in primary and secondary skid trails for the single-tree selection, shelterwood and clearcut methods, respectively.

Table 5 also shows the percent of each stand in each disturbance class. As harvesting levels increased, so did the proportion of the total tract that was trafficked. There was significantly more undisturbed area for the single-tree selection methods than the other two methods. Combining the area disturbance data for the 2 years shows that the single-tree selection method left an average of 42.4 percent of the stand undisturbed as compared to 17.3 percent for the shelterwood method and 10.5 percent for the clearcut method. This results in 144 percent more undisturbed area for the single-tree selection method as compared to the shelterwood method and 300 percent more as compared to the clearcut method. The clearcut method resulted in 163 percent more area with slash than the single-tree selection method and 24 percent more than the shelterwood method. Additionally, the percentage of total area covered by slash increased with increasing harvest intensity. There were no significant differences among treatments for the amount of area that was disturbed (this includes 3 classes).

It should be noted that the single-tree selection method had less area in skid trails and less disturbed area based on total area. This analysis does not account for volume of wood harvested. If disturbance is related to wood recovery, the treatment effects would be more balanced rather than skewed toward less removal levels.

After testing for the effect of distance from the deck, the soil bulk densities were grouped by treatments. If more samples had been collected, the effect of distance from the deck would have probably been significant. The average bulk density on primary skid trails was 1.49 g/cm^3 for the single-tree selection method, 1.30 g/cm^3 for the shelterwood method and 1.26 g/cm^3 for the clearcut method (table 6). There was an increase in bulk density for each harvesting treatment as compared to the off trail (undisturbed) bulk densities. A paired comparison test showed a significant difference for the single-tree selection method only. Due to fewer trees removed (high residual stand density) for the single-tree selection method, the skidders were more restricted in their travel, and therefore, used the same primary trails more frequently than with the shelterwood and clearcut methods. This resulted in a higher increase in bulk density for the single-tree selection method due to cumulative traffic impacts.

Discussion

There were felling and skidding productivity differences among the three methods. The extra time requirement to find marked trees, plan the cut, and work around residual stand components contributed to lower felling productivity for the single-tree selection and shelterwood methods. There were significant productivity differences between the skidder types, and harvesting method affected skidding productivity.

Both felling and skidding productivity increased with stand removal intensity; likewise, costs were affected by harvesting method. The clearcut method was the cost effective method, and the single-tree selection method was the most costly.

A residual impact analysis was completed for 1991 and 1992 (replicated treatments by method), and a soil bulk density analysis was completed for 1992. Average percent of area in skid trails for the 2 years was 6.9, 16.8, and 15.0 for the single-tree selection, shelterwood, and clearcut methods, respectively. The single-tree selection method had the highest percentage of undisturbed area (42.4 percent) after harvesting compared to 17.3 percent for the shelterwood and 10.5 percent for the clearcut methods. There was a significant increase in soil bulk density in the skid trails because of the concentrated traffic patterns. Residual tree damage was higher for the single-tree selection method than for the shelterwood method because of the high residual tree density.

Although the single-tree selection harvesting method had the highest cost and residual tree damage and a soil bulk density increase, it had the least percentage of total area in skid trails and percentage of area disturbed and provided a continuous ground cover. For some forest land managers, the higher cost of the single-tree selection method is compensated by its esthetic quality, continuous canopy, high percentage of site unaffected by harvest, and improved natural regeneration. The effect of multiple, closer spaced entries by harvesting equipments into forest stands on some of these qualities is still unknown.

Table 6. *Summary of soil analysis.*

	Harvest method					
	Single-tree selection		Shelterwood		Clearcut	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Bulk Density (g/cm^3)						
Undisturbed	1.12	0.27	1.22	0.17	1.15	0.21
Trail	1.49	0.19	1.30	0.19	1.26	0.27
Difference	0.37	0.23	0.08	0.25	0.11	0.37
Prob > |t|	0.0003		0.2732		0.3017	

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*U.S. GOVERNMENT PRINTING OFFICE: 1993-766-017/80012

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